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Principal: Mrs O. Tomlinson

OCR CHEMISTRY A

A2 LEVEL

UNIT 5 MORE PAST PAPER QUESTIONS

Barasho wanaagsan!

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2 Acidified bromate(V) ions, BrO_3^-, oxidise bromide ions, Br^-, to form bromine, Br_2.

$$6H^+(aq) + BrO_3^-(aq) + 5Br^-(aq) \longrightarrow 3Br_2(aq) + 3H_2O(l)$$

This reaction was carried out four times using different concentrations of the three reactants. The initial rate of Br_2 formation for each reaction was calculated and the results are shown below.

experiment	$[H^+(aq)]$ /mol dm^{-3}	$[BrO_3^-(aq)]$ /mol dm^{-3}	$[Br^-(aq)]$ /mol dm^{-3}	initial rate /mol dm^{-3} s^{-1}
1	0.300	0.050	0.250	1.68×10^{-5}
2	0.300	0.100	0.250	3.36×10^{-5}
3	0.600	0.050	0.250	6.72×10^{-5}
4	0.300	0.150	0.500	1.01×10^{-4}

(a) (i) For each reactant, deduce the order of reaction. Show your reasoning.

$H^+(aq)$ .....

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$BrO_3^-(aq)$ .....

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$Br^-(aq)$ .....

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.....[6]

(ii) Deduce the rate equation for the reaction.

.....[1]

(iii) Calculate the rate constant, k, for this reaction. Give your answer to an appropriate number of significant figures and state the units for k.

rate constant, k = ... units ..... [4]

(b) Suggest how the initial rate of bromine formation would be calculated from a concentration–time graph.

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.....[1]

(c) What evidence is there that this reaction proceeds by more than one step?

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.....[1]

[Total: 13]

3 Ethanoic acid, CH_3COOH, is a weak acid.

(a) What is meant by a *weak acid*?

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.....[1]

(b) What is the conjugate base of ethanoic acid?

.....[1]

(c) Ethanoic acid takes part in many typical acid reactions.

Complete the equations below for the reactions of ethanoic acid with Na_2CO_3 and with Mg.

(i) Na_2CO_3 + ...

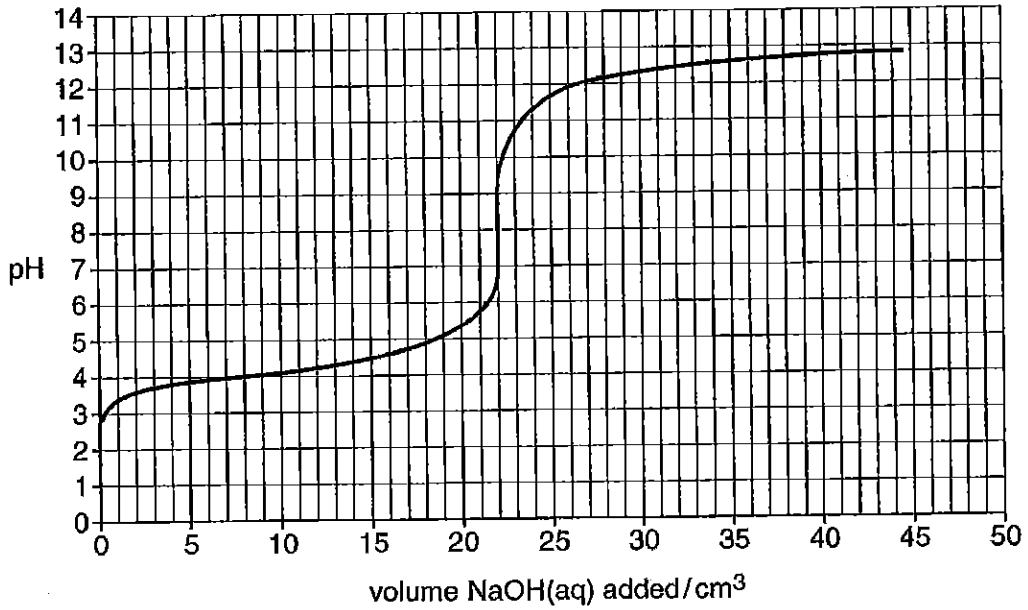
(ii) Mg + ...[3]

(d) The concentration of ethanoic acid can be found by titrating against a standard solution of NaOH(aq).

$$CH_3COOH(aq) + NaOH(aq) \longrightarrow CH_3COONa(aq) + H_2O(l)$$

A student titrated 25.0 cm^3 of ethanoic acid with 0.200 $mol\,dm^{-3}$ NaOH(aq). The NaOH(aq) was added from a burette and the pH was monitored throughout.

The titration pH curve is shown below.



(i) Use the information on page 6 to calculate the concentration, in mol dm^{-3}, of the ethanoic acid.

concentration = ... mol dm^{-3} [2]

(ii) The pH ranges in which the colour changes for three indicators are shown below.

indicator	pH range
metacresol purple	7.4–9.0
bromophenol blue	3.6–4.6
indigo carmine	11.4–13.0

Explain which of the three indicators is most suitable for this titration.

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.....[1]

(e) Vinegar is an aqueous solution of ethanoic acid. It can be prepared by oxidising the ethanol in wine with oxygen gas.

$$CH_3CH_2OH(aq) + O_2(g) \longrightarrow CH_3COOH(aq) + H_2O(l)$$

A 750 cm^3 bottle of wine was taken containing 79.2 g of ethanol. All of the ethanol in the wine was oxidised to ethanoic acid using oxygen gas to make vinegar.

Calculate the pH of the vinegar at 25 °C, showing all your working.

Assume that the only component in the wine having an effect on pH is ethanoic acid.

K_a for ethanoic acid at 25 °C = 1.70×10^{-5} mol dm^{-3}.

pH = ... [6]

(f) Ethanoic acid can be used to make buffer solutions.

(i) State a compound that could be added to ethanoic acid to make a buffer solution.

.....[1]

(ii) Explain how this solution acts as a buffer. Include equations in your answer.

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.....[5]

[Total: 20]

4 'Sour gas' is natural gas that is contaminated with small amounts of hydrogen sulphide, H_2S. The hydrogen sulphide can be removed by the Claus reaction. This converts the hydrogen sulphide in sour natural gas into sulphur.

The Claus reaction takes place in two steps.

Step 1: Some of the hydrogen sulphide is reacted with oxygen to form sulphur dioxide.

Step 2: The remaining hydrogen sulphide reacts with the sulphur dioxide to produce sulphur.

The sulphur can now be oxidised to sulphuric acid that has many uses.

(a) A sour natural gas stream contains 1.8% hydrogen sulphide by mass. The pipeline moves 100 tonnes of sour gas each day.

Calculate the mass, in tonnes, of sulphuric acid that could be obtained each day by completely processing this hydrogen sulphide. 1 tonne = 10^6 g

mass of sulphuric acid = ... tonnes [3]

(b) Construct an equation for each step, Step 1 and Step 2, of the Claus reaction and use these to construct an overall equation for the Claus reaction.

[3]

(c) Explain what happens in the two steps of the Claus reaction in terms of the oxidation states of sulphur.

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.....[3]

(d) The hydrogen sulphide can also be removed in an acid-base reaction by bubbling the sour gas through an aqueous solution containing carbonate ions, CO_3^{2-}. Two ions are formed.

Write a balanced equation for the reaction that takes place and identify the conjugate acid-base pairs.

[3]

(e) After removal of the hydrogen sulphide, the purified natural gas is odourless. A small amount of organic sulphur compounds called thiols is added. The thiols give natural gas its characteristic smell, without which a gas leak would be difficult to detect.

Thiols react in a similar way to alcohols and their composition is such that the oxygen atom in the alcohol has been replaced by a sulphur atom. The thiol most frequently added to natural gas is butane-1-thiol.

Draw the structure of butane-1-thiol and suggest a balanced equation for one reaction of this compound.

[3]

[Total: 15]

END OF QUESTION PAPER

Answer **all** the questions.

1 The hydrolysis of ethyl ethanoate is a reversible reaction. The equation for the equilibrium is shown below.

$$CH_3COOC_2H_5 + H_2O \rightleftharpoons CH_3COOH + C_2H_5OH$$

A student mixed together 8.0 mol ethyl ethanoate and 5.0 mol water. He also added a small amount of hydrochloric acid to catalyse the reaction.

The student left the mixture until it had reached equilibrium at constant temperature. He found that 2.0 mol of ethanoic acid had formed.

(a) Write the expression for K_c for this equilibrium system.

[1]

(b) (i) Complete the table below to show the composition of the equilibrium mixture.

component	$CH_3COOC_2H_5$	H_2O	CH_3COOH	C_2H_5OH
initial amount/mol	8.0	5.0	0.0	0.0
equilibrium amount/mol			2.0	

[2]

(ii) The mole fraction of CH_3COOH can be found from the composition of the equilibrium mixture.

Explain what is meant by the term *mole fraction* and calculate the mole fraction of CH_3COOH in the equilibrium mixture.

mole fraction .....

.....

mole fraction of CH_3COOH

[2]

(iii) Calculate K_c to an appropriate number of significant figures. State the units, if any.

K_c = ... units ..... [3]

(c) The student left the mixture at a higher temperature until a new equilibrium had been reached. He again measured the equilibrium amount of ethanoic acid and found that it had increased.

What conclusions can be drawn about the reaction and its equilibrium constant?

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.....[3]

[Total: 11]

2 Hydrogen peroxide, H_2O_2, is a strong oxidising agent that has bleaching properties.

(a) Hydrogen peroxide oxidises iodide ions, $I^-(aq)$, in the presence of acid, $H^+(aq)$.

The rate equation for this reaction is shown below.

$$\text{rate} = k[H_2O_2(aq)][I^-(aq)]$$

Four experiments were carried out using different initial concentrations of $H_2O_2(aq)$, $I^-(aq)$ and $H^+(aq)$. The initial rate of formation of $I_2(aq)$ was measured for each experiment.

Some of the experimental results are shown in the table below.

experiment	$[H_2O_2(aq)]$ /mol dm^{-3}	$[I^-(aq)]$ /mol dm^{-3}	$[H^+(aq)]$ /mol dm^{-3}	initial rate/mol dm^{-3} s^{-1}
1	0.020	0.010	0.0050	2.30×10^{-6}
2	0.040	0.010	0.0050	
3	0.020	0.010	0.0025	
4	0.100	0.005	0.0100	

(i) Deduce the initial rates for experiments 2, 3 and 4. Complete the table.

[3]

(ii) Use the results of experiment 1 to calculate the rate constant k for this reaction. State the units for k.

rate constant, k = ... units ..... [3]

(iii) The overall equation for this reaction is shown below.

$$H_2O_2(aq) + 2I^-(aq) + 2H^+(aq) \longrightarrow I_2(aq) + 2H_2O(l)$$

The rate equation is: rate = $k[H_2O_2(aq)][I^-(aq)]$.

Explain what the overall equation and the rate equation tell us about the reaction.

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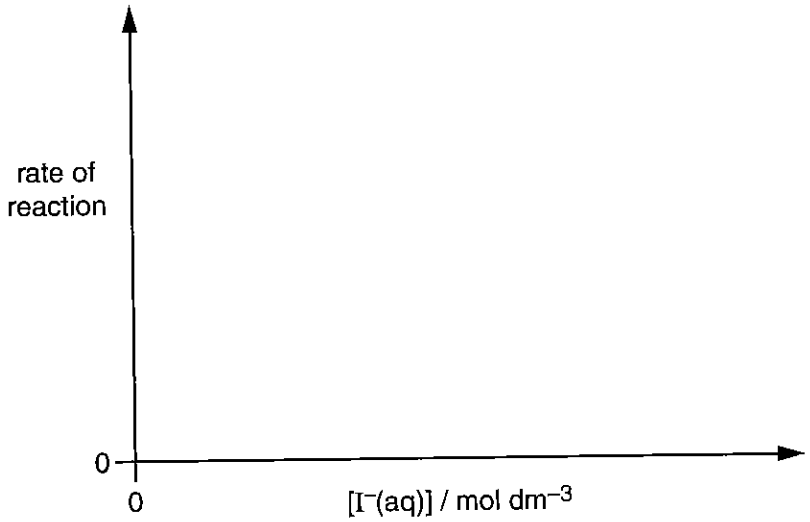
.....[3]

(b) Using the axes below, sketch a graph to show how the rate of this reaction changes with increasing $I^-(aq)$ concentration.



[1]

(c) Hydrogen peroxide is used in the preparation of 'carbamide peroxide', widely used by dentists as a 2.30 mol dm^{-3} solution for teeth-whitening.

Carbamide peroxide has the following percentage composition by mass.

H, 6.38%; O, 51.06%; N, 29.79%; C, 12.77%.

The empirical formula of carbamide peroxide is the same as its molecular formula.

Calculate the mass of carbamide peroxide that is required to prepare 150 cm^3 of a teeth-whitening solution for use by dentists.

[5]

[Total: 15]

[Turn over

3 Potassium hydroxide, KOH, is a strong alkali and vitamin C is a weak Brønsted-Lowry acid.

(a) What is meant by a *weak Brønsted-Lowry acid*?

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.....[2]

(b) An aqueous solution of KOH had a pH of 12.72 at 25 °C.

$$K_w = 1.00 \times 10^{-14}\,\text{mol}^2\,\text{dm}^{-6} \text{ at } 25\,^\circ\text{C}.$$

(i) What is the expression for K_w?

.....[1]

(ii) Calculate the concentration, in mol dm^{-3}, of this solution of KOH.

[2]

(c) Vitamin C, $C_6H_8O_6$, has a K_a value of 6.76×10^{-5} mol dm^{-3}.

The equilibrium for the dissociation of vitamin C in water is shown below.

$$C_6H_8O_6(aq) \rightleftharpoons H^+(aq) + C_6H_7O_6^-(aq)$$

0.500 g of vitamin C was dissolved in water to form a solution with a volume of 125 cm^3.

Calculate the pH of the solution formed.

[6]

[Total: 11]

4 In this question, one mark is available for the quality of use and organisation of scientific terms.

A buffer solution can be prepared by mixing together a weak acid with a salt of the weak acid.

The pK_a values of some weak acids are shown below.

weak acid	pK_a
chloroethanoic acid	2.9
methanoic acid	3.8
ethanoic acid	4.8
carbonic acid	6.4
boric acid	9.2

- Explain what is meant by the term *buffer solution*.
- Explain, with equations, how a buffer solution works.
- Choose from the table above the most appropriate weak acid that could be used to prepare a buffer solution with a pH in the range of 3.5–4.5. Explain how you made your choice and suggest a salt that could be added to this weak acid to prepare the buffer solution.

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Quality of Written Communication [1]

[Total: 9]

TURN OVER FOR QUESTION 5

5 Calcium cyanamide, $CaCN_2$, is an environmentally-friendly fertiliser commonly referred to as 'nitrogen-lime'. It can be prepared in a three-stage synthesis using the readily available raw materials, limestone (calcium carbonate) and coke (carbon).

Stage 1 The calcium carbonate is first converted into calcium oxide by heat.

Stage 2 The calcium oxide is heated with coke to form calcium carbide, CaC_2.

Stage 3 Calcium carbide is reacted with nitrogen gas at a high temperature to produce calcium cyanamide, $CaCN_2$, and an element.

(a) Write balanced equations for the reactions that take place in the three stages of this synthesis.

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.....[3]

(b) Calcium cyanamide is an ionic compound.

Suggest a '*dot-and-cross*' diagram for the cyanamide ion, CN_2^{2-}.

The carbon atom is located between the two nitrogen atoms.

[2]

(c) On making contact with water present in the soil, calcium cyanamide is hydrolysed.

Suggest an equation for this hydrolysis.

State the benefits of the hydrolysis products for the farmer.

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.....[4]

(d) The calcium carbide obtained in Stage 2 can also be reacted with water to prepare ethyne gas, C_2H_2. Ethyne is commonly called 'acetylene' and is used in oxy-acetylene welding.

- Write a balanced equation for the reaction between calcium carbide and water.
- Calculate the volume of ethyne gas, measured at room temperature and pressure, r.t.p., that could be made from 20 kg of limestone.

  1 mol of ethyne occupies 24 dm^3 at r.t.p.
- Write a balanced equation for the reaction that takes place to produce the oxy-acetylene flame during welding.

[5]

[Total: 14]

END OF QUESTION PAPER

Answer **all** the questions.

1 The decomposition of gaseous hydrogen iodide to form hydrogen and iodine gases is a reversible reaction.

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

(a) Write the expression for K_c for an equilibrium mixture of these three gases.

[1]

(b) A student added 0.50 mol HI(g) to a 1.0 dm^3 container. The container was sealed and the contents were allowed to reach equilibrium at constant temperature.

The student then analysed the equilibrium mixture and found that 0.11 mol $I_2(g)$ was present.

(i) Complete the table below to show the amount of each gas in the equilibrium mixture.

gas	HI(g)	$H_2(g)$	$I_2(g)$
initial amount / mol	0.50	0.00	0.00
equilibrium amount / mol			0.11

[2]

(ii) Calculate K_c to an appropriate number of significant figures. State the units, if any.

K_c = ... units, if any ..... **[3]**

(c) The student compressed the equilibrium mixture so that its volume was reduced. The temperature was kept constant.

Comment on the value of K_c and the composition of the equilibrium mixture under these new conditions.

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..... **[2]**

(d) The student repeated the experiment at a higher temperature and found that more $I_2(g)$ was present at equilibrium.

Comment on the value of K_c and explain what additional information this tells you about the reaction.

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..... **[2]**

(e) Hydrogen iodide gas is mixed with chlorine gas.

Two reactions take place forming different compounds of iodine, **A** and **B**.

Compounds **A** and **B** each contain I and C*l* only.

- In the first reaction, compound **A** forms as a reddish brown liquid.
  Compound **A** contains 78.15% of I by mass.
- In the second reaction, compound **B** forms as yellow crystals.
  Compound **B** has a molar mass of $467\,g\,mol^{-1}$.

Deduce possible identities for **A** and **B** and write balanced equations for their formation.

A: .....

equation: .....

B: .....

equation: ..... **[5]**

[Total: 15]

2 The reaction between nitrogen monoxide, NO, and oxygen, O_2, has the following rate equation.

$$\text{rate} = k[NO(g)]^2[O_2(g)]$$

(a) What is the overall order of this reaction?

..... **[1]**

(b) The reaction rate is 6.90×10^{-7} mol dm^{-3} s^{-1} when

- the concentration of NO(g) is 2.80×10^{-4} mol dm^{-3}
- the concentration of $O_2(g)$ is 1.44×10^{-3} mol dm^{-3}.

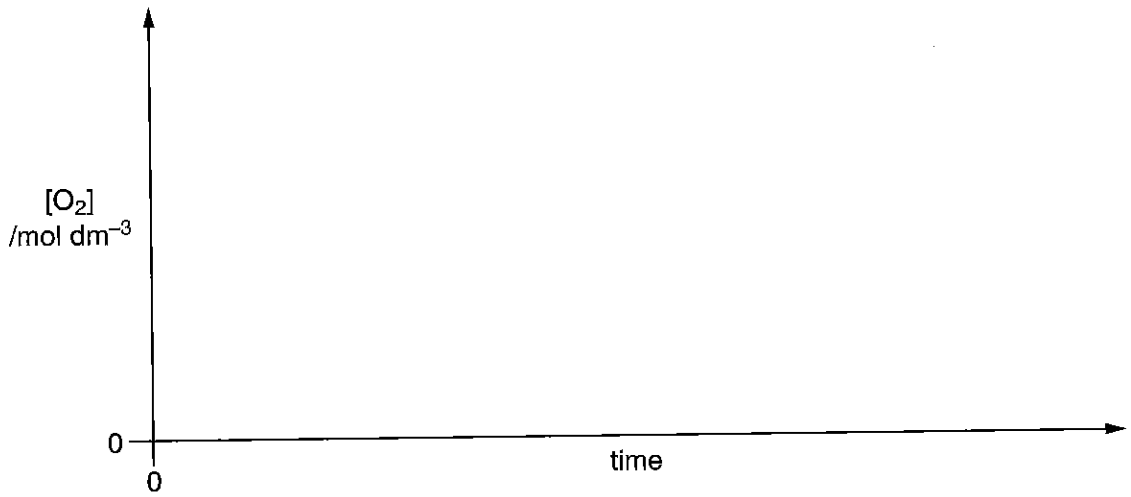
Calculate the rate constant, k, for this reaction. State the units.

Give your answer to an appropriate number of significant figures.

rate constant, k = ... units ..... **[3]**

(c) The rate equation was determined experimentally.

(i) On the axes below, sketch a graph to show how the concentration of O_2 changes during the course of the reaction.



[1]

(ii) Explain how you would use the graph to determine the **initial** rate of the reaction.

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..... **[2]**

(iii) How could you use the graph to confirm that the reaction is first order with respect to O_2?

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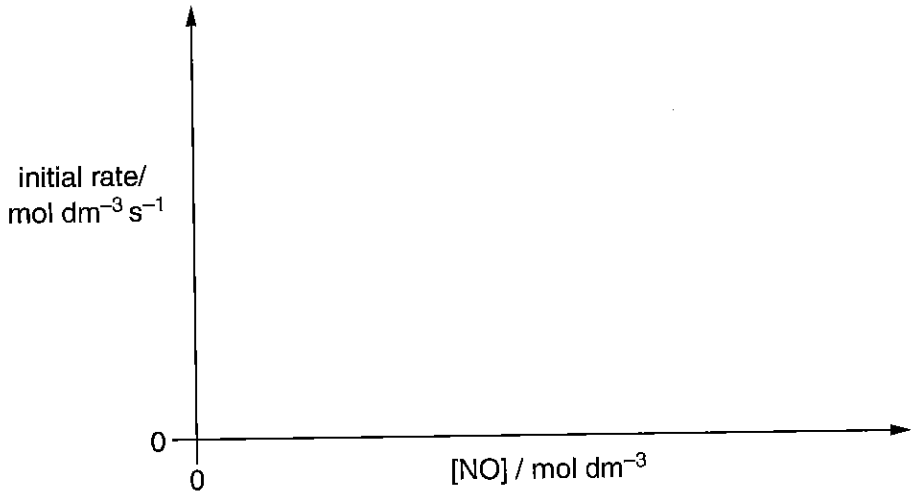
..... **[1]**

(d) The experiment was repeated using different initial concentrations of NO.

(i) Using the axes below, sketch a graph to show how the initial rate of the reaction would change with different initial concentrations of NO.



[1]

(ii) Predict, with a reason, what would happen to the rate when the initial concentration of NO(g) is tripled.

effect on rate: .....

reason: .....

..... **[2]**

(iii) Predict what would happen to the rate when the initial concentration of NO(g) is doubled **and** the initial concentration of O_2(g) is tripled.

effect on rate: ..... **[1]**

[Total: 12]

3 Sulphur dioxide is used as a wine preservative. Sulphur dioxide reacts with water forming sulphurous acid, H_2SO_3.

H_2SO_3 is a weak Brønsted–Lowry acid.

$$H_2SO_3(aq) \rightleftharpoons H^+(aq) + HSO_3^-(aq) \qquad K_a = 1.50 \times 10^{-3}\ \text{mol dm}^{-3} \text{ at } 25\,^\circ\text{C}$$

(a) What is the value of pK_a for H_2SO_3 at 25 °C?

pK_a = ... **[1]**

(b) (i) Write an expression for K_a for the equilibrium above.

[1]

(ii) Use the expression for K_a from **(i)** to calculate the pH of a 0.0265 mol dm^{-3} aqueous solution of H_2SO_3 at 25 °C.

[3]

(iii) The measured pH of 0.0265 mol dm^{-3} sulphurous acid at 25 °C is slightly lower than the pH value calculated using the expression above.

Suggest a reason for this difference.

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..... **[1]**

(c) The constant K_w has a value of 1.00×10^{-14} mol^2 dm^{-6} at 25 °C.

(i) What name is commonly given to K_w?

..... **[1]**

(ii) Write the expression for K_w.

K_w = ... **[1]**

(d) In aqueous solution, potassium hydroxide acts as a strong alkali.

Calculate the pH of 0.0265 mol dm^{-3} KOH(aq) at 25 °C. Show your working.

[2]

(e) A student mixed 25.0 cm^3 0.0265 mol dm^{-3} H_2SO_3(aq) with 25.0 cm^3 0.0265 mol dm^{-3} KOH(aq).

- The student evaporated the water from the solution and obtained a solid **C**.

The student then mixed together 25.0 cm^3 0.0265 mol dm^{-3} H_2SO_3(aq) with 50.0 cm^3 0.0265 mol dm^{-3} KOH(aq).

- The student evaporated the water from the solution and obtained a solid **D**.

Deduce the formulae of compounds **C** and **D**.

Write equations for their formation from KOH(aq) and H_2SO_3(aq).

formula of compound **C**: .....

equation: .....

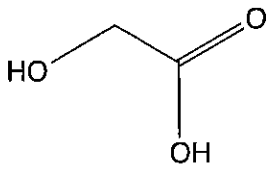
formula of compound **D**: .....

equation: ..... **[4]**

[Total: 14]

4 Alpha-hydroxy-acids (AHAs) are used in skin-care products. For effective treatment of the skin, it is important that the pH of cosmetics is closely controlled. Products are sold in a buffered form with different pH ranges for different uses.

Glycolic acid, shown below, is used as an AHA in many cosmetics.



glycolic acid

(a) Deduce the molecular formula of glycolic acid.

..... **[1]**

(b) Glycolic acid is manufactured in two stages.

- **Stage 1** Chloroethanoic acid, $ClCH_2COOH$, is reacted with aqueous sodium hydroxide.
- **Stage 2** The resulting solution is acidified.

Write equations for each stage in the manufacture of glycolic acid.

Stage 1:

Stage 2:

[3]

(c) In this question, one mark is available for the quality of use and organisation of scientific terms.

A glycolic acid skin-care product has a buffered pH of 4.4.
The buffer contains a solution of glycolic acid and its sodium salt, sodium glycolate.

- Explain what a buffer is and how **this** buffer system works. Include equations in your answer.
- Calculate the proportions of glycolic acid and sodium glycolate in this skin-care product.

Glycolic acid has a K_a value of 1.48×10^{-4} mol dm^{-3}.

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.... **[9]**

Quality of Written Communication [1]

TURN OVER FOR QUESTION 4(d)

(d) A chemist investigated compound **E**, $C_xH_yO_z$, as a prospective cosmetic for skin-care.

A sample of 4.362 g of compound **E** was analysed by burning in oxygen to form 5.119 g of CO_2 and 1.575 g of H_2O. Mass spectrometry produced a molecular ion peak at $m/e = 150.0$.

Calculate the molecular formula of compound **E**. Show your working.

[5]

[Total: 19]

END OF QUESTION PAPER

2 Chlorine dioxide, ClO_2, is a liquid at room temperature and pressure.
In an aqueous solution it is used as a bleach.

(a) In aqueous solution, chlorine dioxide, ClO_2, reacts with hydroxide ions, OH^-.

This reaction is carried out three times using different concentrations of the two reactants. The initial rate of each reaction is determined and the results are shown below.

experiment	$[ClO_2(aq)]$ /mol dm^{-3}	$[OH^-(aq)]$ /mol dm^{-3}	initial rate /mol dm^{-3} s^{-1}
1	0.010	0.030	6.00×10^{-4}
2	0.010	0.075	1.50×10^{-3}
3	0.030	0.030	5.40×10^{-3}

(i) For each reactant, deduce the order of reaction. Show your reasoning.

$OH^-(aq)$ .....

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$ClO_2(aq)$ .....

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..... **[4]**

(ii) Deduce the rate equation for the reaction.

..... **[1]**

(iii) Calculate the rate constant, k, for this reaction. State the units, if any.
Give your answer to an appropriate number of significant figures.

rate constant, k: ..... units: ..... **[3]**

(b) The mechanism for this reaction takes place in several steps.

In the overall equation, 2 mol ClO_2 reacts with 2 mol OH^- to form an aqueous solution containing chlorate(III) ions and chlorate(V) ions.

Chlorate(III) ions have the formula ClO_2^-.

(i) How does the rate equation provide evidence that the reaction takes place by more than one step?

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..... **[1]**

(ii) Suggest the overall equation.

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..... **[2]**

[Total: 11]

3 Benzoic acid, C_6H_5COOH, is a weak acid, used for preserving fruit juices.

The acid dissociation constant, K_a, of benzoic acid is 6.30×10^{-5} mol dm^{-3} at 25 °C.

(a) Write the equation for the dissociation of benzoic acid when dissolved in water.

..... **[1]**

(b) Write the expression for the acid dissociation constant, K_a, of benzoic acid.

[1]

(c) The solubility of benzoic acid in water is 3.40 g dm^{-3} at 25 °C.

Calculate the pH of a saturated solution of benzoic acid in water at 25°C.

[5]

(d) In this question, one mark is available for the quality of use and organisation of scientific terms.

A buffer solution is needed for preserving fruit juice.

A chemist at the fruit juice company prepared a benzoic acid/sodium benzoate buffer with concentrations of 0.105 mol dm^{-3} C_6H_5COOH and 0.125 mol dm^{-3} C_6H_5COONa.

- State what a buffer solution is and explain how this solution acts as a buffer solution. Include equations in your answer.
- Calculate the pH of this benzoic acid/sodium benzoate buffer at 25 °C. Show all your working.

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..... **[8]**

Quality of Written Communication **[1]**

[Total: 16]

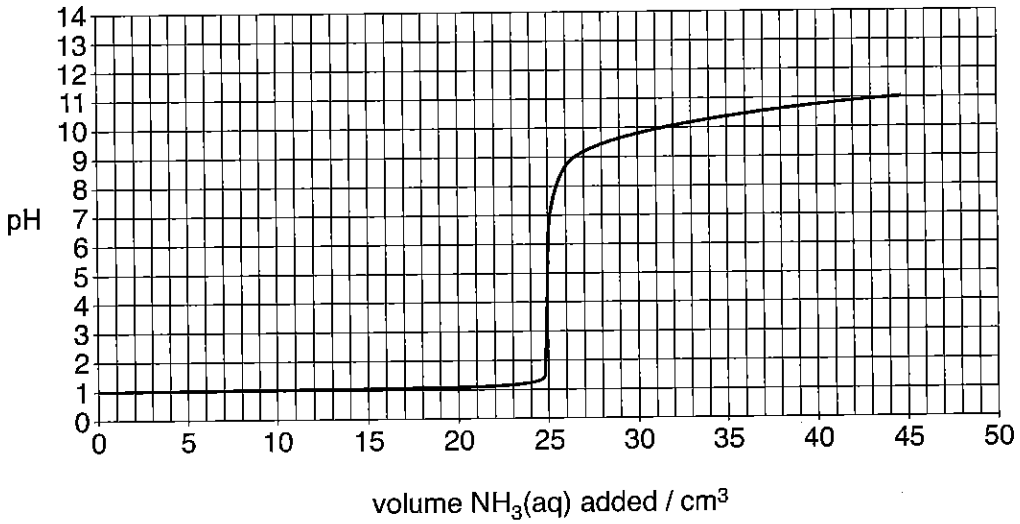
4 Nitric acid, HNO_3, is a strong acid which can also behave as an oxidising agent.

(a) Nitric acid reacts with bases, such as aqueous ammonia, $NH_3(aq)$, to form salts.

A 25.0 cm^3 sample of $HNO_3(aq)$ was placed in a conical flask.

$NH_3(aq)$ was added from a burette until the pH showed little further change.
The NH_3 concentration was the same as the HNO_3 concentration.

The pH curve for this titration is shown below.



(i) Deduce the concentration of the nitric acid.

[1]

(ii) How can you tell from this pH curve that aqueous ammonia is a weak base?

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..... **[1]**

(iii) What is the formula for the salt formed in this reaction?

..... **[1]**

(iv) The pH ranges for four indicators are shown below.

indicator	pH range
malachite green	0.2–1.8
resazurin	3.8–6.4
metacresol purple	7.4–9.0
alizarin yellow R	10.1–12.0

Which of these four indicators is most suitable for this titration?

..... **[1]**

(v) The titration was repeated but using $NH_3(aq)$ with **twice** the concentration of the original ammonia solution.

What **two** differences would there be between this titration curve and the one shown in part **(a)**?

.....

.....

.....

..... **[2]**

(b) When nitric acid reacts with magnesium metal, different gases are formed, depending on the concentration of the nitric acid. Each reaction producing a gas is a redox reaction.

- With very dilute nitric acid, H_2 gas is evolved.
- With concentrated nitric acid, NO_2 gas is evolved.

(i) Write a full equation and an ionic equation for the reaction of magnesium with very dilute nitric acid.

full equation .....

ionic equation ..... **[2]**

(ii) Use oxidation numbers to show the reduction that takes place when magnesium reacts with dilute and with concentrated nitric acid.

dilute HNO_3 .....

concentrated HNO_3 ..... **[2]**

[Total: 10]

5 This question looks at some chemicals in everyday situations.

(a) Plaster of Paris may be used for setting broken limbs. The formula of Plaster of Paris is $CaSO_4.½H_2O$. When water is added, the Plaster of Paris sets as it forms $CaSO_4.2H_2O$.

What is the minimum mass of water needed to set 500 g of Plaster of Paris?

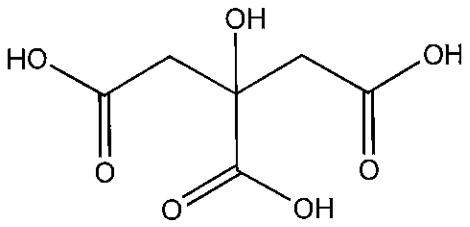
mass of water = ... **[2]**

(b) A bottle contains 0.60 g of nitrogen, N_2. Another bottle of the same volume is filled at the same temperature and pressure with 1.52 g of an unknown gas.
Suggest the molecular formula of the unknown gas.

molecular formula = ... **[2]**

(c) An orange-flavoured drink contains citric acid.

The structure of citric acid is shown below.



(i) Determine the molecular formula of citric acid.

..... **[1]**

(ii) 25.0 cm^3 of the drink was titrated with NaOH(aq).

21.35 cm^3 of 0.00425 mol dm^{-3} NaOH(aq) was needed to reach the end point of the titration.

1 mol of citric acid reacts with 3 mol of NaOH.

A person drank 250 cm^3 of the orange-flavoured drink.
Calculate the mass of citric acid in 250 cm^3 of the drink.

mass citric acid = ... **[5]**

[Total: 10]

END OF QUESTION PAPER

2 Solutions of hydrogen peroxide, H_2O_2, are colourless and widely used as oxidising agents, antiseptic and bleaches for hair and cloth.

Hydrogen peroxide reacts with iodide ions, I^-, in the presence of acid, $H^+(aq)$, forming iodine, I_2.

(a) Suggest a balanced equation for the overall reaction between $H_2O_2(aq)$, $I^-(aq)$ and $H^+(aq)$ to form aqueous iodine.

..... **[2]**

(b) Three experiments were carried out using different initial concentrations of $H_2O_2(aq)$, $I^-(aq)$ and $H^+(aq)$. The initial rate of formation of I_2 was measured for each experiment.

The experimental results are shown below.

experiment	$[H_2O_2(aq)]$ /mol dm^{-3}	$[I^-(aq)]$ /mol dm^{-3}	$[H^+(aq)]$ /mol dm^{-3}	rate /mol dm^{-3} s^{-1}
1	0.050	0.010	0.005	5.75×10^{-6}
2	0.050	0.020	0.005	1.15×10^{-5}
3	0.050	0.040	0.010	2.30×10^{-5}

(i) Showing all your reasoning, determine the orders of reaction for I^- and H^+.

.....

.....

.....

.....

.....

..... **[4]**

(ii) This reaction is first order with respect to H_2O_2.

Use this information and your answers to **(i)** to write the rate equation for this reaction.

..... **[1]**

(iii) Calculate the rate constant, *k*, for this reaction. State the units for *k*.

rate constant, *k*: ..... units: ..... **[3]**

(c) Hydrogen peroxide readily decomposes to give water and oxygen.

Hydrogen peroxide is sold by volume strength. For example, 40 volume hydrogen peroxide is used to bleach hair, fur and bones.

40 volume H_2O_2 produces 40 volumes of oxygen gas, measured at room temperature and pressure, r.t.p., for each volume of aqueous H_2O_2 solution.

(i) Construct an equation for the decomposition of hydrogen peroxide.

..... **[1]**

(ii) Determine the concentration, in mol dm^{-3}, of 40 volume hydrogen peroxide.

1 mol of $O_2(g)$ occupies 24.0 dm^3 at r.t.p.

Show all your working clearly.

answer = ... mol dm^{-3} **[3]**

[Total: 14]

3 This question looks at several acids.

(a) Hydroiodic acid, HI(aq), is a strong acid that is an aqueous solution of hydrogen iodide gas. In the laboratory, hydroiodic acid is prepared by the method below.

A mixture of iodine and water is put into a flask. The mixture is stirred and hydrogen sulphide gas, $H_2S(g)$, is bubbled through the mixture for several hours. The mixture becomes yellow as sulphur separates out.

The sulphur is filtered off and the solution is purified by fractional distillation.

A 225 cm^3 sample of hydroiodic acid is collected containing 47.2 g of HI.

(i) Construct a balanced equation, with state symbols, for the preparation of hydroiodic acid from iodine and hydrogen sulphide.

..... **[2]**

(ii) Calculate the pH of the hydroiodic acid sample that is collected.

pH = ... **[2]**

(b) Ethanoic acid, CH_3COOH, is a weak acid with a K_a value of 1.70×10^{-5} mol dm^{-3}.

(i) Write an equation for the dissociation of ethanoic acid.

..... **[1]**

(ii) The concentration of ethanoic acid in a solution **X** was 2.74×10^{-3} mol dm^{-3}.

Calculate the pH of solution **X**.

pH = ... **[3]**

(iii) When ethanoic acid is mixed with hydroiodic acid, an acid–base reaction takes place.

Complete the acid–base equilibrium that is set up and identify the acid–base pairs.

- label **one** conjugate acid–base pair as **acid 1** and **base 1**,
- label the other conjugate acid–base pair as **acid 2** and **base 2**.

..... + ... ⇌ ..... + ...

.... **[2]**

(c) Methanoic acid, HCOOH, is an ant's main defence mechanism, squirted at potential intruders and injected in 'ant bites'.

(i) The recommended treatment for an ant bite is 'bicarbonate of soda', which contains $NaHCO_3$.

Suggest, with an equation, how $NaHCO_3$ helps to relieve the effect of an ant bite.

.....

.....

..... **[2]**

(ii) Wasp stings are treated with vinegar. What does this suggest about the nature of the active ingredient in a wasp sting? Explain your answer.

.....

.....

..... **[2]**

(iii) Methanoic acid can be used in buffer solutions.

Calculate the pH of a buffer solution containing equal volumes of 0.75 mol dm^{-3} methanoic acid and 1.92 mol dm^{-3} sodium methanoate.

For HCOOH, $K_a = 1.60 \times 10^{-4}$ mol dm^{-3}.

pH = ... **[2]**

[Total: 16]

4 **(a)** A student analysed an unsaturated branched carboxylic acid, **A**, using a titration procedure.

The student dissolved 1.368 g of the compound in water and made the solution up to 100.0 cm^3. The student titrated 25.0 cm^3 of this solution with 0.152 mol dm^{-3} NaOH. The volume of NaOH(aq) required to reach the end-point was 19.80 cm^3.

Each molecule of **A** has one acidic hydrogen atom and it behaves as a monoprotic (monobasic) acid.

- Calculate the molar mass of the unsaturated branched carboxylic acid **A**.
- Determine the molecular formula and show **two** possible structural isomers of the unsaturated branched carboxylic acid **A**.

[8]

(b) In this question, one mark is available for the quality of use and organisation of scientific terms.

This question considers different graphs used in chemistry.

- Explain how the shapes of rate–concentration graphs can be used to deduce the orders with respect to reactants.
- Explain how acid–base titration pH curves can be used to suggest suitable indicators for titrations of strong and weak acids with strong bases.

In your answer, include sketch graphs with labelled axes.

[8]

Quality of Written Communication [1]

[Total: 17]

END OF QUESTION PAPER

Answer **all** the questions.

1 The preparation of ethyl ethanoate from ethanoic acid and ethanol is a reversible reaction which can be allowed to reach equilibrium.

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

(a) Write the expression for K_c for this equilibrium system.

[1]

(b) A student mixed together 8.0 mol ethanoic acid and 14.5 mol ethanol. A small amount of hydrochloric acid was also added to catalyse the reaction. He left the mixture for two days to reach equilibrium, after which time 1.5 mol ethanoic acid remained.

(i) Complete the table below to show the equilibrium composition of the mixture.

component	CH_3COOH	C_2H_5OH	$CH_3COOC_2H_5$	H_2O
initial amount/mol	8.0	14.5	0.0	0.0
equilibrium amount/mol				

[2]

(ii) Calculate K_c to **two** significant figures.

The total volume of the equilibrium mixture is 1.0 dm^3.

K_c = ... **[2]**

(c) The student added more ethanol to the mixture at constant temperature.

(i) State, giving a reason, what would happen to the equilibrium composition of the mixture.

.....

.....

..... **[1]**

(ii) What happens to the value of K_c?

..... **[1]**

(d) State, giving a reason, what would happen to the equilibrium position if the concentration of the acid catalyst were to be increased.

.....

.....

..... **[2]**

(e) The student repeated the experiment at a higher temperature and found that the value of K_c decreased.

Explain what additional information this tells you about this reaction.

.....

.....

.....

..... **[2]**

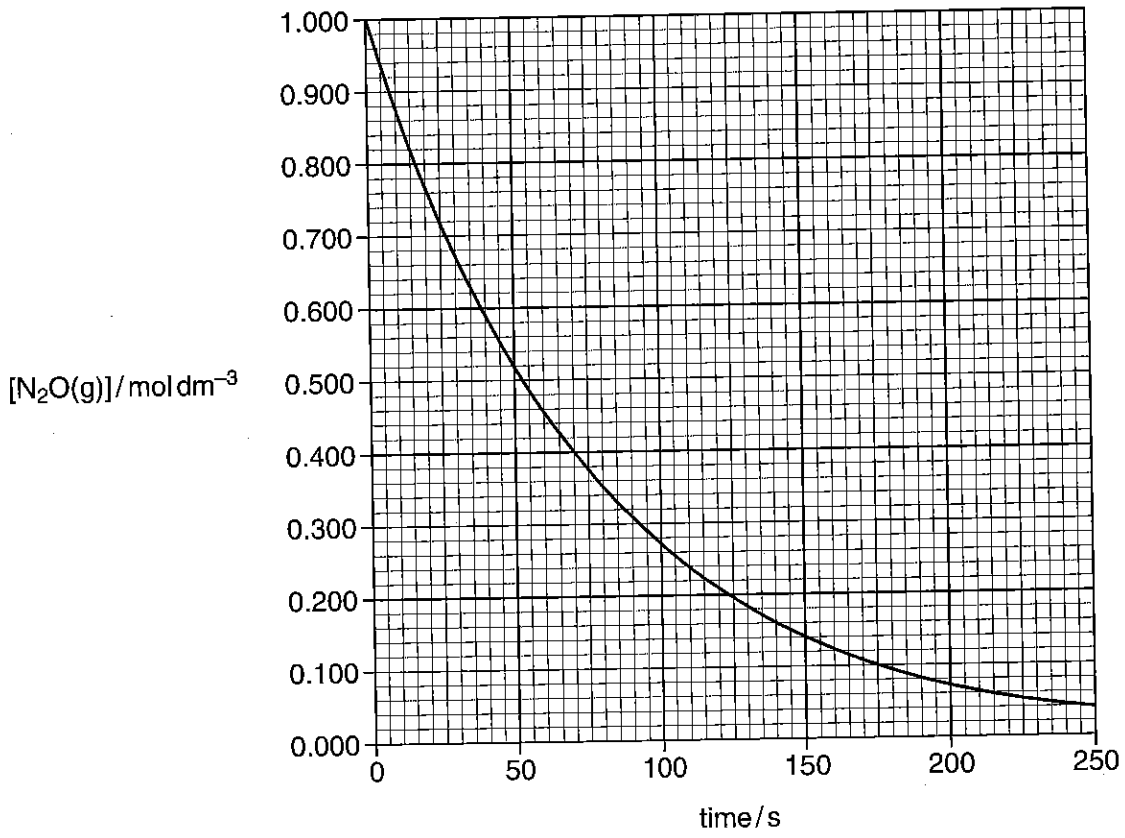
[Total: 11]

2 Nitrous oxide, N_2O, is a colourless gas with a mild, pleasant odour and sweet taste. It is widely used as a propellant in aerosol cans of whipped cream.

(a) When heated strongly, nitrous oxide decomposes into its elements.

$$2N_2O(g) \longrightarrow 2N_2(g) + O_2(g)$$

This reaction is first order with respect to N_2O. This can be confirmed from the graph below using half-lives.



(i) What is meant by the *half-life* of a reaction?

.....

..... **[1]**

(ii) Use this graph to show that this reaction is first order with respect to N_2O.

State the half-life.

.....

.....

..... **[2]**

(iii) What would be the effect on the half-life of this reaction of doubling the initial concentration of N_2O?

..... **[1]**

(b) (i) Write down the rate equation for this reaction.

..... **[1]**

(ii) Use the graph to work out the rate of reaction, in $mol\,dm^{-3}\,s^{-1}$, at 70 seconds.

Show your working on the graph.

rate = ...$mol\,dm^{-3}\,s^{-1}$ **[2]**

(iii) Calculate the rate constant for this reaction. State the units.

k = ... units: ..... **[2]**

(c) What evidence is there that the mechanism of this reaction takes place in more than a single step?

.....

.....

..... **[2]**

(d) Nitrous oxide is formed when ammonium nitrate, NH_4NO_3, is gently heated.

$$NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(l)$$

(i) What mass of N_2O is formed by heating 100 g of NH_4NO_3?

[2]

(ii) In this reaction, what happens to the oxidation number of each nitrogen atom in the ammonium nitrate?

.....

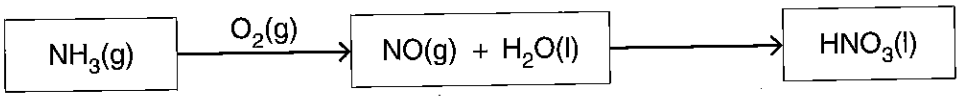
.....

..... **[2]**

(e) Ammonium nitrate is prepared from nitric acid, HNO_3, and ammonia, NH_3.

Each year in the UK, 700 000 tonnes of nitric acid are manufactured for the production of fertilisers, dyes and explosives.

Nitrogen monoxide, NO, is an intermediate in the production of nitric acid from ammonia.



(i) Construct a balanced equation for the formation of NO(g) from $NH_3(g)$.

..... **[1]**

(ii) Assuming that 1 mol NH_3 produces 1 mol HNO_3, and that all NH_3 is converted, calculate the mass of NH_3 that is required to meet the annual demand for HNO_3 in the UK.

1 tonne = 10^6 g

answer = ... **[2]**

[Total: 18]

3 A student carried out some practical work on acids and alkalis.

(a) The student measured the pH of aqueous solutions of hydrochloric acid, HC*l*, and ethanoic acid, CH_3COOH. The results are shown below.

acid	concentration / mol dm^{-3}	pH
HC*l*	0.0200	1.70
CH_3COOH	0.0200	3.23

(i) Why are the pH values of the two acids different?

.....

..... **[1]**

(ii) Calculate the value, including units, of K_a for ethanoic acid.

answer = ... **[3]**

(iii) The student mixed together 25 cm^3 of 0.0200 mol dm^{-3} HC*l* with 75 cm^3 of water.

Determine the pH of the diluted acid. Show your working.

pH = ... **[2]**

(b) The ionic product of water, K_w, has a value of 1.0×10^{-14} mol^2 dm^{-6}.

(i) Complete the expression for K_w below.

K_w = ... **[1]**

(ii) Calculate the pH of 0.015 mol dm^{-3} NaOH(aq). Show your working.

pH = ... **[2]**

(c) The student pipetted 25.0 cm^3 of 0.0200 mol dm^{-3} $CH_3COOH(aq)$ into a conical flask.

She then slowly added an **excess** of 0.0150 mol dm^{-3} NaOH(aq) from a burette. In total, 50.00 cm^3 of the alkali were added.

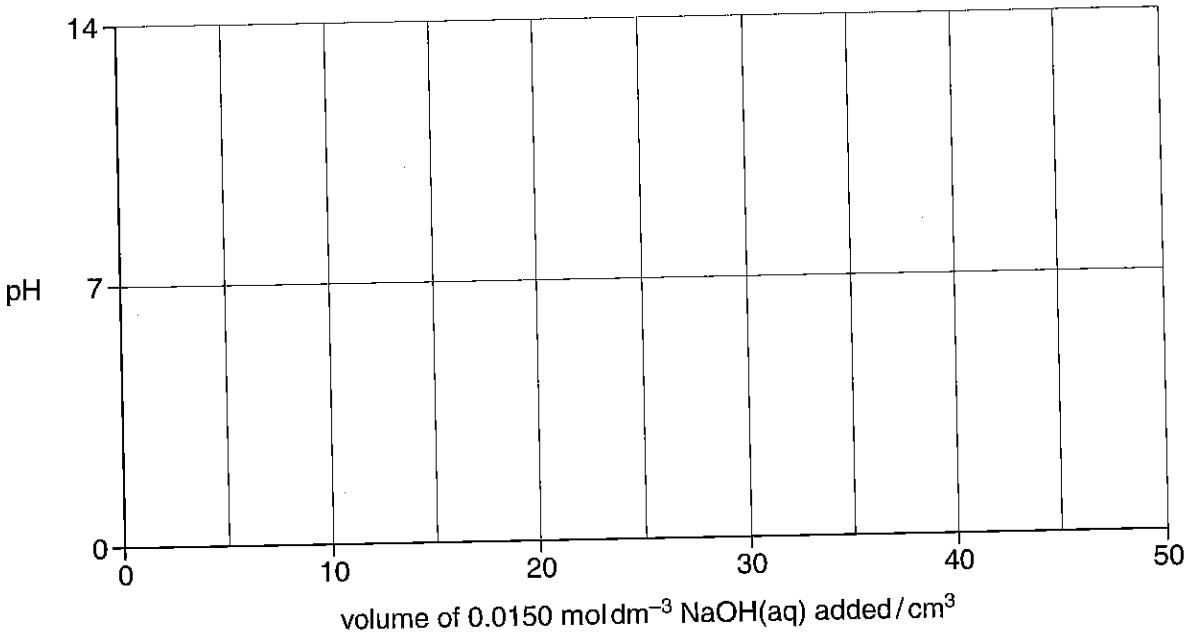
The pH of the solution was measured throughout with a pH meter.

The equation for the reaction is shown below.

$$CH_3COOH(aq) + NaOH(aq) \longrightarrow CH_3COONa(aq) + H_2O(l)$$

(i) Sketch the pH curve for this titration on the grid below.

The initial and final pH values do **not** need to be shown accurately.



[3]

(ii) This titration could be carried out using an indicator. The pH ranges for four indicators are shown below.

indicator	pH range
clayton yellow	12.2–13.2
thymol blue	8.0–9.6
brilliant yellow	6.6–7.8
resazurin	3.8–6.4

Explain which of the four indicators is most suitable for this titration.

.....

.....

..... **[1]**

Turn over

(d) In this question, one mark is available for the quality of use and organisation of scientific terms.

The student prepared a buffer solution by mixing together 25 cm^3 of 1.00 mol dm^{-3} ethanoic acid, CH_3COOH, and 25 cm^3 of 1.00 mol dm^{-3} sodium ethanoate, CH_3COONa.

- Explain what is meant by a *buffer solution* and how this ethanoic acid/sodium ethanoate buffer solution works. Use equations in your answer.

- What would be the effect on the pH of this buffer solution if the CH_3COONa had been twice the concentration of the ethanoic acid? Explain your answer. You do not need to carry out any calculations.

..... **[7]**

Quality of Written Communication **[1]**

[Total: 21]

4 Maleic anhydride, $C_4H_2O_3$, is an important industrial chemical.

(a) Maleic anhydride is produced on a large scale by passing a mixture of butane and air over a hot catalyst.

(i) An incomplete equation for this reaction is given below.

Complete and balance the equation for this reaction.

$$C_4H_{10} + \text{.....} \rightarrow C_4H_2O_3 + \text{.....}$$

[1]

(ii) Calculate the mass, in kg, of maleic anhydride that could be made by completely converting $30\,m^3$ of butane in this reaction.

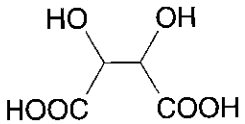
$1\,m^3 = 1000\,dm^3$; $M_r(C_4H_2O_3) = 98.0$

Assume that gas volumes have been measured at room temperature and pressure.

1 mol of gas molecules occupies $24\,dm^3$ at room temperature and pressure.

mass = ... kg **[2]**

(b) Maleic anhydride can be converted into tartaric acid by reaction with water and a suitable oxidising agent. The structure of tartaric acid is shown below.

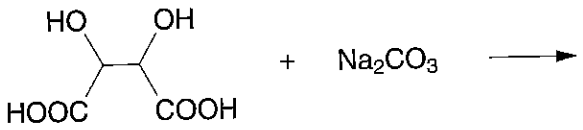


Deduce the **empirical** formula of tartaric acid.

[1]

(c) A student reacted an aqueous solution of tartaric acid with an excess of sodium carbonate, Na_2CO_3.

(i) Complete the equation below for this reaction.



[2]

(ii) Suggest another chemical, apart from a carbonate, that would react with an aqueous solution of tartaric acid.

.....

Write an equation for your chosen reaction.

[3]

(d) Maleic anhydride can be prepared by the dehydration of maleic acid, HOOCCH=CHCOOH.

Suggest the structure of maleic anhydride.

[1]

[Total: 10]

END OF QUESTION PAPER

4 In this question, you should use knowledge, principles and concepts from different areas of chemistry. *(In this question, 1 mark is available for the quality of written communication.)*

Compound **A** was analysed in the laboratory and was shown to have the composition by mass K, 31.9%; C*l*, 29.0%; O, 39.1%.

On gentle heating, compound **A** formed potassium chlorate(VII), $KClO_4$, and compound **B** in a 3:1 molar ratio.

On strong heating, 0.250 g $KClO_4$ was broken down into compound **B** and oxygen gas.

An aqueous solution of compound **B** formed a white precipitate, **C**, with aqueous silver nitrate.

Showing **all** your reasoning,

- identify substances **A – C**, [6]
- write balanced equations for all reactions that took place, [3]
- calculate the mass of **B** formed from 0.250 g of $KClO_4$, [2]
- calculate the volume of oxygen formed, at room temperature and pressure. [2]

[Total : 13]

4 In this question, you should use knowledge, principles and concepts from different areas of chemistry. *(In this question, 1 mark is available for the quality of written communication.)*

(a) The equation for the production of ammonia in the Haber process is shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92\,kJ\,mol^{-1}$$

Explain why the conditions of temperature and pressure used in the Haber process (450 °C, 15 000 kPa) are a **compromise**.

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.....[7]

For Examiner's Use

(b) An *Alka-Seltzer* tablet contains about 0.5 g sodium hydrogencarbonate, $NaHCO_3$, and an excess of citric acid. When water is added to an *Alka-Seltzer* tablet, carbon dioxide gas is released.

The equation for the reaction that takes place is shown below. The formula of citric acid has been simplified as H_3A.

$$3NaHCO_3 + H_3A \longrightarrow Na_3A + 3CO_2 + 3H_2O$$

(i) Explain, using ionic equations, how the addition of water allows the release of carbon dioxide from an *Alka-Seltzer* tablet.

.....

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.....[4]

(ii) Calculate the minimum mass of citric acid that needs to be in an *Alka-Seltzer* tablet to ensure that all the sodium hydrogencarbonate reacts. (M_r citric acid: 192)

.....

.....

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.....

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.....

.....

.....[5]

[Total : 16]

2 Some students were measuring the enthalpy changes for the neutralisation of 1 mol of different acids with different alkalis.

(a) In a first experiment, a student investigated the neutralisation of hydrochloric acid, HC*l*(aq), with aqueous potassium hydroxide, KOH(aq).

The student poured 200 cm^3 of 2.00 mol dm^{-3} hydrochloric acid into a plastic cup. He added 200 cm^3 of 2.00 mol dm^{-3} potassium hydroxide and the temperature increased from 21.3 °C to 34.9 °C.

(i) Calculate the energy, in kJ, produced in the reaction.

The specific heat capacity of aqueous solutions is 4.18 J g^{-1} K^{-1}.
The density of aqueous solutions is 1.00 g cm^{-3}.

energy produced = ... kJ **[2]**

(ii) Calculate the enthalpy change, ΔH, for the neutralisation of 1 mol of hydrochloric acid by aqueous potassium hydroxide.

ΔH = ... kJ mol^{-1} **[3]**

(b) The enthalpy change that occurs when 1 mol of water is produced by reacting an aqueous acid with an aqueous alkali is the enthalpy change of neutralisation.

Write the **ionic** equation for the enthalpy change of neutralisation.

.....

..... **[1]**

(c) The enthalpy changes for the neutralisation of 1 mol of three acids are given below.

- **experiment 1**
  $HNO_3(aq)$ with NaOH(aq) $\Delta H = -57.3\ kJ\,mol^{-1}$
- **experiment 2**
  $HCl(aq)$ with NaOH(aq) $\Delta H = -57.3\ kJ\,mol^{-1}$
- **experiment 3**
  $CH_3COOH(aq)$ with NaOH(aq) $\Delta H = -55.2\ kJ\,mol^{-1}$

Explain why the enthalpy change is the same for **experiments 1** and **2** but different for **experiment 3**.

.....

.....

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.....

.....

..... **[3]**

[Total: 9]

For Examiner's Use

Answer **all** questions.

1 Enthalpy changes of formation can be calculated using Born-Haber cycles.

(a) Construct a labelled Born-Haber cycle for magnesium chloride, $MgCl_2$, using the information below.

enthalpy change	energy/kJ mol^{-1}
atomisation of magnesium	+148
atomisation of chlorine	+122
1st ionisation energy of magnesium	+738
2nd ionisation energy of magnesium	+1451
1st electron affinity of chlorine	–349
lattice enthalpy of magnesium chloride	–2526
formation of magnesium chloride	?

[5]

For Examiner's Use

(b) Use the Born-Haber cycle to calculate a value for the enthalpy change of formation of magnesium chloride.

[2]

(c) State and explain which compound has the **most exothermic** lattice enthalpy; $MgCl_2$, $MgBr_2$ or MgI_2.

.....

.....

.....

.....[3]

[Total : 10]

[Turn over

2 Iron in compounds commonly exists as Fe^{2+} and Fe^{3+}.

(a) Complete the electronic configuration of the Fe^{3+} **ion.**

$1s^2\ 2s^2\ 2p^6$ .....[1]

(b) **(i)** State **one** reason why transition metals are good catalysts.

.....

.....[1]

(ii) State **one** example of iron or a compound of iron being used as a catalyst in industry.

.....[1]

(c) Complete the following notes taken during a laboratory experiment.

Aqueous thiocyanate ions were added to aqueous iron(III) ions.
The solution changed colour

from ..... *to* .....

Equation:.....[4]

(d) Aqueous manganate(VII) ions were titrated against 25.0 cm^3 of 0.0500 mol dm^{-3} Fe(II) ions in acid solution.

$$5Fe^{2+}(aq) + MnO_4^-(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$$

The volume of aqueous manganate(VII) ions required to reach the end point was 12.3 cm^3.

(i) State the colour change observed at the end point.

from ..... to.....[1]

(ii) Calculate the concentration of the aqueous manganate(VII) ions used in the titration.

Answer.....mol dm^{-3} [3]

[Total : 11]

For Examiner's Use

(b) Using complex ions of copper as examples, explain what is meant by the terms *complex ion* and *ligand*.

Explain what is meant by *ligand substitution*, giving two examples that are accompanied by a colour change and including equations in your answer.

Describe, using suitable examples, two different shapes of complex ions. [13]

[Total : 15]

For Examiner's Use

Answer **all** questions.

1 **(a)** **(i)** Explain what is meant by the term *transition element*.

.....

.....[1]

(ii) Complete the electronic configuration of the vanadium atom.

$1s^2 2s^2 2p^6$.....[1]

(b) Aqueous transition metal ions can react with aqueous hydroxide ions.

(i) Complete the table below.

metal ion	**formula** and **state symbol** of the product of the reaction with $OH^-(aq)$	colour of product
$Fe^{2+}(aq)$		
$Fe^{3+}(aq)$		

[5]

(ii) Aqueous ammonia reacts with water in the following way.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

When aqueous ammonia is added dropwise to aqueous copper(II) ions, a very pale blue precipitate is observed which disappears in excess ammonia to give a deep blue solution.

Write equations to show the formation from aqueous copper(II) ions of

the pale blue precipitate,

.....

the deep blue solution.

.....[4]

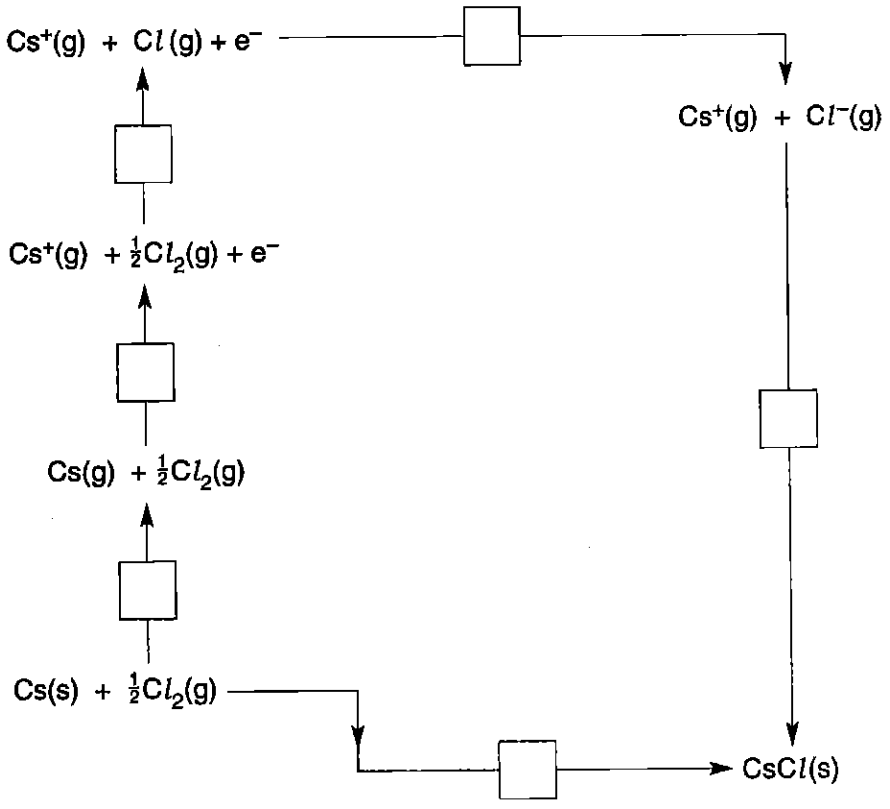
[Total : 11]

3 The lattice enthalpy of caesium chloride, CsCl, can be calculated using a Born-Haber cycle.

The table below shows the enthalpy changes and corresponding data for this cycle.

enthalpy change		energy/kJ mol^{-1}
lattice enthalpy of CsCl	**A**	?
atomisation of caesium	**B**	+76
atomisation of chlorine	**C**	+122
1st ionisation energy of caesium	**D**	+376
1st electron affinity of chlorine	**E**	–349
formation of CsCl	**F**	–443

(a) On the cycle below, put the letter for each enthalpy change in the appropriate box.



[3]

(b) Calculate the lattice enthalpy of caesium chloride.

Answer .....kJ mol^{-1} [2]

(c) The lattice enthalpy of sodium chloride is **more exothermic** than the lattice enthalpy of caesium chloride.

State and explain the relative strengths of the ionic bonding in sodium chloride and caesium chloride.

.....

.....

.....

.....[3]

(d) What would you expect to observe when solid caesium chloride is added to water?

.....

.....

.....[2]

(e) Describe how you would distinguish between aqueous caesium chloride and aqueous caesium iodide using a simple laboratory test. State the observations you would make.

.....

.....

.....

.....[3]

[Total : 13]

4 The manganate(VII) ion, MnO_4^-, is a strong oxidising agent frequently used in laboratory analysis. It reacts with the ethanedioate ion, $C_2O_4^{2-}$, in hot acidic solution to form CO_2 and Mn^{2+} ions.

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$
$$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$$

(a) Construct the full ionic equation for this reaction.

[2]

(b) Calculate the volume of 0.0200 mol dm^{-3} potassium manganate(VII) required to react with 25.0 cm^3 of 0.0400 mol dm^{-3} sodium ethanedioate.

[3]

[Total : 5]

3 Iron is a typical transition element.

- Iron shows more than one oxidation state in its compounds.
- Iron and its compounds are used as catalysts.

(a) Complete the electronic configuration for an **iron(III) ion, Fe^{3+}**, and use it to explain why iron is a transition element.

Fe^{3+}: $1s^2 2s^2 2p^6$ .....

explanation .....

..... [2]

(b) State **one** use of iron or one of its compounds as a catalyst. State the name of the catalyst and the reaction catalysed.

name of catalyst .....

reaction catalysed ..... [1]

(c) Under certain conditions iron can be oxidised to form sodium ferrate, Na_2FeO_4. This is a red-purple coloured substance that has properties very similar to that of potassium manganate(VII).

(i) Analysis of a sample of sodium ferrate showed that it contains the following percentage composition by mass,

Na, 27.74%, Fe, 33.66% and O, 38.60%.

Show that these data are consistent with the formula Na_2FeO_4.

[2]

(ii) Deduce the oxidation state of iron in sodium ferrate, Na_2FeO_4.

..... [1]

(d) The half-equation for the reduction of ferrate ions, FeO_4^{2-}, in acidic conditions is shown below.

$$FeO_4^{2-} + 8H^+ + 4e^- \longrightarrow Fe^{2+} + 4H_2O$$

Acidified $FeO_4^{2-}(aq)$ ions oxidise aqueous iodide ions, I^-, to form aqueous iodine, I_2.

(i) Construct the half-equation for the oxidation of iodide ions to form iodine.

..... [1]

(ii) Construct the ionic equation for the redox reaction that occurs between aqueous FeO_4^{2-} and aqueous I^- in the presence of H^+.

.....

.....

..... [2]

(iii) Predict the colour change you would see when aqueous FeO_4^{2-} is added to an excess of aqueous I^- in the presence of H^+.

from ..... to ..... [1]

[Total: 10]

4 In this question, one mark is available for the quality of written communication.

Iron forms complex ions such as $[Fe(H_2O)_6]^{2+}$ and $[Fe(H_2O)_6]^{3+}$.

- Describe and explain the bonding in, and the shape of, **one** of these complex ions.
- Explain why the H—O—H bond angle in water in an isolated gaseous molecule is different from that in the complex $[Fe(H_2O)_6]^{2+}$.
- Describe, with the aid of suitable equations, how the two complex ions can be distinguished by means of a chemical test.

For Examiner's Use

Answer **all** the questions.

1 Calcium carbonate thermally decomposes into calcium oxide and carbon dioxide as shown in the equation.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

(a) Show that the thermal decomposition of calcium carbonate is **not** a redox reaction. Use oxidation states in your answer.

.....

.....

..... [2]

(b) Magnesium carbonate also thermally decomposes. Describe and explain the difference in the ease of thermal decomposition between magnesium carbonate and calcium carbonate. Use ideas about charge density and polarisation in your answer.

.....

.....

.....

.....[3]

(c) Calculate the enthalpy change of reaction, ΔH_r, for the thermal decomposition of calcium carbonate using the enthalpy changes of formation given in the table.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CaCO_3(s)$	−1207
$CaO(s)$	−635
$CO_2(g)$	−393

answer ..... kJ mol^{-1} [2]

[Turn over

(d) The lattice enthalpy of magnesium oxide is $-3916\ kJ\ mol^{-1}$.

Explain, with the aid of a suitable equation, what is meant by the statement the 'lattice enthalpy of magnesium oxide is $-3916\ kJ\ mol^{-1}$'.

.....

.....

.....

..... [3]

(e) The table below shows the enthalpy changes needed to calculate the lattice enthalpy of magnesium oxide.

process	equation	enthalpy change / kJ mol^{-1}
first ionisation energy of magnesium	$Mg(g) \rightarrow Mg^+(g) + e^-$	+735
second ionisation energy of magnesium	$Mg^+(g) \rightarrow Mg^{2+}(g) + e^-$	+1445
first electron affinity of oxygen	$O(g) + e^- \rightarrow O^-(g)$	−141
second electron affinity of oxygen	$O^-(g) + e^- \rightarrow O^{2-}(g)$	+878
enthalpy change of formation for magnesium oxide	$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$	−602
enthalpy change of atomisation for magnesium	$Mg(s) \rightarrow Mg(g)$	+150
....	$\frac{1}{2}O_2(g) \rightarrow O(g)$	+247

(i) Complete the table by writing in the missing process. [1]

(ii) Explain why the second ionisation energy of magnesium is **more endothermic** than the first ionisation energy.

.....

.....

.....[2]

(iii) Draw a labelled Born-Haber cycle using the information in the table. Show, by calculation, that the lattice enthalpy of magnesium oxide is $-3916\ kJ\ mol^{-1}$.

[4]

(f) State **one** use for magnesium oxide that relies on its high lattice enthalpy.

..... [1]

[Total: 18]

(e) In the octahedral complex, $[Cu(NH_3)_x(H_2O)_y]^{2+}$, ammonia is a ligand.

(i) Explain why ammonia can behave as a ligand.

.....

..... [1]

(ii) The bond angle around the nitrogen atom in an ammonia molecule is 107° but it is 109.5° in the octahedral complex. Explain why the bond angles differ.

.....

.....

.....

.....

..... [2]

(f) Aqueous copper(II) ions react with concentrated hydrochloric acid to give a yellow solution of $[CuCl_4]^{2-}(aq)$. This reaction is an example of ligand substitution.

(i) Write an equation to show the formation of $[CuCl_4]^{2-}(aq)$.

[1]

(ii) Draw the shape of the $[CuCl_4]^{2-}$ ion.

[1]

[Total: 15]

Answer **all** the questions.

1 Iron is a transition element. It forms compounds in which the oxidation number of iron is +2, +3 or +6.

(a) Give the electronic configuration of Fe^{2+} and use it to explain why iron is a transition element.

.....

.....

..... [1]

(b) Transition elements form complex ions.

Choose an example of a complex ion in which iron has the +2 oxidation state.

(i) Write the formula for your chosen complex ion formed by iron.

..... [1]

(ii) Draw the shape of your chosen complex ion. Indicate clearly the three-dimensional shape and the bond angles.

[2]

(iii) Describe the bonding within your chosen complex ion.

.....

.....

..... [2]

(c) Complex ions containing transition elements often undergo ligand substitution reactions.

Describe one ligand substitution reaction of a complex ion containing iron in the +3 oxidation state.

Include in your answer:

- an equation;
- the colour change that is seen during the reaction.

.....

..... [2]

(d) Describe how aqueous sodium hydroxide can be used to distinguish between aqueous solutions of iron(II) chloride and iron(III) chloride. Write an ionic equation, with state symbols, for **one** of the reactions you describe.

.....

.....

.....

..... [2]

(e) FeO_4^{2-} reacts with Cr^{3+} ions as shown in the following equation.

$$FeO_4^{2-} + Cr^{3+} \longrightarrow CrO_4^{2-} + Fe^{3+}$$

Use oxidation numbers to explain why this reaction involves both oxidation and reduction.

.....

.....

..... [2]

(f) FeO_4^{2-} decomposes in the presence of hydrogen ions, forming iron(III) ions, oxygen and water.

Construct the ionic equation for this reaction.

.....

..... [2]

[Total: 14]

2 Lattice enthalpy is a measure of ionic bond strength.

(a) Explain, with the aid of an equation, what is meant by the *lattice enthalpy of sodium oxide*, Na_2O.

.....

.....

..... [2]

(b) Magnesium oxide, MgO, is used to line furnaces.

Draw a Born-Haber cycle for MgO.

Include:

- state symbols;
- names of the energy changes involved.

[5]

(c) Describe and explain the difference between the lattice enthalpies of magnesium oxide and magnesium carbonate.

.....

.....

..... [2]

(d) Calcium carbonate is decomposed in a lime-kiln to make calcium oxide.

(i) Write an equation for this decomposition.

..... [1]

(ii) Explain why the decomposition temperature for calcium carbonate is much higher than for magnesium carbonate.

.....

.....

.....

..... [2]

[Total: 12]

3 Ethanedioic acid is a poisonous substance found in rhubarb leaves.

A sample of ethanedioic acid was isolated as hydrated crystals with the formula $(COOH)_2.xH_2O$.

The value of **x** in $(COOH)_2.xH_2O$ can be determined by its reaction with acidified manganate(VII) ions.

- **Stage 1** – A sample of known mass is added to a conical flask.
- **Stage 2** – The sample has 25.0 cm^3 of 1 mol dm^{-3} sulphuric acid added to it.
- **Stage 3** – The contents of the flask are heated to 60 °C.
- **Stage 4** – The hot contents of the flask are titrated against 0.0200 mol dm^{-3} MnO_4^-.

In **stage 2** the hydrated crystals dissolve.

$$(COOH)_2.xH_2O(s) + (aq) \longrightarrow (COOH)_2(aq) + xH_2O(l)$$

In **stage 4** the equation for the reaction between $(COOH)_2$ and acidified MnO_4^- is shown below.

$$5(COOH)_2(aq) + 6H^+(aq) + 2MnO_4^-(aq) \longrightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

(a) Suggest what you would see at the end-point of this titration.

..... [1]

(b) In **stage 1** a student used 0.120 g of $(COOH)_2.xH_2O$.

In **stage 4** the titre was 19.05 cm^3.

Calculate the relative formula mass of $(COOH)_2.xH_2O$. Hence determine the value of **x**.

relative formula mass = ...

x = ... [4]

(c) Ethanedioic acid also reacts with magnesium. Write down the formula of the organic product of the reaction.

..... [1]

[Total: 6]

Answer **all** the questions.

1 Oxy salts such as carbonates, nitrates and sulphates can thermally decompose.

(a) Describe and explain how the decomposition temperature of barium carbonate compares with that of strontium carbonate.

.....

.....

.....

..... [3]

(b) Magnesium nitrate, $Mg(NO_3)_2$, thermally decomposes to form magnesium oxide, oxygen and nitrogen dioxide.

(i) Write the equation for this decomposition.

..... [1]

(ii) Explain why the lattice enthalpy of magnesium oxide is much more exothermic than that of magnesium nitrate.

.....

.....

..... [2]

(c) Anhydrous iron(II) sulphate thermally decomposes as shown in the equation below.

$$2FeSO_4(s) \longrightarrow Fe_2O_3(s) + SO_2(g) + SO_3(g)$$

(i) Use oxidation numbers to show that this reaction involves both oxidation and reduction.

.....

.....

..... [2]

(ii) The table below shows some enthalpy changes of formation, ΔH_f.

substance	ΔH_f/kJ mol^{-1}
$FeSO_4(s)$	–929
$Fe_2O_3(s)$	–826
$SO_2(g)$	–297
$SO_3(g)$	–396

Use the data in the table to calculate the enthalpy change of reaction, ΔH_r, for the decomposition of 2 mol of iron(II) sulphate.

$$2FeSO_4(s) \longrightarrow Fe_2O_3(s) + SO_2(g) + SO_3(g)$$

ΔH_r = ... kJ mol^{-1} [2]

(iii) An impure sample of hydrated iron(II) sulphate, $FeSO_4.7H_2O$, is heated strongly until it reaches constant mass.

A sample of 2.784 g of impure $FeSO_4.7H_2O$ gives 92.5 cm^3 of sulphur dioxide measured at room temperature and pressure.

Calculate the percentage purity of the $FeSO_4.7H_2O$.

Quote your answer to an appropriate number of significant figures.

Assume that the impurities in the sample do not thermally decompose.

One mole of gas molecules at room temperature and pressure occupies 24.0 dm^3.

% purity = ... [3]

[Total: 13]

2 This question is about molybdenum and iron.

Molybdenum steel is extremely hard.
Molybdenum is made by heating molybdenum(VI) oxide, MoO_3, with aluminium powder.

(a) Construct an equation to show the reduction of molybdenum(VI) oxide to molybdenum metal by aluminium.

..... [1]

(b) Molybdenum has the electronic configuration $[Kr]4d^5 5s^1$ where [Kr] represents the electronic configuration for krypton.

Complete the electronic configuration for Mo^{3+} and use it to explain why molybdenum is a transition element.

[Kr] .....

explanation ..... [1]

(c) Molybdenum(IV) oxide, MoO_2, can be oxidised by dichromate(VI) ions, $Cr_2O_7^{2-}$, under acidic conditions.

The relevant half-equations are as follows.

$$MoO_2(s) + 2H_2O(l) \rightarrow MoO_4^{2-}(aq) + 4H^+(aq) + 2e^-$$

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

Construct the equation for the oxidation of MoO_2 by $Cr_2O_7^{2-}$ ions under acidic conditions.

.....

.....

..... [2]

(d) Iron can form the ferrate(VI) ion, FeO_4^{2-}.

(i) What is the formula for potassium ferrate(VI)?

..... [1]

(ii) Aqueous ferrate(VI) ions can be made by the oxidation of iron(III) oxide by chlorine in alkaline conditions.

$$Fe_2O_3 + 3Cl_2 + 10OH^- \rightarrow 2FeO_4^{2-} + 6Cl^- + 5H_2O$$

A 1.00 g sample of Fe_2O_3 is added to 10.0 cm^3 of 4.00 mol dm^{-3} KOH.

Which reagent, Fe_2O_3 or KOH, is in excess? Explain your answer.

[3]

[Total: 8]

3 This question is about oxides and chlorides.

(a) Complete the following table about some of the enthalpy changes needed to determine the lattice enthalpy of calcium oxide.

Include the state symbols in equations for any process.

enthalpy change	process
enthalpy change of formation of calcium oxide	$Ca(s) + \frac{1}{2}O_2(g) \rightarrow CaO(s)$
second ionisation energy of calcium	
	$\frac{1}{2}O_2(g) \rightarrow O(g)$
	$O^-(g) + e^- \rightarrow O^{2-}(g)$
enthalpy change of atomisation of calcium	

[4]

(b) Explain, in terms of structure and bonding, why aluminium oxide has a much higher melting point than aluminium chloride.

.....

.....

.....

..... [3]

(c) Compare the action of water on aluminium oxide with that of water on aluminium chloride.

Include experimental observations where relevant.

.....

.....

.....

..... [3]

4 In this question, one mark is available for the quality of use and organisation of scientific terms.

Transition elements form complex ions that have characteristic colours.

Describe, using complex ions containing **copper**,

- the bonding within a complex ion
- the shape of a complex ion clearly indicating relevant bond angles
- ligand substitution illustrating any reaction with an equation
- the colours of two different complex ions.

[10]

Quality of Written Communication [1]

[Total: 11]

END OF QUESTION PAPER

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Answer **all** the questions.

1 Copper is a transition element. It forms compounds in which the oxidation number of copper is +1 or +2.

(a) Complete the electronic configuration of the copper(II) ion, Cu^{2+}.

$1s^2\ 2s^2\ 2p^6$..... **[1]**

(b) Transition elements form coloured complex ions. Choose an example of a coloured complex ion in which copper has the +2 oxidation state.

(i) Write the formula of your chosen coloured copper(II) complex ion.

..... **[1]**

(ii) What is the colour of your chosen complex ion?

..... **[1]**

(iii) Name and describe the bonding between the ligand and the metal ion within your chosen complex ion.

.....

.....

.....

..... **[2]**

(c) Aqueous sodium hydroxide is added to aqueous copper(II) sulphate.

(i) Describe what you would see.

..... **[1]**

(ii) Write an ionic equation for the reaction taking place.

..... **[1]**

(d) A compound containing a copper complex ion was analysed. A sample was found to contain 0.938 g of potassium, 0.508 g of copper, 0.384 g of carbon and 0.448 g of nitrogen.

(i) Calculate the empirical formula of the compound.

[2]

(ii) Suggest the formula for the copper complex ion.

..... **[1]**

[Total: 10]

3 This question is about redox reactions of some compounds of transition elements.

(a) Chromium(III) ions can be oxidised by hydrogen peroxide under alkaline conditions.

The relevant half-equations are as follows.

$$H_2O_2(aq) + 2e^- \longrightarrow 2\ OH^-(aq)$$

$$Cr^{3+}(aq) + 8\ OH^-(aq) \longrightarrow CrO_4^{2-}(aq) + 4H_2O(l) + 3e^-$$

Construct the equation for the oxidation of Cr^{3+} by H_2O_2 under alkaline conditions.

.....

.....

..... **[2]**

(b) Hydrated iron(II) ammonium sulphate has the formula $Fe(NH_4)_2(SO_4)_2.xH_2O$.

The value of x in $Fe(NH_4)_2(SO_4)_2.xH_2O$ can be determined by its reaction with acidified manganate(VII) ions.

- **Stage 1** – A sample of hydrated iron(II) ammonium sulphate of known mass is added to a conical flask.
- **Stage 2** – The sample has 25 cm^3 of 1 mol dm^{-3} sulphuric acid added to it.
- **Stage 3** – The contents of the flask are titrated against 0.0200 mol dm^{-3} MnO_4^-.

In **stage 2**, the hydrated crystals dissolve.

$$Fe(NH_4)_2(SO_4)_2.xH_2O(s) + (aq) \rightarrow Fe^{2+}(aq) + 2NH_4^+(aq) + 2SO_4^{2-}(aq) + xH_2O(l)$$

In **stage 3**, the equation for the reaction between Fe^{2+} and acidified MnO_4^- is shown below.

$$5Fe^{2+}(aq) + 8H^+(aq) + MnO_4^-(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$$

In **stage 1**, a student used 0.907 g of $Fe(NH_4)_2(SO_4)_2.xH_2O$.

In **stage 3**, the titre was 23.15 cm^3.

Calculate the relative formula mass of $Fe(NH_4)_2(SO_4)_2.xH_2O$. Hence determine the value of x.

relative formula mass = ...

x = ... **[4]**

[Total: 6]

(b) In this question, one mark is available for the quality of your spelling, punctuation and grammar.

Lattice enthalpy is a measure of ionic bond strength.

- Distinguish, with the aid of equations, between the terms *lattice enthalpy* of sodium oxide and *enthalpy change of formation* of sodium oxide, Na_2O.

- Draw a labelled Born-Haber cycle. Include the names of all relevant enthalpy changes.

  Describe how the lattice enthalpy of sodium oxide can be calculated.

- Arrange the following compounds in order of their lattice enthalpies with the most exothermic first. Explain your answer.

  magnesium oxide **potassium bromide** **sodium chloride**

.... [12]

Quality of Written Communication [1]

[Total: 17]

END OF QUESTION PAPER

Answer **all** the questions.

1 The lattice enthalpy of an ionic compound can be determined using a Born-Haber cycle.

(a) Complete the following table which shows some of the enthalpy changes needed to calculate the lattice enthalpy of barium oxide.

name of enthalpy change	process
.....	$Ba(s) \rightarrow Ba(g)$
first ionisation energy of barium	.....
.....	$O^-(g) + e^- \rightarrow O^{2-}(g)$
enthalpy change of formation of barium oxide	.....

[4]

(b) Suggest why the lattice enthalpy of an ionic solid cannot be measured directly.

.....

..... **[1]**

(c) The lattice enthalpy of barium oxide is more exothermic than that of barium carbonate.

Explain why.

.....

.....

.....

..... **[2]**

3 **(a)** Hydrogen peroxide, H_2O_2, is sold as an aqueous solution.

The concentration of $H_2O_2(aq)$ can be determined by its reaction with acidified manganate(VII) ions.

- **Stage 1** – A 25.0 cm^3 sample of $H_2O_2(aq)$ is added to a 250 cm^3 graduated flask.
- **Stage 2** – Sufficient distilled water is added to the graduated flask to make 250 cm^3 of diluted $H_2O_2(aq)$.
- **Stage 3** – A 10.0 cm^3 sample of diluted $H_2O_2(aq)$ is added to a conical flask.
- **Stage 4** – The diluted sample has 25.0 cm^3 of 1 mol dm^{-3} sulphuric acid added to it.
- **Stage 5** – The contents of the flask are titrated against 0.0200 mol dm^{-3} MnO_4^-.

In **stage 5**, the equation for the reaction between $H_2O_2(aq)$ and acidified MnO_4^- is shown below.

$$5H_2O_2(aq) + 6H^+(aq) + 2MnO_4^-(aq) \longrightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(l)$$

In **stage 5**, the titre was 28.55 cm^3.

Calculate the concentration, in g dm^{-3}, of the **undiluted** H_2O_2.

concentration of undiluted $H_2O_2(aq)$ = ... g dm^{-3} **[4]**

(b) Aqueous iron(II) ions, Fe^{2+}, can be oxidised by hydrogen peroxide, H_2O_2, under acidic conditions.

The reduction half-equation is as follows.

$$H_2O_2(aq) + 2H^+(aq) + 2e^- \longrightarrow 2H_2O(l)$$

Construct the equation for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$ by hydrogen peroxide under acidic conditions.

.....

.....

..... **[2]**

(c) Describe, with the aid of an ionic equation, how aqueous sodium hydroxide can be used to confirm the presence of $Fe^{3+}(aq)$ ions.

.....

.....

..... **[2]**

(d) An unusual oxide of potassium is potassium superoxide, KO_2. It contains the mole ratio of one potassium ion to one superoxide ion. It is used in submarines to provide an emergency supply of oxygen and to remove carbon dioxide from the air.

$$4KO_2 + 2H_2O \longrightarrow 4KOH + 3O_2$$

$$2KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

In KO_2, one of the oxygen atoms has an oxidation state of –1 and the other an oxidation state of 0.

(i) What is the charge on the superoxide ion?

..... **[1]**

(ii) The reaction between potassium superoxide and water involves both oxidation and reduction.

Use oxidation numbers to explain why.

.....

.....

..... **[2]**

(iii) What volume of carbon dioxide, measured at room temperature and pressure, can be removed from air using 1.00 kg of potassium superoxide?

One mole of gas molecules at room temperature and pressure occupies 24.0 dm^3.

volume of carbon dioxide = ... dm^3 **[3]**

[Total: 14]

4 In this question, one mark is available for the quality of use and organisation of scientific terms.

One of the typical properties of transition elements is that they form complex ions.

- State three **other** typical properties of the compounds or ions of a transition element.
- Describe the bonding and shape of a complex ion containing **iron**. Include relevant bond angles in your answer.
- Describe, with the aid of an equation, ligand substitution using an example taken from the chemistry of **iron** or **copper**. Include experimental observations in your answer.

[11]

Quality of Written Communication [1]

[Total: 12]

END OF QUESTION PAPER

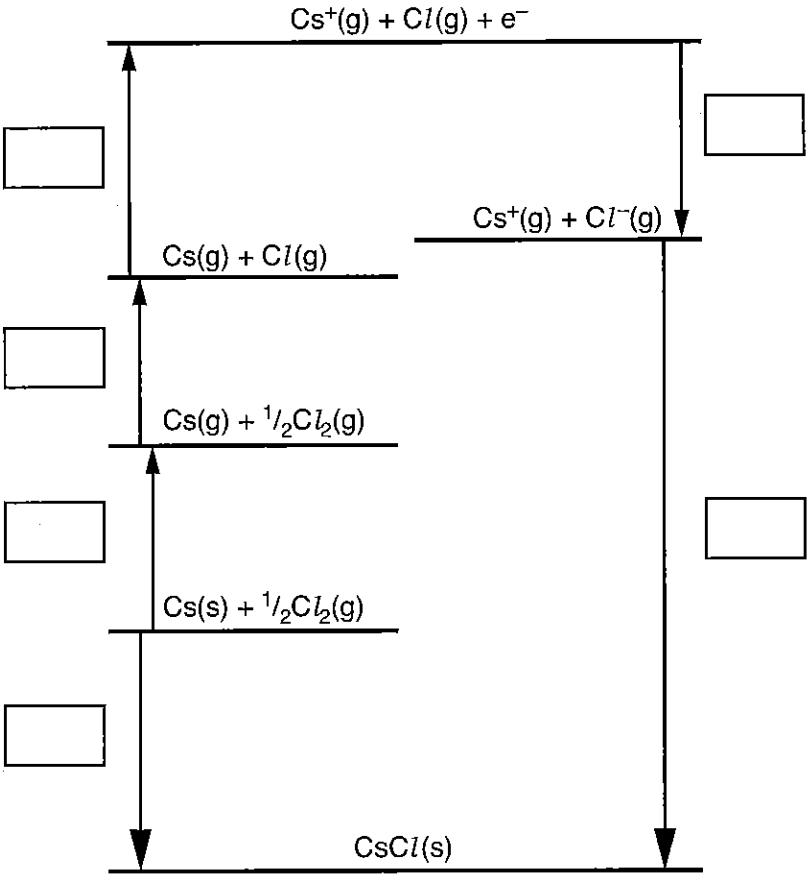
Answer **all** the questions.

1 The lattice enthalpy of caesium chloride, $CsCl$, can be calculated using a Born–Haber cycle.

The table below shows the enthalpy changes and corresponding data for this cycle.

enthalpy change	label	energy/kJ mol^{-1}
lattice enthalpy of caesium chloride	**A**	?
1st electron affinity of chlorine	**B**	–349
1st ionisation energy of caesium	**C**	+376
atomisation of chlorine	**D**	+122
formation of caesium chloride	**E**	–443
atomisation of caesium	**F**	+76

(a) On the cycle below, put the letter for each enthalpy change in the appropriate box.



[3]

(b) Use the Born–Haber cycle to calculate the lattice enthalpy of caesium chloride.

answer = ... $kJ\,mol^{-1}$ **[2]**

(c) State and explain the relative sizes of the lattice enthalpies in sodium chloride and caesium chloride.

.....

.....

.....

.....

.....

..... **[3]**

[Total: 8]

3 Aqueous hydrogen peroxide, H_2O_2, is used to sterilise contact lenses. H_2O_2 decomposes to make oxygen and water, as shown in the equation below.

$$2H_2O_2(aq) \longrightarrow 2H_2O(l) + O_2(g)$$

(a) Decomposition of hydrogen peroxide is a redox reaction.

Using oxidation numbers, show that oxidation and reduction take place.

.....

.....

..... **[2]**

(b) The concentration of an aqueous solution of hydrogen peroxide can be determined by titration. Aqueous potassium manganate(VII), $KMnO_4$, is titrated against a solution of hydrogen peroxide in the presence of acid.

The half-equation for the oxidation of H_2O_2 is as follows.

$$H_2O_2(aq) \longrightarrow 2H^+(aq) + O_2(g) + 2e^-$$

The half-equation for the reduction of acidified MnO_4^- is as follows.

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$$

(i) Construct the equation for the reaction between H_2O_2, MnO_4^- ions and H^+ ions.

.....

.....

..... **[2]**

(ii) A student followed the procedure below:

- Pipette 25.0 cm^3 of aqueous hydrogen peroxide into a conical flask;
- Add sulphuric acid to acidify the hydrogen peroxide;
- Titrate this sample against a solution containing 0.0150 mol dm^{-3} $MnO_4^-(aq)$ ions.

23.35 cm^3 of the solution containing $MnO_4^-(aq)$ ions is required.

2 mol MnO_4^- reacts with 5 mol H_2O_2.

Calculate the concentration, in mol dm^{-3}, of the aqueous hydrogen peroxide.

concentration = ... mol dm^{-3} **[3]**

(c) Acidified hydrogen peroxide oxidises $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

Describe a simple chemical test to show the presence of $Fe^{3+}(aq)$.

name of reagent used .....

observation .....

..... **[2]**

[Total: 9]

4 Copper is an example of a transition element.

(a) Complete the electronic configuration for a copper(II) ion, Cu^{2+}, and use it to explain why copper is a transition element.

Cu^{2+}: $1s^2 2s^2 2p^6$ .....

explanation .....

.....

..... **[2]**

(b) In this question, one mark is available for the quality of spelling, punctuation and grammar.

Transition elements form complex ions.

- Explain what is meant by the terms *complex ion* and *ligand.*
- Using complex ions of copper, give two examples of ligand substitution reactions that are accompanied by a colour change. Include equations in your answer.
- Describe, using suitable examples and 3-D diagrams, two different shapes of complex ions.

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[12]

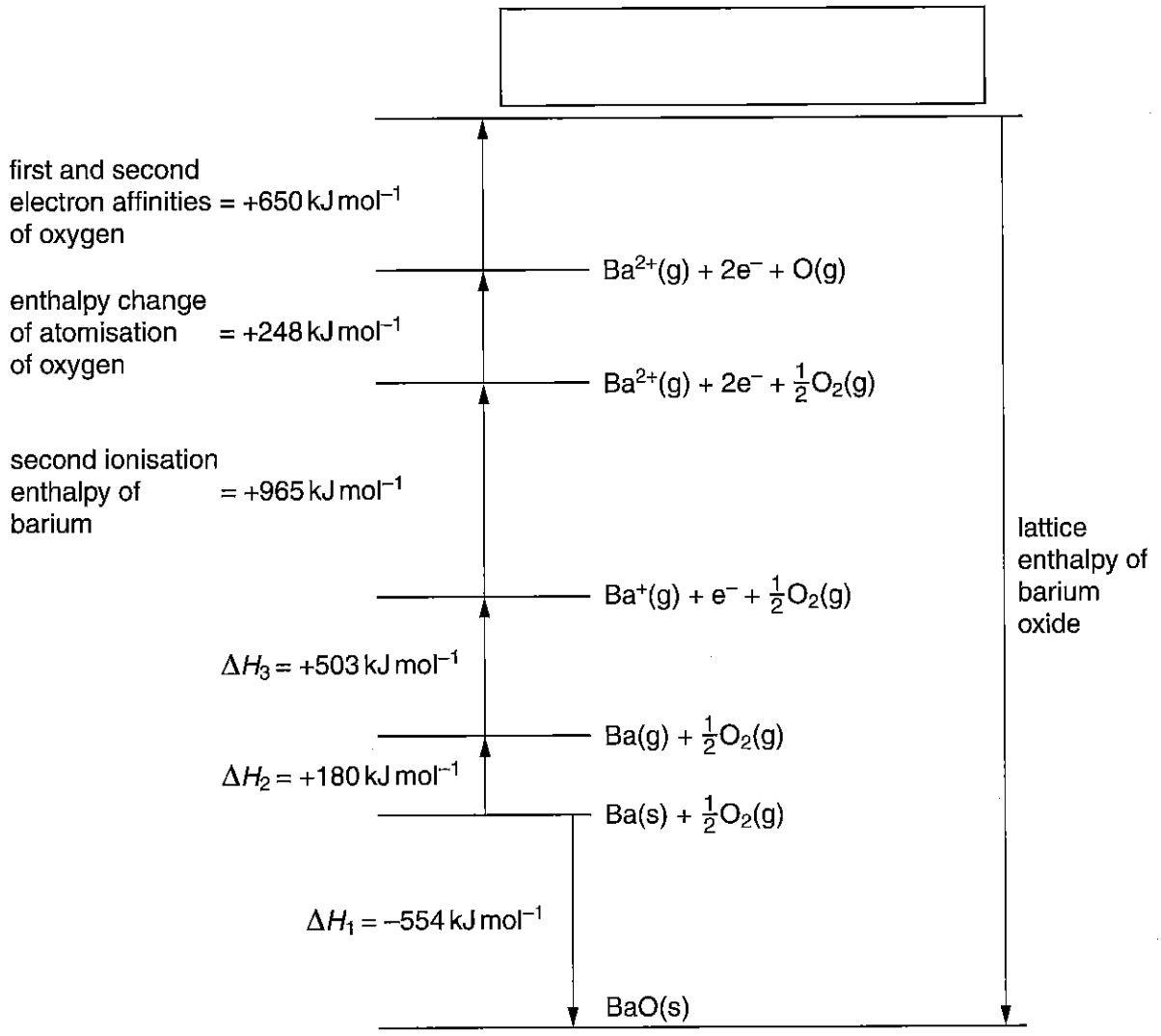
Quality of Written Communication [1]

[Total: 15]

END OF QUESTION PAPER

Answer **all** the questions.

1 The Born-Haber cycle below can be used to calculate the lattice enthalpy for barium oxide.



(a) (i) Write down the name for each of the following enthalpy changes in the Born-Haber cycle above.

ΔH_1 .....

ΔH_2 .....

ΔH_3 ..... **[3]**

(ii) Write down the missing formulae in the box at the top of the Born-Haber cycle.

Include state symbols. **[1]**

(b) (i) Use the Born-Haber cycle to calculate the lattice enthalpy of barium oxide.

answer = ... $kJ\,mol^{-1}$ **[2]**

(ii) The lattice enthalpy of barium oxide is different from that of magnesium oxide.

Explain why these lattice enthalpies differ.

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..... **[3]**

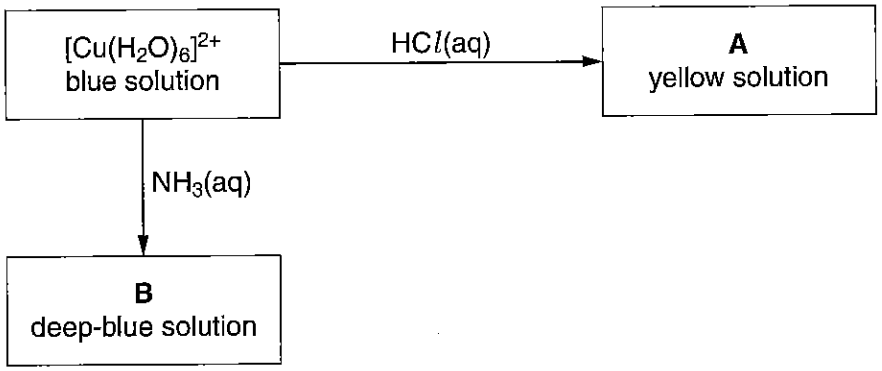
(c) Give **one** reason why magnesium oxide is a good material to use for the lining of a furnace.

..... **[1]**

2 Dilute aqueous copper(II) sulphate is a blue solution containing $[Cu(H_2O)_6]^{2+}$ complex ions.

Two ligand substitution reactions involving $[Cu(H_2O)_6]^{2+}$ are shown below.

A and **B** are two other complex ions of copper.



(a) (i) Draw a diagram showing the shape of the $[Cu(H_2O)_6]^{2+}$ complex ion.

Include the bond angles in your diagram.

[2]

(ii) Write the formula for:

complex ion **A** .....

complex ion **B** ..... **[2]**

(b) (i) What is meant by the term *ligand*?

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..... **[1]**

(ii) Explain, with the aid of a balanced equation, what is meant by the term *ligand substitution*.

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..... **[2]**

[Total: 7]

3 Iron is a typical transition element.

- Iron shows more than one oxidation state in its compounds.
- Iron and its compounds are used as catalysts.

(a) Complete the electronic configuration for an iron(III) ion, Fe^{3+}, and use it to explain why iron is a transition element.

Fe^{3+}: $1s^2 2s^2 2p^6$ .....

explanation .....

.....

..... **[2]**

(b) State **one** use of iron as a catalyst.

..... **[1]**

(c) Aqueous manganate(VII) ions were titrated against 25.0 cm^3 of 0.0500 mol dm^{-3} Fe(II) ions in acid solution.

$$8H^+(aq) + 5Fe^{2+}(aq) + MnO_4^-(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$$

The volume of aqueous manganate(VII) ions required to reach the end point was 12.30 cm^3.

(i) State the colour change observed at the end point.

from ..... to ..... **[1]**

(ii) Calculate the concentration of the aqueous manganate(VII) ions used in the titration.

Give your answer to **three** significant figures.

answer = ... mol dm^{-3} **[3]**

(d) Aqueous ferrate ions, $FeO_4^{2-}(aq)$, have oxidising properties very similar to manganate(VII) ions.

The half-equation for the reduction of aqueous ferrate ions, $FeO_4^{2-}(aq)$, in acidic conditions is shown below.

$$8H^+(aq) + FeO_4^{2-}(aq) + 4e^- \longrightarrow Fe^{2+}(aq) + 4H_2O(l)$$

Acidified $FeO_4^{2-}(aq)$ ions oxidise aqueous iodide ions, $I^-(aq)$, to form aqueous iodine, $I_2(aq)$.

(i) Deduce the oxidation state of iron in the ferrate ion, FeO_4^{2-}.

..... **[1]**

(ii) Construct the half-equation for the oxidation of iodide ions to form iodine.

..... **[1]**

(iii) Construct the ionic equation for the redox reaction that occurs between $FeO_4^{2-}(aq)$ ions and $I^-(aq)$ ions in the presence of $H^+(aq)$.

[2]

(e) A student added aqueous sodium thiocyanate, NaSCN(aq), to a solution containing $[Fe(H_2O)_6]^{3+}$ complex ions.

(i) State the change in colour when the solutions were mixed together.

..... **[1]**

(ii) Write an ionic equation for the reaction that takes place.

..... **[1]**

[Total: 13]