

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Monday 13 June 2022 – Morning

A Level Chemistry A

H432/01 Periodic table, elements and physical chemistry

**Time allowed: 2 hours 15 minutes
plus your additional time allowance**

YOU MUST HAVE:
the Data Sheet for Chemistry A

YOU CAN USE:
a scientific or graphical calculator
an HB pencil

Please write clearly in black ink.

Centre number

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Candidate number

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First name(s) _____

Last name _____

READ INSTRUCTIONS OVERLEAF



INSTRUCTIONS

Use black ink. You can use an HB pencil, but only for graphs and diagrams.

Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.

Answer ALL the questions.

Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

The total mark for this paper is 100.

The marks for each question are shown in brackets [].

Quality of extended response will be assessed in questions marked with an asterisk (*).

ADVICE

Read each question carefully before you start your answer.

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SECTION A

You should spend a maximum of 20 minutes plus your additional time allowance on this section.

Write your answer to each question in the box provided.

Answer ALL the questions.

- 1 An aqueous solution contains a mixture of chloride, bromide and iodide ions.

$\text{AgNO}_3(\text{aq})$ is added to this mixture, followed by an excess of dilute $\text{NH}_3(\text{aq})$.

The resulting mixture is then filtered.

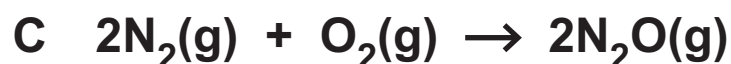
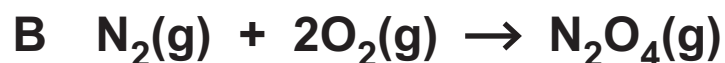
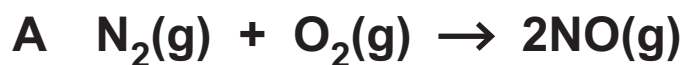
Which compound(s) is/are present in the residue on the filter paper? [1]

- A AgCl only
- B AgCl and AgBr
- C AgBr only
- D AgBr and AgI

Your answer

- 2 20 cm³ of nitrogen gas reacts with 10 cm³ of oxygen gas to form 20 cm³ of a gaseous product.

Which equation is the most likely for the reaction? [1]



Your answer

- 3 0.541 g of an element X is reacted with oxygen to form 0.790 g of the oxide X₂O₃.

What is the element X? [1]

A Al

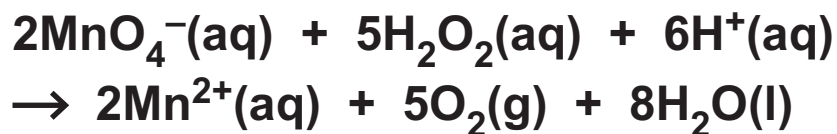
B Cr

C Ga

D Sc

Your answer

- 4 Hydrogen peroxide, H_2O_2 , can be oxidised by manganate(VII) ions under acid conditions as shown below.



In a titration, 25.00 cm^3 of a disinfectant containing hydrogen peroxide reacts with 22.00 cm^3 of $0.125\text{ mol dm}^{-3}\text{ KMnO}_4(\text{aq})$.

What is the concentration of H_2O_2 , in mol dm^{-3} , in the disinfectant?

Assume that KMnO_4 only reacts with H_2O_2 in the disinfectant. [1]

A 0.0440

B 0.110

C 0.275

D 0.550

Your answer

- 5 The mass of 4 molecules of a substance is 2.125×10^{-22} g.

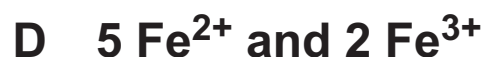
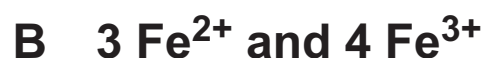
What is the possible formula of the substance? [1]



Your answer

- 6 Prussian blue, $\text{C}_{18}\text{Fe}_7\text{N}_{18}$, is a deep blue pigment containing Fe^{2+} , Fe^{3+} and CN^- ions.

What are the numbers of Fe^{2+} and Fe^{3+} ions in one formula unit of $\text{C}_{18}\text{Fe}_7\text{N}_{18}$? [1]



Your answer

7 Bond enthalpies are shown in the table.

Bond	C–C	C–H	O–H	C–O	C=O	O–O	O=O
Bond enthalpy /kJ mol ⁻¹	347	435	464	358	805	144	498

What is the enthalpy change, in kJ mol⁻¹, for the reaction below? [1]



A -730

B -544

C +544

D +730

Your answer

8 The half-life for a first order reaction is 80 s.

What is the rate constant k , in s^{-1} , for this reaction? [1]

A 8.66×10^{-3}

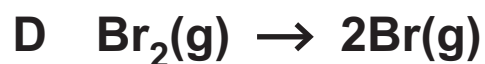
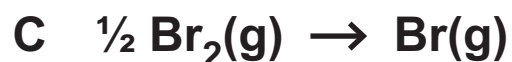
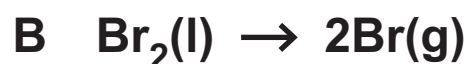
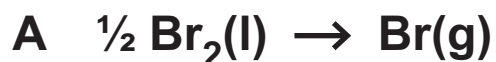
B 0.0125

C 55.5

D 115

Your answer

9 Which equation represents the change that accompanies the standard enthalpy change of atomisation of bromine? [1]



Your answer

10 For the condensation of ammonia gas, what are the signs of ΔH and ΔS ? [1]

A ΔH -ve ΔS -ve

B ΔH -ve ΔS +ve

C ΔH +ve ΔS +ve

D ΔH +ve ΔS -ve

Your answer

12 Ammonia and water react to set up an acid–base equilibrium.

What are the Brønsted–Lowry acids in the equilibrium mixture? [1]

A H_2O and OH^-

B OH^- and NH_3

C NH_4^+ and H_2O

D NH_4^+ and NH_3

Your answer

13 Standard electrode potentials for two redox systems are shown below.



What is the standard electrode potential for $\text{Cr}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cr}(\text{s})$? [1]

A -0.32 V

B -0.90 V

C -1.16 V

D -1.80 V

Your answer

14 The three reactions below each form one product only.

Which reaction(s) form(s) a product with non-polar molecules? [1]



A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

15 Which ion(s) contain(s) one or more unpaired electrons? [1]

1 Mn^{3+}

2 V^{3+}

3 Cu^+

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

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SECTION B

Answer ALL the questions.

16 A catalytic converter in a car removes nitrogen monoxide, NO, and carbon monoxide, CO, from the exhaust gases.

(a) One reaction that happens in a catalytic converter is shown below.

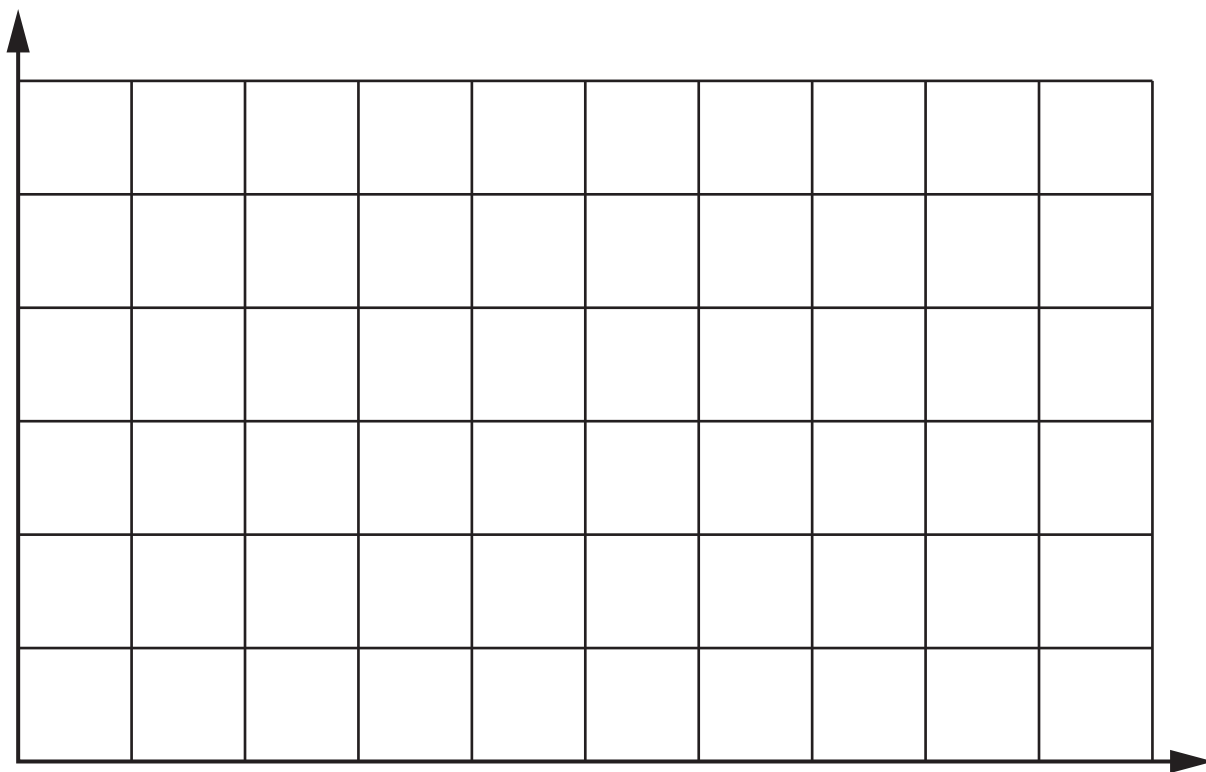
REACTION 16.1



(i) Explain how increasing the temperature increases the rate of REACTION 16.1.

Include a labelled sketch, using Boltzmann distributions, on the grid below.

Label the axes.



[3]

- (ii) The rate of REACTION 16.1 is investigated by carrying out three experiments at the same temperature. The results are shown below.

Experiment	[NO(g)] /mol dm ⁻³	[CO(g)] /mol dm ⁻³	Initial rate /mol dm ⁻³ s ⁻¹
1	2.75×10^{-4}	7.25×10^{-4}	1.85×10^{-4}
2	5.50×10^{-4}	7.25×10^{-4}	7.40×10^{-4}
3	1.10×10^{-3}	2.90×10^{-3}	1.18×10^{-2}

Determine the orders with respect to NO and CO, the rate equation, and the rate constant, k , including units.

Explain your reasoning.

$k =$ _____ units _____ [5]

- (b) Carbon monoxide also reacts with nitrogen dioxide as shown in REACTION 16.2.

REACTION 16.2



The rate equation for REACTION 16.2 is shown below:

$$\text{rate} = k[\text{NO}_2\text{(g)}]^2$$

Suggest a possible two-step mechanism for REACTION 16.2.

The first step is much slower than the second step.

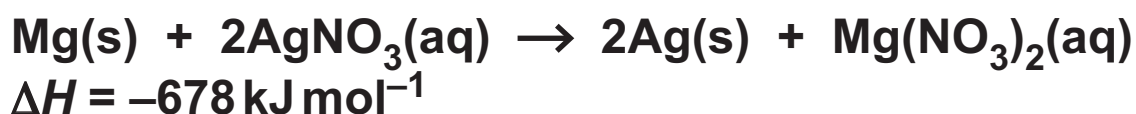
STEP 1 _____

STEP 2 _____

[2]

17 This question is about energy changes.

- (a) Magnesium reacts with aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$ as shown below.**



**A student adds an excess of magnesium to 100.0 cm^3 of $0.400 \text{ mol dm}^{-3} \text{ AgNO}_3(\text{aq})$.
The initial temperature is 20.0°C .**

- (i) Determine the maximum temperature reached in this reaction.
Give your answer to 3 significant figures.**

Assume that the specific heat capacity and density of the solution are the same as for water, and that there are no heat losses.

maximum temperature reached = _____ $^\circ\text{C}$ [4]

- (ii) The student wants to repeat the experiment, but there is not enough $\text{AgNO}_3(\text{aq})$ left to use another 100.0 cm^3 portion.

The student decides to modify the method by adding an excess of magnesium to 50.0 cm^3 of $0.400 \text{ mol dm}^{-3} \text{AgNO}_3(\text{aq})$.

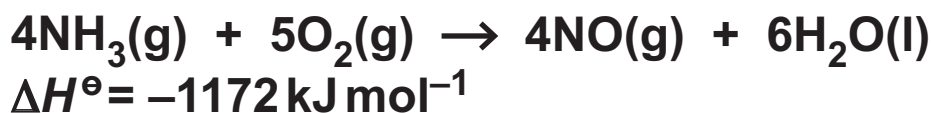
Predict, with reasons, how this modification would affect the maximum temperature reached. Assume that there are no heat losses.

[1]

(b) Nitric acid is manufactured from ammonia in a multi-stage process.

The equation for the first stage in this process is shown in REACTION 17.1.

REACTION 17.1



Some standard enthalpy changes of formation are shown in the table.

Compound	$\Delta_f H^\ominus / \text{kJ mol}^{-1}$
$\text{NH}_3(\text{g})$	-46
$\text{H}_2\text{O}(\text{l})$	-286

(i) Explain the term ENTHALPY CHANGE OF FORMATION.

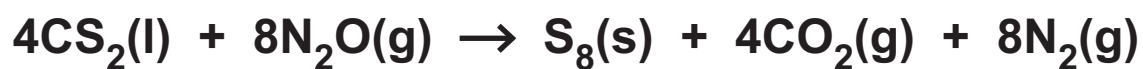
[1]

- (ii) Calculate the standard enthalpy change of formation, $\Delta_f H^\ominus$, of NO(g).

$\Delta_f H^\ominus$ of NO(g) = _____ kJ mol⁻¹ [2]

- (c) Carbon disulfide, CS_2 , reacts with dinitrogen oxide, N_2O , as shown in REACTION 17.2.

REACTION 17.2



Standard entropies, S^\ominus , are shown in the table.

Substance	$\text{CS}_2(\text{l})$	$\text{N}_2\text{O}(\text{g})$	$\text{S}_8(\text{s})$	$\text{CO}_2(\text{g})$	$\text{N}_2(\text{g})$
$S^\ominus/\text{JK}^{-1}\text{mol}^{-1}$	151	220	256	214	192

- (i) Explain the term ENTROPY.

[1]

- (ii) The free energy change, ΔG , of REACTION 17.2 is $-2672 \text{ kJ mol}^{-1}$ at 25°C .

Calculate the enthalpy change, ΔH , of REACTION 17.2, in kJ mol^{-1} .

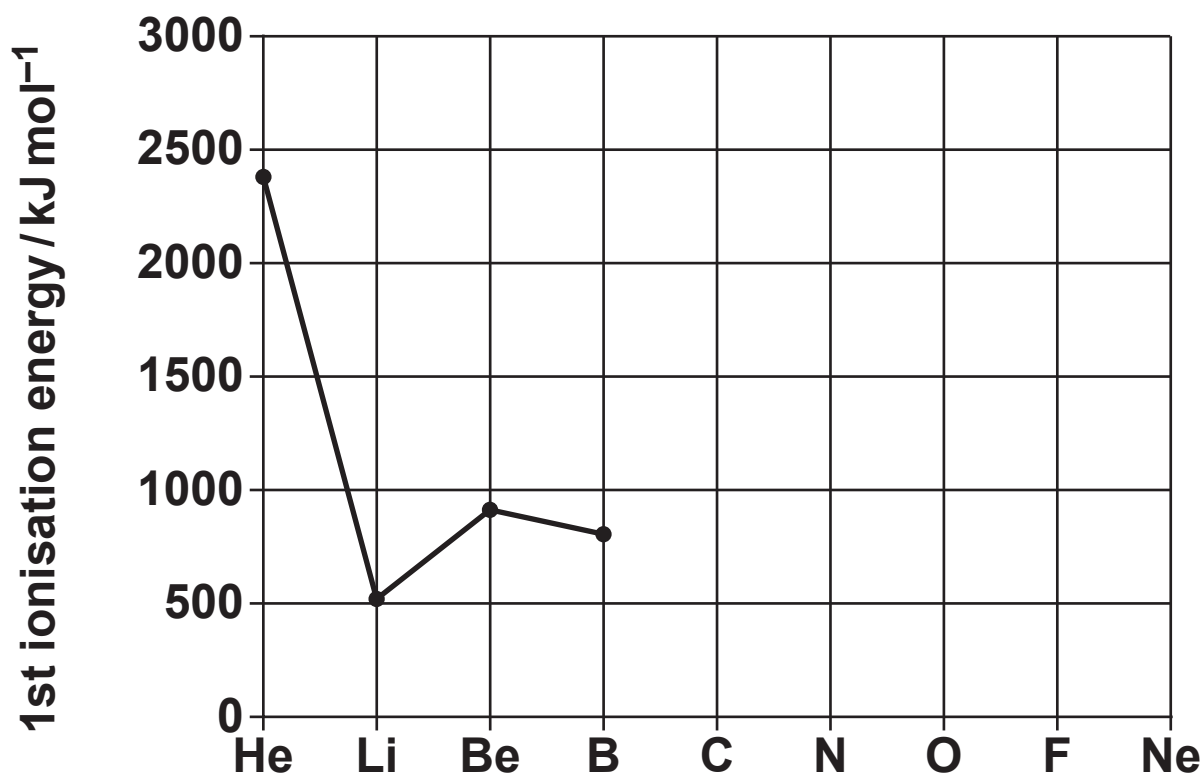
$\Delta H = \underline{\hspace{2cm}} \text{ kJ mol}^{-1}$ [3]

- (iii) A student concludes that REACTION 17.2 is feasible at all temperatures.

Explain whether the student is correct or not.

[2]

- 18 The graph shows the first ionisation energies for elements from helium, He, to boron, B, in the periodic table.



- (a) Complete the graph for C, N, O, F and Ne. [2]
- (b) Estimate the energy required to form ONE $\text{Li}^+(\text{g})$ ion from one $\text{Li}(\text{g})$ atom.

Give your answer in kJ, in standard form, and to TWO significant figures.

energy = _____ kJ [1]

- (c) Explain why the first ionisation energies of He and Be are both higher than the first ionisation energy of Li.**

Explanation for He: _____

Explanation for Be: _____

[4]

- (d) Explain why the first ionisation energy of Be is higher than the first ionisation energy of B.**

[2]

19 This question is about acids and buffer solutions.

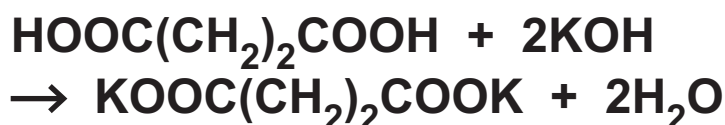
- (a) Succinic acid, $\text{HOOC}(\text{CH}_2)_2\text{COOH}$, is a weak dibasic acid that is used in tablet form in health supplements.**

A student plans to determine the mass of succinic acid in one tablet of a succinic acid health supplement.

The student carries out a titration with potassium hydroxide.

The end point occurs when both acidic protons in succinic acid have been replaced as shown in EQUATION 19.1.

EQUATION 19.1



The student uses the following method.

- | | |
|----------------|---|
| STAGE 1 | The student crushes four tablets of the health supplement and dissolves the powdered tablets in distilled water. |
| STAGE 2 | The student makes up the solution from STAGE 1 to 250.0 cm^3 in a volumetric flask. |
| STAGE 3 | The student titrates 10.0 cm^3 portions of the solution obtained in STAGE 2 with $0.0600\text{ mol dm}^{-3}$ potassium hydroxide, using phenolphthalein as the indicator. |

The student carries out a trial titration, followed by three further titrations.
The results are shown below.

Titration	Trial	1	2	3
Final burette reading / cm ³	25.25	23.75	25.35	25.75
Initial burette reading / cm ³	2.50	1.30	2.65	3.20
Titre / cm ³				

- (i) Complete the table and calculate the mean titre that the student should use for analysing the results.

mean titre = _____ cm³ [2]

- (ii) Use the student's results and EQUATION 19.1 to calculate the mass, in mg, of succinic acid in ONE tablet of the health supplement.

Give your answer to 3 significant figures.

mass = _____ mg [5]

- (b) Glycolic acid, HOCH_2COOH , ($\text{p}K_{\text{a}} = 3.83$) is a weak monobasic acid used in some skincare products.

A buffer solution is prepared by adding 60.0 cm^3 of $0.750 \text{ mol dm}^{-3}$ glycolic acid to 40.0 cm^3 of $0.625 \text{ mol dm}^{-3}$ potassium hydroxide, KOH .

- (i) Explain why a buffer solution is formed.

_____ [1]

- (ii) Calculate the pH of the buffer solution that has been prepared.

Give your answer to 2 decimal places.

pH = _____ [4]

- (iii) A small amount of aqueous ammonia, $\text{NH}_3(\text{aq})$, is added to the buffer solution.

Explain, in terms of equilibrium, how the buffer solution would respond to the added $\text{NH}_3(\text{aq})$.

[2]

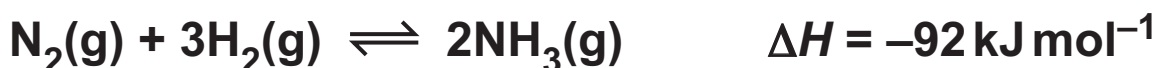
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20 This question is about equilibria involving hydrogen.

(a)* Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.

EQUILIBRIUM 20.1



1.20 mol $\text{N}_2(\text{g})$ is mixed with 3.60 mol $\text{H}_2(\text{g})$ in a 8.00 dm^3 container.

The mixture is heated to 550°C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3 .

Determine the equilibrium constant K_c for EQUILIBRIUM 20.1, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia. [6]

Additional answer space if required.

- (b) In industry, hydrogen is also used to reduce the iron oxide Fe_3O_4 as shown in EQUILIBRIUM 20.2.

The reaction is carried out at 500°C .

EQUILIBRIUM 20.2



- (i) When the temperature is decreased, the value of K_p decreases.

Determine whether the forward reaction is exothermic or endothermic.
Explain your answer.

[1]

- (ii) Two students are discussing the effect of pressure on the equilibrium position of EQUILIBRIUM 20.2.

Student 1 says:

“There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side.”

Student 2 disagrees.

Determine which student is correct. Justify your answer.

[1]

21 This question is about the reactions of Group 2 metals and their compounds.

(a) A student adds magnesium to dilute hydrochloric acid in one test tube.

The student adds calcium to dilute hydrochloric acid in a second test tube.

A redox reaction takes place in each test tube.

(i) Suggest TWO observations from the student's experiment that would show that calcium is more reactive than magnesium.

1 _____

2 _____

_____ **[1]**

(ii) Write half-equations for the reaction of magnesium with hydrochloric acid.

Oxidation half-equation: _____

Reduction half-equation: _____ **[2]**

(b) A sample of barium oxide is added to distilled water at 25°C.

A colourless solution forms containing barium hydroxide, $\text{Ba}(\text{OH})_2$.

The solution is made up to 250.0 cm^3 with distilled water.

The pH of this solution is 13.12.

(i) Determine the mass of barium oxide that was used.

Give your answer to 3 significant figures.

mass of barium oxide = _____ g [5]

- (ii) 10 cm^3 of dilute sulfuric acid is added to 10 cm^3 of the colourless solution of $\text{Ba}(\text{OH})_2$.

Write an ionic equation, including state symbols, for the reaction.

_____ [1]

(c) Limestone and huntite are two calcium minerals.

- (i) A typical sample of limestone contains 95.0% by mass of calcium carbonate, CaCO_3 .

Fertiliser Z,
 $\text{Ca}_5\text{NH}_4(\text{NO}_3)_{11} \cdot 10\text{H}_2\text{O}$ ($M_r = 1080.5\text{ g mol}^{-1}$)
can be made from limestone.

Calculate the mass, in g, of limestone needed to make 1.50 kg of fertiliser Z.

Give your answer to 3 significant figures.

mass of limestone = _____ g [3]

- (ii) Huntite is a carbonate mineral with the chemical formula $\text{Mg}_3\text{Ca}(\text{CO}_3)_4$.

Huntite reacts with dilute hydrochloric acid to produce bubbles of a gas and a colourless solution.

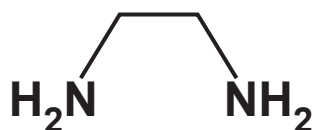
Construct the equation for the reaction.
Include state symbols.

[2]

22 This question is about reactions of transition metal compounds.

- (a) Ethane-1,2-diamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is a bidentate ligand.**

The structure of ethane-1,2-diamine is shown below.



- (i) Explain why ethane-1,2-diamine can act as a bidentate ligand.**

[1]

- (ii) The iron(III) ion, Fe^{3+} , forms a complex ion A with two ethane-1,2-diamine ligands and two chloride ligands.**

Complex ion A has *cis* and *trans* stereoisomers.

One of these stereoisomers exists as optical isomers.

Determine the empirical formula, with charge, of complex ion A and draw the 3-D structures of the three stereoisomers. [4]

Empirical formula with charge _____

Structures

(b) Aqueous sodium hydroxide is added to an aqueous solution of iron(II) sulfate.
A pale green precipitate forms which turns brown when left to stand in air.

(i) Write an ionic equation for the formation of the pale green precipitate.

_____ [1]

(ii) Use the information below to explain why the pale green precipitate turns brown when left to stand in air and construct an equation for the reaction which occurs.

Redox System	Equation	E° / V
1	$\text{Fe(OH)}_3(\text{s}) + \text{e}^-$ $\rightleftharpoons \text{Fe(OH)}_2(\text{s}) + \text{OH}^-(\text{aq})$	-0.56 V
2	$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^-$ $\rightleftharpoons 4\text{OH}^-(\text{aq})$	$+0.40 \text{ V}$

[4]

(c)* This question is about copper and copper compounds.

EXPERIMENT 1

Hydrochloric acid, HCl(aq) , is added to an aqueous solution containing $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

A yellow-green solution forms containing complex ion B.

EXPERIMENT 2

A piece of copper metal is heated with concentrated sulfuric acid.

A reaction takes place forming a pale blue solution C and 45cm^3 of a gas D, measured at RTP. The mass of gas D is 0.12 g.

EXPERIMENT 3

An excess of copper(II) oxide is heated with dilute nitric acid. The resulting mixture is filtered. The filtrate is a blue solution E.

Aqueous potassium iodide, KI(aq) , is added to the blue solution E.

A white precipitate F and a brown solution G form.

Determine the formulae of B–G.

Construct equations for the reactions taking place, include any changes in oxidation number, and show your working where appropriate. [6]

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Additional answer space if required.

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).

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