OCR
Oxford Cambridge and RSA

Tuesday 5 October 2021 – Afternoon

A Level Chemistry A

H432/01 Periodic table, elements and physical chemistry

Time allowed: 2 hours 15 minutes

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. **Do not write in the barcodes.**

Centre number | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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 (*).
- This document has **32** pages.

ADVICE
- Read each question carefully before you start your answer.

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SECTION A

You should spend a maximum of 20 minutes on this section

Write your answer to each question in the box provided.

Answer **all** the questions.

1 Which statement describes electronegativity?

A A measure of the reactivity of an element.

B The ability of an atom to attract an electron to become a 1– ion.

C The attraction of a bonded atom for the electrons in a covalent bond.

D The attraction of an atom for a lone pair of electrons.

Your answer ☐ **[1]**

2 A chlorate(VII) ion has a 1– charge.

What is the formula for sodium chlorate(VII)?

A $NaClO_3$

B $NaClO_4$

C $NaClO_7$

D $NaClO_8$

Your answer ☐ **[1]**

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3 The unbalanced equation for the reaction of silver with concentrated nitric acid is shown below.

….. Ag(s) + ….. NO_3^-(aq) + ….. H^+(aq) ⟶ ….. Ag^+(aq) + ….. NO(g) + ..… H_2O(l)

Which numbers for Ag and H_2O will balance the equation?

	Ag(s)	H_2O(l)
A	1	2
B	2	3
C	3	1
D	3	2

Your answer ☐ **[1]**

4 Which sample contains the greatest number of molecules?

A 140.0 g C_2H_2

B 180.0 g C_2H_6

C 240.0 g C_4H_{10}

D 400.0 g C_6H_6

Your answer ☐ **[1]**

5 Chromium(III) oxide, Cr_2O_3, is reduced to chromium by heating with magnesium.

What is the minimum mass of Mg required to reduce 11.4 g of chromium(III) oxide?

A 0.61 g

B 0.91 g

C 3.65 g

D 5.47 g

Your answer ☐ **[1]**

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6 A student is supplied with 100.0 cm^3 of a solution of 0.400 mol dm^{-3} magnesium iodide, MgI_2.

A student plans to dilute this solution so that the iodide concentration is 0.250 mol dm^{-3}.

What volume of water, in cm^3, does the student need to add?

A 60.0

B 160.0

C 220.0

D 320.0

Your answer ☐ **[1]**

7 Which row shows elements in order of increasing first ionisation energy?

A Ca < Si < P < N

B N < P < Si < Ca

C Ca < N < P <Si

D C < Si < P < Ca

Your answer ☐ **[1]**

8 Bond enthalpies are given in the table.

Bond	H–S	O=O	S=O	O–H
Bond enthalpy / kJ mol^{-1}	+346	+498	+531	+464

What is the enthalpy change, in kJ mol^{-1}, for the reaction below?

$2H_2S(g) + 3O_2(g) \longrightarrow 2SO_2(g) + 2H_2O(g)$

A –174

B –1102

C –1794

D –2098

Your answer ☐ **[1]**

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9 An equilibrium system is shown below.

$CO(g) + NO_2(g) \rightleftharpoons CO_2(g) + NO(g)$

Different amounts of CO, NO_2, CO_2 and NO are added to four containers, as shown below.

Container	CO / mol	NO_2 / mol	CO_2 / mol	NO / mol
A	1	1	0	0
B	1	0	1	1
C	1	1	1	0
D	0	1	1	1

Which container would have the largest concentration of CO(g) at equilibrium?

Your answer ☐ **[1]**

10 An aqueous solution of ethanoic acid, CH_3COOH, has a concentration of $0.50\,mol\,dm^{-3}$.
pK_a for CH_3COOH = 4.76 at 25 °C.

What is the pH of the ethanoic acid solution at 25 °C?

A 2.53

B 2.68

C 4.91

D 5.06

Your answer ☐ **[1]**

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11 The feasibility of a chemical reaction depends on the temperature and the signs of ΔH and ΔS.

Which row has signs for ΔH and ΔS for a reaction that is feasible at high temperatures but is **not** feasible at low temperatures?

	ΔH	ΔS
A	+	+
B	+	–
C	–	+
D	–	–

Your answer ☐ **[1]**

12 Two redox systems are shown below.

$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$ $\quad E^{\ominus} = -0.44\,V$

$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ $\quad E^{\ominus} = +0.34\,V$

Which species in the two redox systems is the strongest oxidising agent?

A $Fe^{2+}(aq)$

B Fe(s)

C $Cu^{2+}(aq)$

D Cu(s)

Your answer ☐ **[1]**

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13 Which statement(s) explain(s) the trend in boiling points down the halogens group?

1: The induced dipole–dipole interactions (London forces) become stronger.

2: The covalent bonds become stronger.

3: The permanent dipole–dipole interactions become stronger.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

14 Which statement(s) about a molecule of C*l*–N=O is/are correct?

1: It is a polar molecule.

2: It contains 6 lone pairs of electrons.

3: It has a bond angle of 180°.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

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15 $NH_4Fe(SO_4)_2 \cdot 12H_2O$ is a hydrated 'double salt'.

A student analyses this double salt using test tube tests.

Which row(s) gives/give correct result(s) for the stated test?

	Test	Results
1	Reaction with cold NaOH(aq)	Green precipitate
2	Reaction with $Ba(NO_3)_2$(aq)	White precipitate
3	Reaction with warm NaOH(aq)	Red-brown precipitate and an alkaline gas

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

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SECTION B

Answer **all** the questions.

16 This question is about magnesium and magnesium halides.

(a) Magnesium has metallic bonding and is a good conductor of electricity.

Describe, with the aid of a labelled diagram, the metallic bonding in magnesium and explain why magnesium conducts electricity.

Include the correct charges on the particles in your diagram.

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

(b) The 12 successive ionisation energies of magnesium are shown in **Table 16.1**.

Ionisation number	Ionisation energy / kJ mol^{-1}
1	738
2	1451
3	7733
4	10541
5	13629
6	17995
7	21704
8	25657
9	31644
10	35463
11	169996
12	189371

Table 16.1

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(i) Write an equation to represent the **fourth** ionisation energy of magnesium.

Include state symbols.

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

(ii) Explain how the successive ionisation energies provide evidence that magnesium is in Group 2 of the periodic table.

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

(iii) Electrons occupy orbitals.

In **Table 16.2** below, add a tick (✓) below the ionisation numbers that are responsible for removing an electron from a full orbital in a magnesium atom.

Ionisation number	1	2	3	4	5	6	7	8	9	10	11	12

Table 16.2 **[1]**

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(c) The enthalpy change of solution for magnesium fluoride, MgF_2, can be determined indirectly using an energy cycle based on the enthalpy changes below.

Enthalpy change	Energy / kJ mol^{-1}
Lattice enthalpy of magnesium fluoride	–2926
Hydration of magnesium ions	–1920
Hydration of fluoride ions	–506

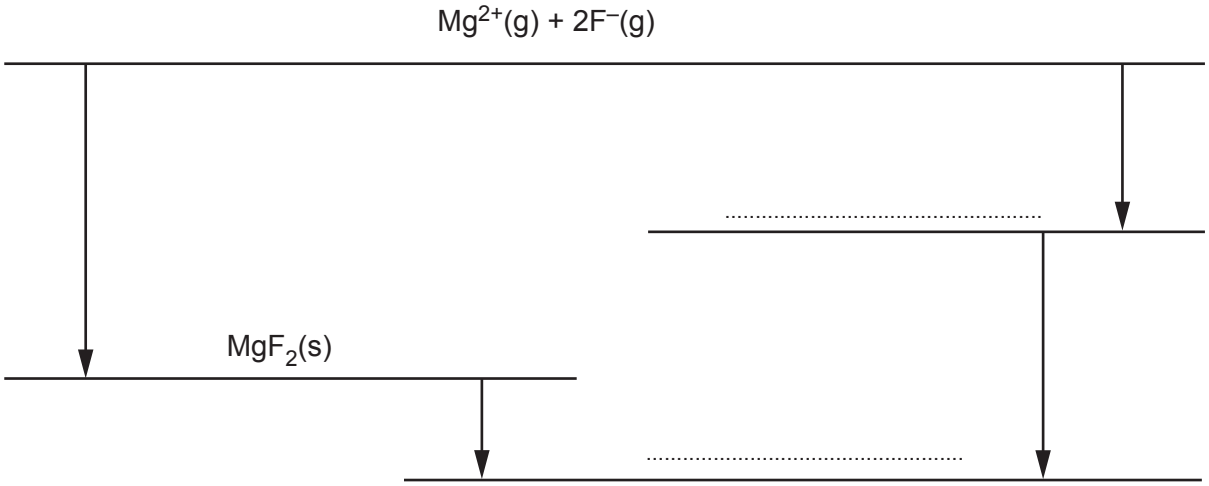
(i) Explain what is meant by **enthalpy change of solution**.

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

(ii) On the dotted lines, add the species present, including state symbols.



[2]

(iii) Calculate the enthalpy change of solution of MgF_2.

enthalpy change of solution = ... kJ mol^{-1} **[1]**

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(iv) The enthalpy changes of solution of the magnesium halides show a trend from MgF_2 to MgI_2.

Explain why it is difficult to predict whether the enthalpy change of solution becomes more exothermic or less exothermic down the group from MgF_2 to MgI_2.

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

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17 This question is about d-block elements.

(a) Most d-block elements are also classified as transition elements.

Explain why scandium and zinc are classified as d-block elements but are **not** also transition elements.

Your explanations should include full electron configurations.

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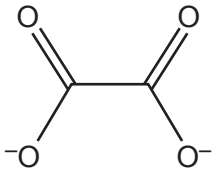
(b) Compound **A** is a hydrated chromium(III) salt with a molar mass of $608.3\,g\,mol^{-1}$ and the following percentage composition by mass:

Cr, 17.10%; H, 3.94%; O, 63.13%; S, 15.83%.

A student dissolves compound **A** in water.
The resulting solution contains the complex ion $[Cr(H_2O)_6]^{3+}$.

The student mixes this solution with aqueous sodium ethanedioate, $Na_2C_2O_4$.
A ligand substitution reaction takes place forming a solution containing three stereoisomers of a complex ion **B** of chromium(III).

Complex ion **B** is six-coordinate and contains two ethanedioate ligands and two water ligands.
The ethanedioate ion is the bidentate ligand shown below.



Ethanedioate ligand

(i) What is meant by a **bidentate ligand**?

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

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(ii)* Determine the formulae of **A** and **B**. Write the ionic equation for the ligand substitution and show 3D structures for the three stereoisomers of **B**.

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18 A student carries out an experiment to determine the percentage by mass of copper in an ore containing copper in its +2 oxidation state.

The student is provided with a sample of the copper ore, 1 mol dm^{-3} potassium iodide, KI(aq), and 0.0200 mol dm^{-3} sodium thiosulfate, $Na_2S_2O_3$.

The student's method is outlined below.

Step 1 Add an excess of warm nitric acid to 2.50 g of the ore.
The copper(II) compounds in the ore react, forming aqueous copper(II) nitrate.

Step 2 Filter the mixture to remove the unreacted rock. Neutralise the filtrate.

Step 3 Add an excess of aqueous potassium iodide, KI(aq).
A precipitate of copper(I) iodide and a solution of iodine, I_2(aq), forms.

Step 4 Titrate the mixture from **Step 3** using 0.0200 mol dm^{-3} sodium thiosulfate, $Na_2S_2O_3$ in the burette.

$$I_2(aq) + 2S_2O_3^{2-}(aq) \longrightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

26.55 cm^3 of 0.0200 mol dm^{-3} $Na_2S_2O_3$ are required to reach the end point.

(a) In **Step 1**, the student observed that bubbles of gas were produced.

Suggest the formula of the copper(II) compound which reacted with HNO_3 to form the gas, and write a full equation for the reaction.

Formula: .....

Equation: ..... **[2]**

(b) Write an **ionic** equation, including state symbols, for the reaction in **Step 3**.

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

(c) Suggest a suitable indicator for this titration and state the colour change at the end point in **Step 4**.

Indicator: .....

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

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(d) Determine the percentage, by mass, of copper in the copper ore.
Give your answer to an **appropriate** number of significant figures.

percentage = ... % **[4]**

(e) Explain whether the calculated percentage by mass of copper would be higher, lower or the same if the following changes were made to the method.

(i) The potassium iodide was not in excess, in **Step 3**.

.....

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

(ii) The burette readings were read from the top of the meniscus, in **Step 4**.

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

(f) The student then modifies the method in order to obtain a more accurate value for the percentage by mass of copper in the ore. The student decides to use 25.00 g of the copper ore in **Step 1**.

What further modifications should the student make to produce a more accurate value for the percentage by mass of copper in the ore?

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

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19 Storage cells and fuels cells are types of electrochemical cell.

The electrode potentials for five redox systems are shown in **Table 19.1**.

Redox system	Half-equation			E^{-e-}/V
1	$Cr^{3+}(aq) + 3e^-$	$\rightleftharpoons$	$Cr(s)$	–0.74
2	$O_2(g) + 2H_2O(l) + 4e^-$	$\rightleftharpoons$	$4OH^-(aq)$	+0.40
3	$MnO_4^-(aq) + e^-$	$\rightleftharpoons$	$MnO_4^{2-}(aq)$	+0.56
4	$MnO_4^-(aq) + 8H^+(aq) + 5e^-$	$\rightleftharpoons$	$Mn^{2+}(aq) + 4H_2O(l)$	+1.51
5	$MnO_4^{2-}(aq) + 4H^+(aq) + 2e^-$	$\rightleftharpoons$	$MnO_2(s) + 2H_2O(l)$	+1.70

Table 19.1

(a) A student sets up an electrochemical cell based on redox systems **1** and **4** in **Table 19.1**.

(i) Draw a labelled diagram to show how this cell could be set up in the laboratory.

[3]

(ii) Construct the equation for the overall cell reaction.

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

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(b) In acid conditions, $MnO_4^{2-}(aq)$ disproportionates to form $MnO_2(s)$ and $MnO_4^{-}(aq)$.

(i) Explain, in terms of oxidation numbers, why disproportionation has taken place.

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

(ii) Explain, in terms of electrode potentials and equilibrium shifts why $MnO_4^{2-}(aq)$ disproportionates in acid conditions. Use the information in **Table 19.1**.

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

(c) An **alkaline** hydrogen-oxygen fuel cell is set up.

The overall equation for the cell reaction is shown below.

$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$

Redox system **2** in **Table 19.1** is the positive electrode of this cell.

(i) Write the half-equation at the negative electrode.

.....

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

(ii) The cell potential is 1.23 V.

Calculate the electrode potential of the negative electrode.

electrode potential = ... V **[1]**

(iii) State **one** important feature of a fuel cell that is different from a conventional storage cell.

.....

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

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20 This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **Equilibrium 20.1**.

Equilibrium 20.1 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = -114\,kJ\,mol^{-1}$

$\Delta S = -147\,J\,mol^{-1}\,K^{-1}$

(a) A dynamic equilibrium exists in a closed system.

State **one** other feature of a dynamic equilibrium.

.....

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

(b) **(i)** Show that the formation of NO_2 in **Equilibrium 20.1** is feasible at 25 °C.

[2]

(ii) Determine the maximum temperature, in K, for feasibility.

Give your answer to an **appropriate** number of significant figures.

maximum temperature = ... K **[1]**

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(c) A chemist investigates the equilibrium shown in **Equilibrium 20.1**.

The chemist mixes together 1.60 mol of NO(g) and 1.50 mol of O_2(g) in a container and the mixture is allowed to reach equilibrium.

At equilibrium:
- 75% of the NO(g) has been converted to NO_2(g)
- the total pressure is 1.21 MPa.

(i) Calculate K_p, in MPa^{-1}, for **Equilibrium 20.1**.

Give your answer to **3** significant figures.

K_p = ... MPa^{-1} **[4]**

(ii) The chemist then repeats the experiment three times. In each experiment, the chemist makes **one** change but uses the same initial amounts of NO and O_2.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words **greater**, **smaller** or **same**.

Change	K_p	Equilibrium amount of NO_2(g)	Initial rate
Temperature increase			
Pressure increase			
Catalyst added			

[3]

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21 This question is about how the rate of reaction is affected by changes in conditions.

A student carries out two investigations using the reaction between aqueous thiosulfate ions, $S_2O_3^{2-}(aq)$, and aqueous hydrogen ions, $H^+(aq)$.

Reaction 21.1 $S_2O_3^{2-}(aq) + 2H^+(aq) \longrightarrow S(s) + SO_2(g) + H_2O(l)$

(a) In **Investigation 1**, the student determines how the rate of **Reaction 21.1** is affected by changes in concentration.

The results are shown in the table.

Experiment	$[S_2O_3^{2-}(aq)]$ / mol dm^{-3}	$[H^+(aq)]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.16	1.00	0.0120
2	0.08	1.00	0.0060
3	0.02	0.50	0.0015

From the results, the student concludes that the rate equation is
rate = k $[S_2O_3^{2-}(aq)]$

(i) Explain how the student's results support this rate equation.

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

(ii) Predict a possible two-step mechanism for **Reaction 21.1**.
The first step is the rate-determining step.

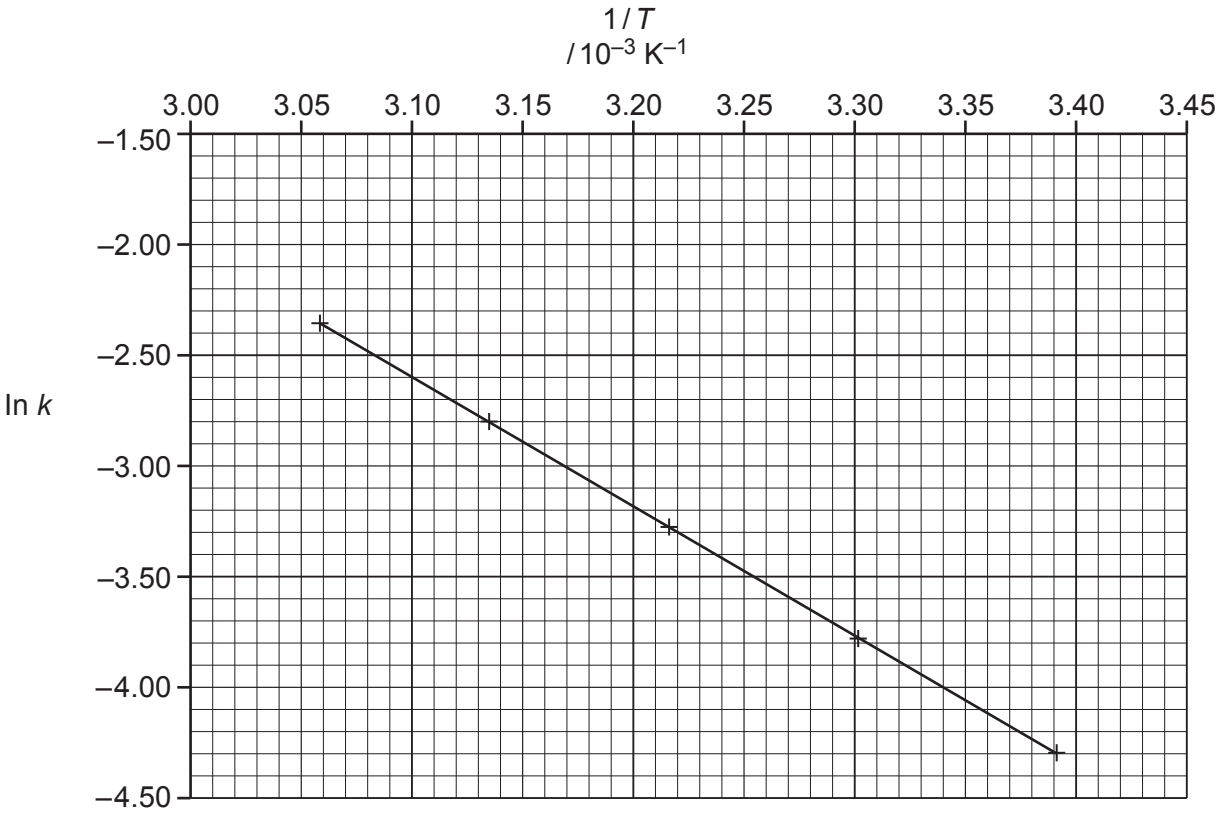
Step 1 .....

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

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(b) In **Investigation 2** the student determines the rate constant k of **Reaction 21.1** at different temperatures, T.

From the results, the student plots a graph of ln k against $1/T$ as shown below.



Graph 21.2

(i) Calculate the activation energy, E_a, for **Reaction 21.1**, in kJ mol^{-1}.

Give your answer to **3** significant figures.

E_a = ... kJ mol^{-1} **[3]**

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(ii) From the graph the student estimates the value of ln A as –2.00.
(A is the pre-exponential factor.)

Explain what mistake the student has made.

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

(iii) The student calculates the value of k in **Investigation 1** as $0.075\,s^{-1}$.

Using **Graph 21.2**, determine the temperature, in °C, at which **Investigation 1** was carried out.

temperature = ... °C **[2]**

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22 This question is about acids, bases and buffers.

(a) Sodium hydroxide, NaOH, is a strong base.

Calculate the pH of 0.140 mol dm^{-3} NaOH(aq) at 298 K.

Give your answer to **2** decimal places.

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

(b) Sulfuric acid reacts with sodium hydroxide as shown in **Equation 22.1**.

Equation 22.1 $H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$ ΔH_1

This is a neutralisation reaction.

A student carries out an experiment to determine the enthalpy change ΔH_1 and uses this value to deduce the enthalpy change of neutralisation, $\Delta_{neut}H$.

The student measures out two solutions:
- 25.0 cm^3 of 1.60 mol dm^{-3} $H_2SO_4(aq)$
- 55.0 cm^3 of 1.50 mol dm^{-3} NaOH(aq) (an excess).

The temperature of each solution is the same.

The student mixes the two solutions. The temperature increases by 13.0 °C.

(i) Show that NaOH is in excess.

[2]

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(ii) Calculate the enthalpy change, ΔH_1, for **Equation 22.1**, and deduce the value for the enthalpy change of neutralisation, $\Delta_{neut}H$, in $kJ\,mol^{-1}$.

Assume that the densities of all solutions and the specific heat capacity, *c*, of the reaction mixture are the same as for water.

enthalpy change, ΔH_1 = ... $kJ\,mol^{-1}$

enthalpy change of neutralisation, $\Delta_{neut}H$ = ... $kJ\,mol^{-1}$ **[4]**

(iii) The student repeats the experiment using $50.0\,cm^3$ of $1.60\,mol\,dm^{-3}$ H_2SO_4 and $110.0\,cm^3$ of $1.50\,mol\,dm^{-3}$ NaOH.

Predict the increase in temperature.

Explain your reasoning.

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

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(c)* Nitrous acid, HNO_2, is a weak Brønsted–Lowry acid with a pK_a value of 3.34 at room temperature.

HNO_2 can be prepared by reacting N_2O_3 with water.
HNO_2 is the only product.

A chemist makes up a buffer solution by the following method.

Step 1 The chemist weighs a sample of N_2O_3.
Water is then added to form 100 cm^3 of 0.500 mol dm^{-3} HNO_2(aq).

Step 2 The chemist adds 100 cm^3 of 0.150 mol dm^{-3} NaOH(aq) to the 100 cm^3 solution of 0.500 mol dm^{-3} solution of HNO_2(aq).
The resulting solution is made up to 1.00 dm^3.

Explain why a buffer solution forms in **Step 2**. Determine the pH of this buffer solution and the mass of N_2O_3 that was used in **Step 1**.

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END OF QUESTION PAPER

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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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