

## 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

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Candidate number

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First name(s)

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Last name

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#### 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.

**2**  
**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]

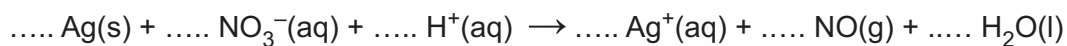
- 2** A chlorate(VII) ion has a 1– charge.  
What is the formula for sodium chlorate(VII)?

- A**  $\text{NaClO}_3$
- B**  $\text{NaClO}_4$
- C**  $\text{NaClO}_7$
- D**  $\text{NaClO}_8$

Your answer

[1]

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



Which numbers for Ag and H<sub>2</sub>O will balance the equation?

	Ag(s)	H <sub>2</sub> O(l)
<b>A</b>	1	2
<b>B</b>	2	3
<b>C</b>	3	1
<b>D</b>	3	2

Your answer

[1]

- 4 Which sample contains the greatest number of molecules?

- A** 140.0g C<sub>2</sub>H<sub>2</sub>  
**B** 180.0g C<sub>2</sub>H<sub>6</sub>  
**C** 240.0g C<sub>4</sub>H<sub>10</sub>  
**D** 400.0g C<sub>6</sub>H<sub>6</sub>

Your answer

[1]

- 5 Chromium(III) oxide, Cr<sub>2</sub>O<sub>3</sub>, 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]

- 6 A student is supplied with  $100.0 \text{ cm}^3$  of a solution of  $0.400 \text{ mol dm}^{-3}$  magnesium iodide,  $\text{MgI}_2$ .  
A student plans to dilute this solution so that the iodide concentration is  $0.250 \text{ mol dm}^{-3}$ .

What volume of water, in  $\text{cm}^3$ , 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  $\text{Ca} < \text{Si} < \text{P} < \text{N}$   
B  $\text{N} < \text{P} < \text{Si} < \text{Ca}$   
C  $\text{Ca} < \text{N} < \text{P} < \text{Si}$   
D  $\text{C} < \text{Si} < \text{P} < \text{Ca}$

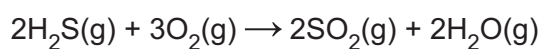
Your answer

[1]

- 8 Bond enthalpies are given in the table.

<b>Bond</b>	H-S	O=O	S=O	O-H
<b>Bond enthalpy / <math>\text{kJ mol}^{-1}</math></b>	+346	+498	+531	+464

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

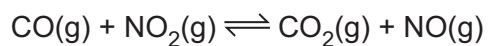


- A -174  
B -1102  
C -1794  
D -2098

Your answer

[1]

- 9 An equilibrium system is shown below.



Different amounts of CO, NO<sub>2</sub>, CO<sub>2</sub> and NO are added to four containers, as shown below.

Container	CO/mol	NO <sub>2</sub> /mol	CO <sub>2</sub> /mol	NO/mol
<b>A</b>	1	1	0	0
<b>B</b>	1	0	1	1
<b>C</b>	1	1	1	0
<b>D</b>	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<sub>3</sub>COOH, has a concentration of 0.50 mol dm<sup>-3</sup>.  
pK<sub>a</sub> for CH<sub>3</sub>COOH = 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]

- 11 The feasibility of a chemical reaction depends on the temperature and the signs of  $\Delta H$  and  $\Delta S$ .

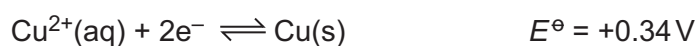
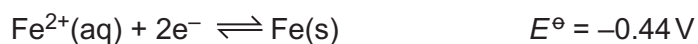
Which row has signs for  $\Delta H$  and  $\Delta S$  for a reaction that is feasible at high temperatures but is **not** feasible at low temperatures?

	$\Delta H$	$\Delta S$
<b>A</b>	+	+
<b>B</b>	+	-
<b>C</b>	-	+
<b>D</b>	-	-

Your answer

[1]

- 12 Two redox systems are shown below.



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

- A**  $\text{Fe}^{2+}(\text{aq})$
- B**  $\text{Fe}(\text{s})$
- C**  $\text{Cu}^{2+}(\text{aq})$
- D**  $\text{Cu}(\text{s})$

Your answer

[1]

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  $Cl-N=O$  is/are correct?

- 1: It is a polar molecule.
- 2: It contains 6 lone pairs of electrons.
- 3: It has a bond angle of  $180^\circ$ .

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

[1]

15  $\text{NH}_4\text{Fe}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$  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 $\text{NaOH}(\text{aq})$	Green precipitate
2	Reaction with $\text{Ba}(\text{NO}_3)_2(\text{aq})$	White precipitate
3	Reaction with warm $\text{NaOH}(\text{aq})$	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.

.....

.....

..... [3]

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

Ionisation number	Ionisation energy / kJ mol <sup>-1</sup>
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**

- (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.

.....  
 .....  
 .....  
 ..... [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]

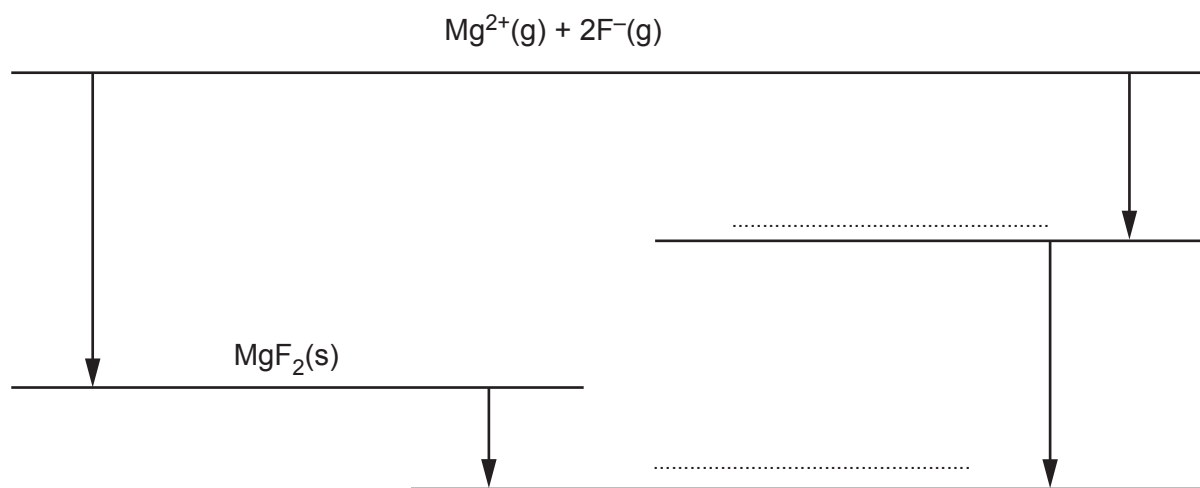
- (c) The enthalpy change of solution for magnesium fluoride,  $\text{MgF}_2$ , can be determined indirectly using an energy cycle based on the enthalpy changes below.

Enthalpy change	Energy / $\text{kJ mol}^{-1}$
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**.

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

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



[2]

- (iii) Calculate the enthalpy change of solution of  $\text{MgF}_2$ .

enthalpy change of solution = .....  $\text{kJ mol}^{-1}$  [1]





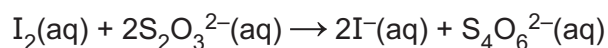


- 18** A student carries out an experiment to determine the percentage by mass of copper in an ore containing copper in its +2 oxidation state.

The student is provided with a sample of the copper ore,  $1 \text{ mol dm}^{-3}$  potassium iodide,  $\text{KI(aq)}$ , and  $0.0200 \text{ mol dm}^{-3}$  sodium thiosulfate,  $\text{Na}_2\text{S}_2\text{O}_3$ .

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,  $\text{KI(aq)}$ .  
A precipitate of copper(I) iodide and a solution of iodine,  $\text{I}_2(\text{aq})$ , forms.
- Step 4** Titrate the mixture from **Step 3** using  $0.0200 \text{ mol dm}^{-3}$  sodium thiosulfate,  $\text{Na}_2\text{S}_2\text{O}_3$  in the burette.



$26.55 \text{ cm}^3$  of  $0.0200 \text{ mol dm}^{-3}$   $\text{Na}_2\text{S}_2\text{O}_3$  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  $\text{HNO}_3$  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]



- (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**.

.....  
..... [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 25.00g 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?

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

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	$E^{\ominus}/V$
1	$\text{Cr}^{3+}(\text{aq}) + 3\text{e}^{-} \rightleftharpoons \text{Cr}(\text{s})$	-0.74
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
3	$\text{MnO}_4^{-}(\text{aq}) + \text{e}^{-} \rightleftharpoons \text{MnO}_4^{2-}(\text{aq})$	+0.56
4	$\text{MnO}_4^{-}(\text{aq}) + 8\text{H}^{+}(\text{aq}) + 5\text{e}^{-} \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
5	$\text{MnO}_4^{2-}(\text{aq}) + 4\text{H}^{+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{MnO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l})$	+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]

(b) In acid conditions,  $\text{MnO}_4^{2-}(\text{aq})$  disproportionates to form  $\text{MnO}_2(\text{s})$  and  $\text{MnO}_4^{-}(\text{aq})$ .

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

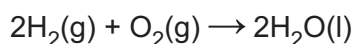
.....  
 .....  
 .....  
 ..... [2]

(ii) Explain, in terms of electrode potentials and equilibrium shifts why  $\text{MnO}_4^{2-}(\text{aq})$  disproportionates in acid conditions. Use the information in **Table 19.1**.

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

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

The overall equation for the cell reaction is shown below.



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.

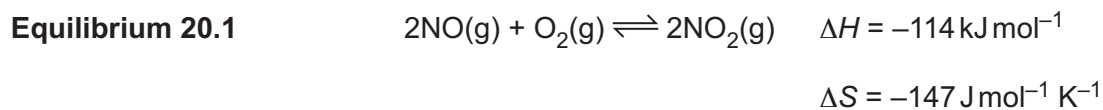
electrode potential = ..... V [1]

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

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

20 This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O<sub>2</sub>, react to form nitrogen dioxide, NO<sub>2</sub>, in the reversible reaction shown in **Equilibrium 20.1**.



(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<sub>2</sub> 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]

- (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<sub>2</sub>(g) in a container and the mixture is allowed to reach equilibrium.

At equilibrium:

- 75% of the NO(g) has been converted to NO<sub>2</sub>(g)
- the total pressure is 1.21 MPa.

- (i) Calculate  $K_p$ , in MPa<sup>-1</sup>, for **Equilibrium 20.1**.

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

$$K_p = \dots\dots\dots \text{MPa}^{-1} \quad [4]$$

- (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<sub>2</sub>.

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 <sub>2</sub> (g)	Initial rate
Temperature increase			
Pressure increase			
Catalyst added			

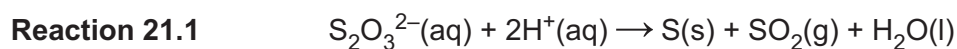
[3]

22  
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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,  $\text{S}_2\text{O}_3^{2-}(\text{aq})$ , and aqueous hydrogen ions,  $\text{H}^+(\text{aq})$ .



(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	$[\text{S}_2\text{O}_3^{2-}(\text{aq})]$ / $\text{mol dm}^{-3}$	$[\text{H}^+(\text{aq})]$ / $\text{mol dm}^{-3}$	initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
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  
 $\text{rate} = k [\text{S}_2\text{O}_3^{2-}(\text{aq})]$

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

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..... [2]

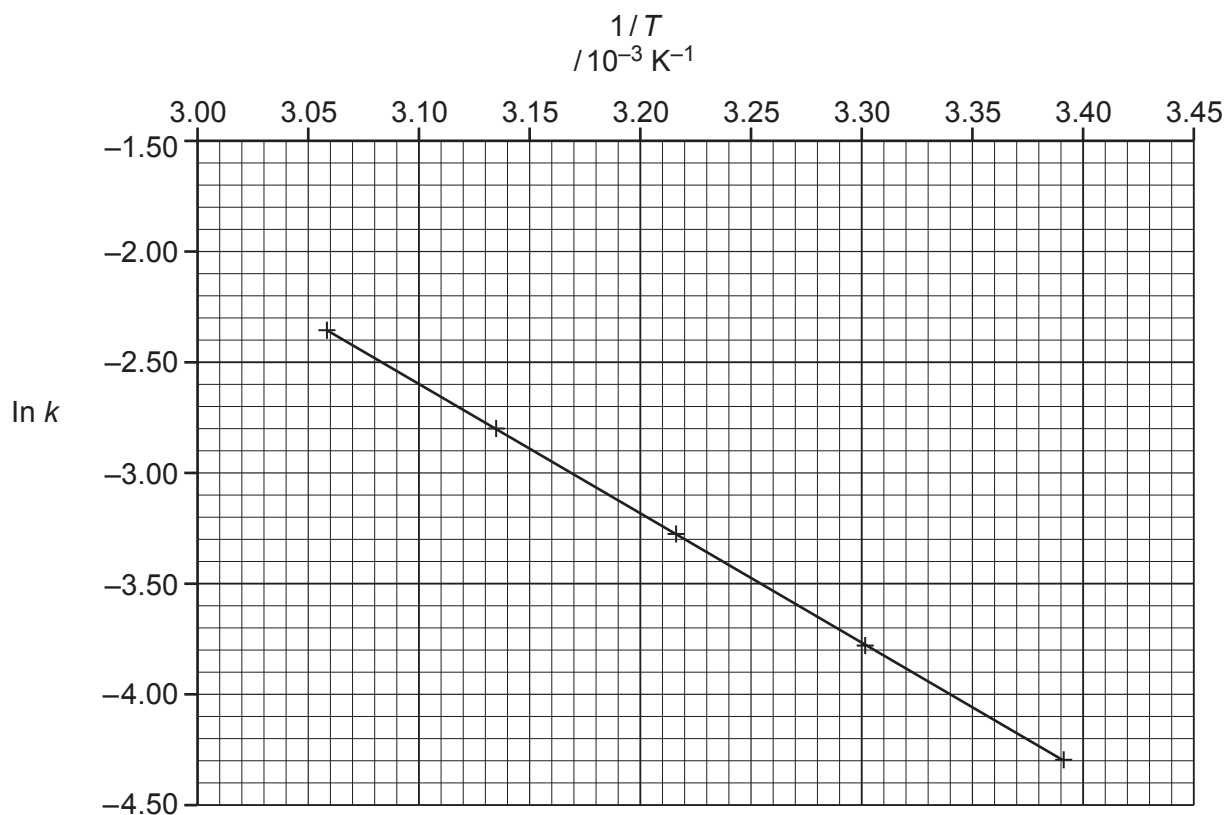
(ii) Predict a possible two-step mechanism for **Reaction 21.1**.  
 The first step is the rate-determining step.

**Step 1** .....

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

- (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  $\text{kJ mol}^{-1}$ .

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

$$E_a = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$



- (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.

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

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

Using **Graph 21.2**, determine the temperature, in  $^{\circ}\text{C}$ , at which **Investigation 1** was carried out.

temperature = .....  $^{\circ}\text{C}$  [2]

22 This question is about acids, bases and buffers.

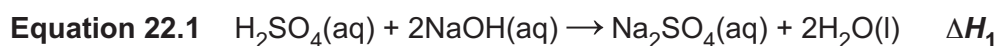
(a) Sodium hydroxide, NaOH, is a strong base.

Calculate the pH of 0.140 mol dm<sup>-3</sup> 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**.



This is a neutralisation reaction.

A student carries out an experiment to determine the enthalpy change  $\Delta H_1$  and uses this value to deduce the enthalpy change of neutralisation,  $\Delta_{\text{neut}}H$ .

The student measures out two solutions:

- 25.0 cm<sup>3</sup> of 1.60 mol dm<sup>-3</sup> H<sub>2</sub>SO<sub>4</sub>(aq)
- 55.0 cm<sup>3</sup> of 1.50 mol dm<sup>-3</sup> 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]

- (ii) Calculate the enthalpy change,  $\Delta H_1$ , for **Equation 22.1**, and deduce the value for the enthalpy change of neutralisation,  $\Delta_{\text{neut}}H$ , in  $\text{kJ mol}^{-1}$ .

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,  $\Delta H_1 = \dots\dots\dots \text{kJ mol}^{-1}$

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

- (iii) The student repeats the experiment using  $50.0 \text{ cm}^3$  of  $1.60 \text{ mol dm}^{-3}$   $\text{H}_2\text{SO}_4$  and  $110.0 \text{ cm}^3$  of  $1.50 \text{ mol dm}^{-3}$   $\text{NaOH}$ .

Predict the increase in temperature.

Explain your reasoning.

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

(c)\* Nitrous acid,  $\text{HNO}_2$ , is a weak Brønsted–Lowry acid with a  $\text{p}K_a$  value of 3.34 at room temperature.

$\text{HNO}_2$  can be prepared by reacting  $\text{N}_2\text{O}_3$  with water.  
 $\text{HNO}_2$  is the only product.

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

**Step 1** The chemist weighs a sample of  $\text{N}_2\text{O}_3$ .  
Water is then added to form  $100\text{ cm}^3$  of  $0.500\text{ mol dm}^{-3}$   $\text{HNO}_2(\text{aq})$ .

**Step 2** The chemist adds  $100\text{ cm}^3$  of  $0.150\text{ mol dm}^{-3}$   $\text{NaOH}(\text{aq})$  to the  $100\text{ cm}^3$  solution of  $0.500\text{ mol dm}^{-3}$  solution of  $\text{HNO}_2(\text{aq})$ .  
The resulting solution is made up to  $1.00\text{ dm}^3$ .

Explain why a buffer solution forms in **Step 2**. Determine the pH of this buffer solution and the mass of  $\text{N}_2\text{O}_3$  that was used in **Step 1**.

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Additional answer space if required.

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**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).

A large area of lined paper for writing, consisting of 25 horizontal dotted lines. A solid vertical line runs down the left side of the page, creating a margin. The rest of the page is open for writing.

Handwriting practice lines consisting of multiple horizontal dotted lines and a vertical solid line on the left side.

A large rectangular area with a solid vertical line on the left side and horizontal dotted lines extending across the page, providing a space for writing answers.



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