WATP

CHEMISTRY UNIT 3 2019

MARKING GUIDE

Section One: Multiple-choice **(50 marks)**

1	a ☐ b ■ c ☐ d ☐
2	a ☐ b ☐ c ☐ d ■
3	a ☐ b ☐ c ☐ d ■
4	a ☐ b ☐ c ■ d ☐
5	a ☐ b ☐ c ☐ d ■

6	a ■ b ☐ c ☐ d ☐
7	a ☐ b ☐ c ■ d ☐
8	a ☐ b ☐ c ■ d ☐
9	a ☐ b ☐ c ■ d ☐
10	a ☐ b ■ c ☐ d ☐

11	a ☐ b ☐ c ☐ d ■
12	a ■ b ☐ c ☐ d ☐
13	a ☐ b ☐ c ■ d ☐
14	a ☐ b ☐ c ■ d ☐
15	a ■ b ☐ c ☐ d ☐

16	a ☐ b ■ c ☐ d ☐
17	a ☐ b ■ c ☐ d ☐
18	a ☐ b ☐ c ☐ d ■
19	a ■ b ☐ c ☐ d ☐
20	a ☐ b ■ c ☐ d ☐

21	a ■ b ☐ c ☐ d ☐
22	a ☐ b ■ c ☐ d ☐
23	a ☐ b ■ c ☐ d ☐
24	a ☐ b ☐ c ☐ d ■
25	a ☐ b ■ c ☐ d ☐

(2 marks per question)

Section Two: Short answer   **35%   (70 marks)**

Question 26   **(7 marks)**

A group of chemistry students constructed the electrochemical cell shown below.
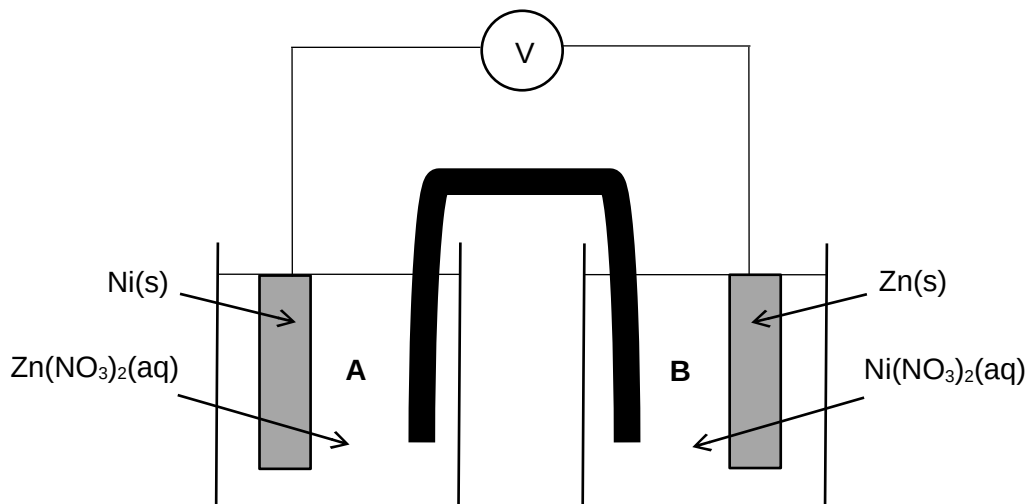
No voltage was recorded for this cell because it was incorrectly set up.

(a)   Note any changes the students would have observed in each half-cell.   (3 marks)

A	**No changes observed (1)**
B	**Green solution fades in colour, electrode decreases in size, new silver/grey solid forms (2; any two changes)**

(b)   Explain why no voltage was produced in this electrochemical cell and state what the students could do to correct the set up.   (2 marks)

- **a metal displacement reaction occurs in half-cell B therefore there is no potential difference between cells / no current flows through the external circuit**
- **swapping the electrodes (or the electrolyte beakers) will correct the set up**

The students corrected their set up of the cell and it was functioning as expected.

(c)   Write the overall equation for the reaction occurring in this cell.   (1 mark)

Zn(s) + Ni²⁺(aq) → Ni(s) + Zn²⁺(aq)   OR
$$Zn(s) + Ni^{2+}(aq) \rightarrow Ni(s) + Zn^{2+}(aq) \qquad OR$$
$$Zn(s) + Ni(NO_3)_2(aq) \rightarrow Ni(s) + Zn(NO_3)_2(aq)$$
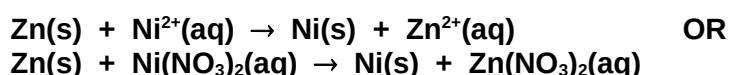
(d)   What is the maximum EMF that could be recorded for this cell if it was operating under standard conditions?   (1 mark)

EMF   =   - 0.24 + 0.76   =   0.52 V

Question 27   **(10 marks)**

(a)   Select a compound from the passage above that you could add to soil to;   (4 marks)

     (i)   increase the pH. Support your answer with an appropriate chemical equation.

     -   CaCO$_3$
     -   CO$_3^{2-}$(aq) + H$_2$O(l) $\rightleftharpoons$ HCO$_3^-$(aq) + OH$^-$(aq)

     (ii)   decrease the pH. Support your answer with an appropriate chemical equation.

     -   NH$_4$NO$_3$ OR
     -   NH$_4^+$(aq) + H$_2$O(l) $\rightleftharpoons$ NH$_3$(aq) + H$_3$O$^+$(aq)
         OR
     -   Ca(H$_2$PO$_4$)$_2$
     -   H$_2$PO$_4^-$(aq) + H$_2$O(l) $\rightleftharpoons$ HPO$_4^{2-}$(aq) + H$_3$O$^+$(aq)

To test the pH of the soil, 1 g of soil can be mixed in a test tube with either 5 mL of distilled water or 5 mL of 0.01 mol L^{-1} CaCl$_2$(aq). The test tube is then shaken, and a few drops of universal indicator is added to measure the pH.

(b)   Explain why mixing the soil with CaCl$_2$(aq) will give the same measured pH as mixing the soil with water.   (2 marks)

     -   it is a neutral salt
     -   neither the Ca^{2+} or the Cl$^-$ ion hydrolyses with water

Red cabbage leaves can be used to produce an indicator. Once the leaves are boiled in water, the liquid can then be collected and used to distinguish between acidic and alkaline solutions.

The general equation illustrating the ability of red cabbage indicator (denoted as H*Ind* / *Ind* $^-$) to change colour is shown below.

$$\text{H}Ind(aq) + \text{H}_2\text{O(l)} \rightleftharpoons Ind^-(aq) + \text{H}_3\text{O}^+(aq)$$
                    red   green
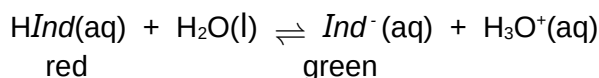
A few drops of red cabbage indicator was added to separate samples of 0.1 mol L^{-1} HCl(aq) and 0.1 mol L^{-1} NaOH(aq).

(c)   Use Le Chatelier's principle and the equation above, to justify how the addition of several drops of indicator results in a visible colour change in each case.   (4 marks)

     -   in acid solution the concentration of H$_3$O$^+$ is high which favours the reverse reaction
     -   this causes the indicator to appear red
     -   in basic solution the concentration of H$_3$O$^+$ is low (neutralised by the OH$^-$) which favours the forward reaction
     -   this causes the indicator to appear green

Question 28   **(8 marks)**

Write observations for the changes occurring when the substances below are mixed. In your answers include the appearance of the reactants and any products that form.

(a)   Chlorine gas is bubbled through a solution of potassium bromide.   (2 marks)

> **Pale yellow green gas dissolves in colourless solution,**
> **orange solution forms**

(b)   A 5.0 mL aliquot of 0.5 mol L^{-1} HCl(aq) is placed in a beaker with several drops of methyl orange indicator. A 6.0 mL aliquot of 0.5 mol L^{-1} NaOH(aq) is then added dropwise to the beaker.   (2 marks)

> **A red / pink solution has a colourless solution added to it,**
> **the solution turns orange / yellow**

Write balanced ionic equations for the following reactions, showing all state symbols.

(c)   Standardised aqueous sodium carbonate is titrated against a nitric acid solution of unknown concentration.   (2 marks)
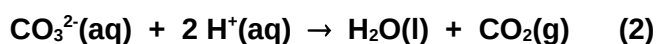
> $$CO_3^{2-}(aq) + 2\,H^+(aq) \rightarrow H_2O(l) + CO_2(g) \quad \textbf{(2)}$$
>
> **(1 for correct and balanced molecular equation)**

(d)   A small piece of potassium metal is placed in a large glass bowl filled with water. (2 marks)
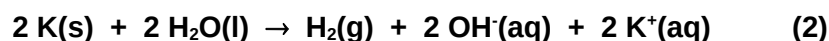
> $$2\,K(s) + 2\,H_2O(l) \rightarrow H_2(g) + 2\,OH^-(aq) + 2\,K^+(aq) \quad \textbf{(2)}$$
>
> **(1 for correct and balanced molecular equation)**

Question 29   **(9 marks)**

Potassium hydrogen iodate, $KH(IO_3)_2$, is a common primary standard used in acid-base titrations.

A sample of $KH(IO_3)_2(s)$ weighing 1.218 g was dissolved in distilled water and made up to 250.0 mL in a volumetric flask. 20.00 mL aliquots of this primary standard were taken and titrated against a sodium hydroxide solution, $NaOH(aq)$, of unknown concentration. An average titre of 23.74 mL was required to reach the end point.

The equation for the titration reaction is;

$$KH(IO_3)_2(aq) \; + \; NaOH(aq) \; \rightarrow \; NaIO_3(aq) \; + \; KIO_3(aq) \; + \; H_2O(l)$$

(a)   List two (2) characteristics that $KH(IO_3)_2$ must have in order to be used as a primary
        standard.   (2 marks)

-     **high molecular weight**
-     **not deliquescent / hygroscopic**
-     **soluble in water**
-     **obtainable in pure form   (any 2 relevant characteristics)**

(b)   Calculate the concentration of the $NaOH(aq)$ solution. State your answer to the appropriate
        number of significant figures.   (7 marks)

$n(KH(IO_3)_2)$ **=**   **m/M**
                       =   **1.218 / 389.908**   **(1 for M)**
                       =   **0.0031238 mol**   **(1)**

$c(KH(IO_3)_2)$ **=**   **n/V**
                       =   **0.0031238 / 0.250**
                       =   **0.012495 mol L^{-1}**   **(1)**

$n(KH(IO_3)_2$ in 20 mL)   **=**   **cV**
                                   =   **0.012495 x 0.020**
                                   =   **0.000249905 mol OR 2.49905 x 10^{-4} mol (1)**

n(NaOH in av. titre)   **=**   **0.000249905 mol OR 2.49905 x 10^{-4} mol (1)**

c(NaOH)   **=**   **n/V**
               =   **0.000249905 / 0.02374**
               =   **0.01052675 mol L^{-1}**   **(1)**

               =   **0.01053 mol L^{-1} OR   1.053 x 10^{-2} mol L^{-1} (4 SF)**   **(1 for SF)**

Question 30   **(9 marks)**

The following equation shows the equilibrium that exists between tetraphosphorus (P_4) and diphosphorus (P_2) in a reaction chamber at 1000 °C.

$$P_4(g) \quad + \quad heat \quad \rightleftharpoons \quad 2 \, P_2(g)$$

A sample of $P_4(g)$ was injected into an evacuated chamber, where the temperature was maintained at 1000 °C. The initial partial pressure of $P_4(g)$ was 183 kPa. The system was allowed to establish equilibrium and this occurred at Time E1. At this time, the partial pressure of $P_4(g)$ was 158 kPa.

(a)   Sketch a graph on the axes below, showing the partial pressure changes of **both species** from Time 0 until the establishment of equilibrium at Time E1. Continue your sketch after Time E1 to illustrate the attainment of equilibrium.   (4 marks)
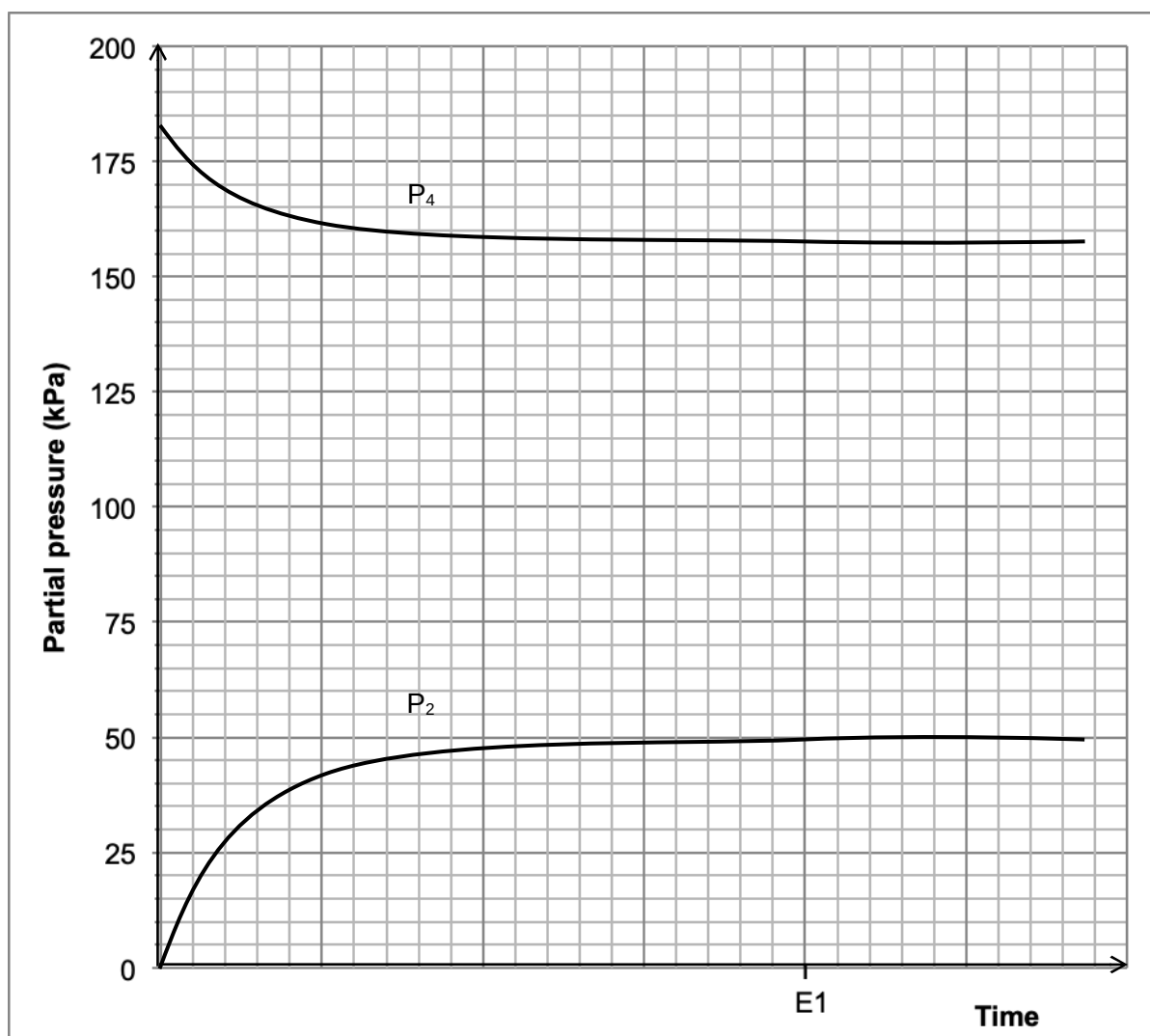
(1 for P_4 start/end value, 1 for P_2 start/end value,
1 for shape of curves from Time 0 to E1, 1 for horizontal after E1)

(b)   Write the equilibrium constant (K) expression for this reaction.   (1 mark)

$$K \quad = \quad \frac{[P_2]^2}{[P_4]}$$

(c)   Predict how
- the mass of P_2(g), and
- the forward reaction rate

will differ from their original equilibrium values at E1 after the following changes are imposed on the system and equilibrium has been re-established. Use the terms **increase**, **decrease** or **no change**.   (4 marks)

|	Mass of P_2(g) present (increase, decrease, no change)	Rate of forward reaction (increase, decrease, no change)
Temperature decreased	**decrease**	**decrease**
Total volume increased	**increase**	**decrease**

Question 31   **(10 marks)**

The final stage of copper refining involves the electrochemical process illustrated below.

(a)   Write the overall equation for this electrochemical cell.   (1 mark)

$$Cu^{2+}(aq) \ + \ Cu(s) \ \rightarrow \ Cu(s) \ + \ Cu^{2+}(aq)$$
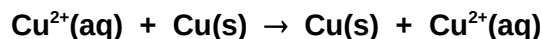
(b)   Is this a galvanic or electrolytic cell? Justify your answer.   (2 marks)

- **electrolytic**
- **energy is required to drive the reaction / EMF for this reaction is greater than 0 / battery or power pack is required to force electrons to move**

(c)   Describe briefly the sequence of steps that an atom of copper takes as it moves from the blister copper electrode to the pure copper electrode.   (5 marks)

- **copper atom at anode loses 2 electrons / copper atom is oxidised / copper atom becomes a copper ion / $Cu \rightarrow Cu^{2+} + 2e^-$ (2 of these points for 2 marks)**
- **copper ion moves into electrolyte and travels to cathode   (1)**
- **copper ion picks up 2 electrons at cathode / $Cu^{2+} \ + \ 2e^- \ \rightarrow \ Cu$ / copper ion becomes copper metal / copper ion is reduced and plates   (2 of these points for 2 marks)**

The $CuSO_4(aq)$ electrolyte is acidified with $H_2SO_4(aq)$ to prevent oxygen gas forming at the blister copper electrode.

(d)   Explain how the formation of $O_2(g)$ would be possible in the absence of acid. Support your answer with a relevant half-equation.   (2 marks)

- **the oxygen could be formed by the preferential oxidation of water**
- **$2 H_2O(l) \ \rightarrow \ O_2(g) \ + \ 4 H^+(aq) \ + \ 4 e^-$**

Question 32 **(9 marks)**

A group of chemistry students was investigating buffers. They prepared four (4) different solutions in separate beakers, as shown below.

They then tested the ability of each solution to act as a buffer, by adding NaOH(aq) dropwise to each beaker and recording the pH.

The results of their investigation are shown in the table below.

					Drops of NaOH(aq) added			
	Solution	0	5	10	15	20	25	30
pH	A	1.6	3.3	4.5	9.4	10.6	12.2	12.9
	B	5.9	5.9	5.9	6.0	6.0	6.1	6.1
	C	3.7	5.1	8.8	10.1	11.5	11.9	12.1
	D	7.0	10.2	11.8	12.5	12.8	12.9	13.0

(a)   Match each solution with its identity.   (4 marks)

A	HCl / NaCl
B	HNO_2 / KNO_2
C	HNO_2 / H_2O
D	NaCl / H_2O

(b)   Justify your choices in part (a).   (5 marks)

- **Only B demonstrates ability to buffer (since pH does not alter greatly)**
- **Therefore must consist of a weak conjugate acid / base pair**

- **A has lowest pH, corresponding to strong acid HCl (mixed with neutral NaCl which has no effect on pH)**

- **C has moderately low pH, corresponding to weak acid HNO_2 (mixed with neutral H_2O which has no effect on pH)**

- **D is neutral, corresponding to NaCl (mixed with neutral H_2O which has no effect on pH)**

Question 33   **(8 marks)**

The formic acid fuel cell is commonly used in small portable devices, as well as having some application in vehicles. The cell uses formic acid (HCOOH) as the fuel, in addition to oxygen gas which is extracted from the air. It is able to produce an EMF of 1.45 V under standard conditions. As the cell operates (under acidic conditions), carbon dioxide gas and water vapour are produced.

(a)   Complete the table below by writing the cathode and anode half-equations, the overall cell equation and calculating the voltage data (assuming standard conditions).   (5 marks)

Cathode half-equation	$O_2(g) + 4 H^+(aq) + 4 e^- \rightarrow 2 H_2O(l)$	$E^0_{(red)} = $ **+1.23 V**
Anode half-equation	$HCOOH(aq) \rightarrow CO_2(g) + 2 H^+(aq) + 2 e^-$	$E^0_{(ox)} = $ **+0.22 V**
Overall equation	$2\ HCOOH(aq) + O_2(g) \rightarrow 2 H_2O(l) + CO_2(g)$	EMF = 1.45 V

(b)   State an environmental disadvantage of using formic acid as a fuel instead of hydrogen gas, $H_2(g)$.   (1 mark)

   CO_2 is produced which is a greenhouse gas (whereas hydrogen fuel cell only produces water)

The EMF produced by the formic acid fuel cell is greater than that produced by the hydrogen-oxygen acid fuel cell.

(c)   What information does this provide regarding the comparative strength of H_2 and HCOOH as reductants (reducing agents)? Justify your answer.   (2 marks)

   -    **indicates HCOOH is a stronger reducing agent**
   -    **the half-cells must be further apart on the SRPT / there is a greater difference in E^0 value when HCOOH is used**

End of Section Two

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Section Three: Extended answer   **40%   (80 marks)**

This section contains **five (5)** questions. You must answer **all** questions. Write your answers in the spaces provided below.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression. Lists or dot points are unlikely to gain full marks.

Final answers to calculations should be expressed to the appropriate number of significant figures.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 70 minutes.

Question 34   **(16 marks)**

Ozone is an important chemical within our atmosphere and acts as a protective shield to stop many of the harmful ultraviolet rays from the Sun reaching us. One of the many important reactions occurring in our atmosphere is that between molecules of ozone (O_3) and nitric oxide (NO).

Nitric oxide is produced from natural occurrences such as lightning, forest fires and chemical processes in the soil, as well as in large amounts from human activities involving the use of fossil fuels.

Nitric oxide is an unstable molecule, and when it comes into contact with ozone the following reaction takes place, producing nitrogen dioxide (NO_2) and oxygen (O_2).

$$O_3(g) + NO(g) \rightleftharpoons NO_2(g) + O_2(g)$$
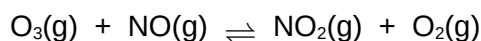
The reaction between ozone and nitric oxide is referred to as 'chemiluminescent' because it produces light. Whilst nitrogen dioxide is a brown gas, the other gases involved in this reaction are colourless.

Due to the importance of this reaction within our atmosphere, much study has been done regarding the thermodynamics of this process, as well as the effects of temperature and pressure on this system.

The activation energy for the forward reaction is 10.8 kJ, whilst the activation energy for the reverse reaction is 210.5 kJ.

Using the information given;

(a)   Sketch an energy profile diagram for this reaction. Label the enthalpy change along with its
       value.   (3 marks)

Progress of reaction
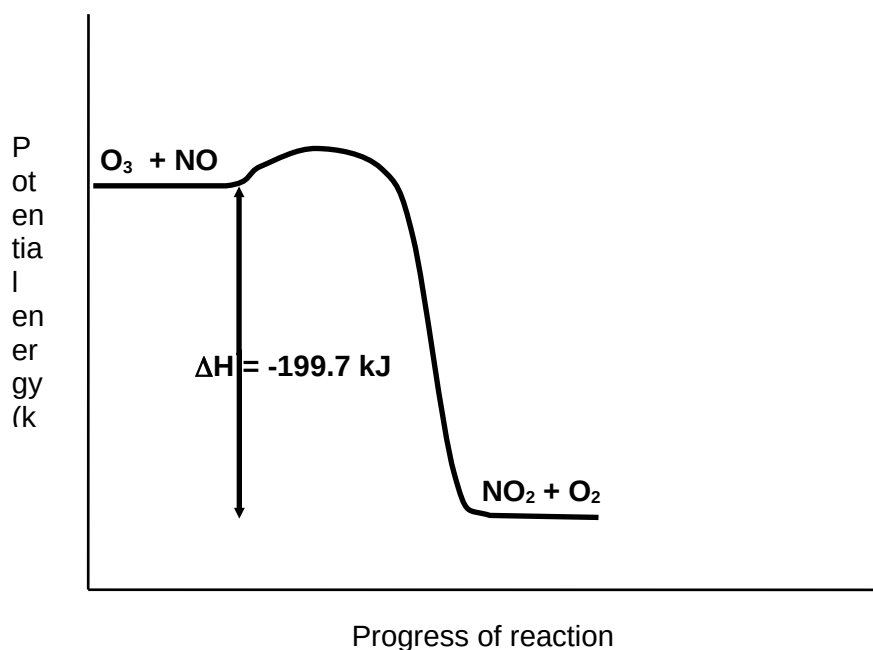
(1 for shape, 1 for reactants/products labels, 1 for ΔH value and label)

Considering the activation energy values provided;

(b)   Comment on the likely reversibility of this reaction and explain how this would affect the
       size of the equilibrium constant (K_c).   (3 marks)

       -    **not likely to be reversible, since forward Ea very small and reverse Ea very large**
       -    **this suggests there would be lots of products present at equilibrium**
       -    **this would result in a large value of K_c**

The reaction between ozone and nitric oxide was studied in a closed system, by injecting both gases into an evacuated chamber. Equilibrium was then allowed to establish.

Various changes were made to the system and the resultant effects were examined. Some of the data collected is displayed in the following graph. Note that only the nitrogen-containing species have been plotted.

$$O_3(g) \; + \; NO(g) \; \rightleftharpoons \; NO_2(g) \; + \; O_2(g)$$
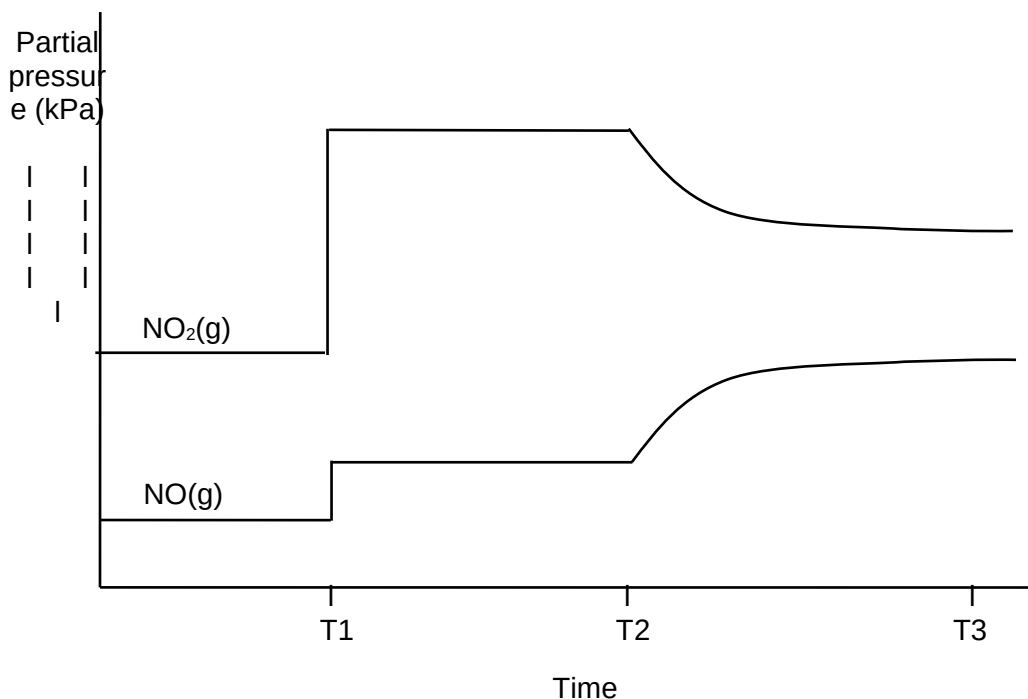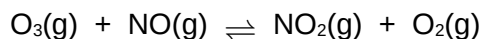
(c)   State the change imposed at T1. Give any corresponding observations.   (3 marks)

-    **doubling of total pressure / halving of total volume (2)**

     (allocate 1 mark for 'pressure increase / volume decrease' without note of 'doubling/halving')

-    **brown colour of gas mixture darkens (1)**

(d)   Explain the shape of the graph between T1 and T2.   (2 marks)

-    **equilibrium is not disturbed**
-    **since there are equal number of moles of gas on both sides of the equation**

At T2 the temperature of the system was increased, followed by the re-establishment of equilibrium at T3.

(e)   Sketch a graph showing the effect on both the forward and reverse reaction rates between T2 and T3. Label the forward and reverse reaction rates.   (2 marks)
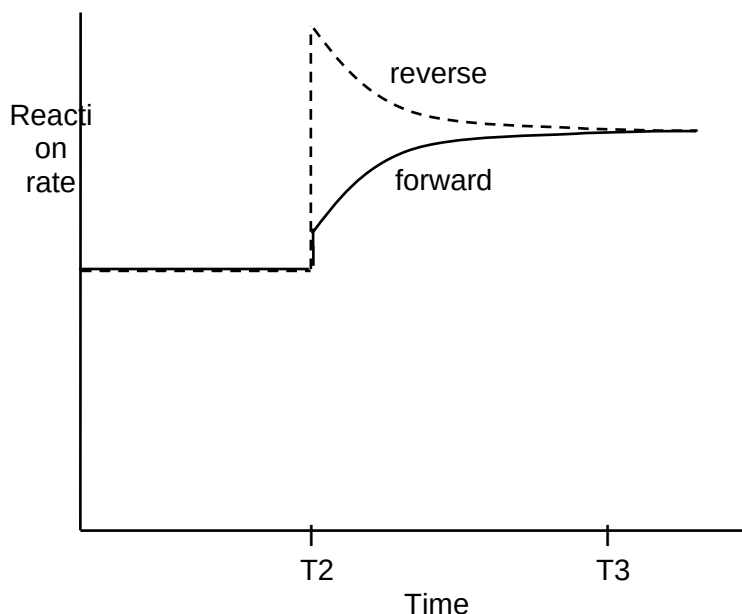
**(1 for initial large increase in reverse and small increase forward,
1 for reverse and forward then coming together and horizontal at T3)
((-1) if no for/rev labels shown)**

(f)   State **one other** change that could have been made to the system which would have resulted in the partial pressure changes observed (see original graph on previous page) between T2 and T3. Justify your answer.   (3 marks)

-     **increase partial pressure of O_2 / increase concentration of O_2 / inject some O_2**
-     **this would favour the reverse reaction in order to decrease the concentration of O_2**
-     **this would result in the observed decrease in NO_2 and increase in NO**

        OR

-     **decrease partial pressure of O_3 / decrease concentration of O_3 / remove some O_3**
-     **this would favour the reverse reaction in order to increase the concentration of O_3**
-     **this would result in the observed decrease in NO_2 and increase in NO**

Question 35 **(18 marks)**

'Aqua regia' is a mixture of nitric acid and hydrochloric acid and is typically made by combining HNO_3(aq) and HCl(aq) in the optimal molar ratio of 1:3 respectively.

As soon as nitric and hydrochloric acids are mixed, the aqua regia solution produced has a yellow-orange fuming appearance. It is very reactive and quickly begins to decompose, therefore the solution needs to be prepared just before use.

A fresh batch of aqua regia was being prepared by a chemist. If the beaker already contained 165 mL of 0.152 mol L^{-1} HNO_3(aq);

(a)   Calculate the volume of 0.218 mol L^{-1} HCl(aq) that should be added to this to produce the optimum composition aqua regia. (3 marks)

n(HNO$_3$)	**=**	**cV**
	=	**0.152 x 0.165**
	=	**0.02508 mol**

n(HCl required)	**=**	**3 x n(HNO$_3$)**
	=	**0.07524 mol**

V(HCl)	**=**	**n/c**
	=	**0.07524 / 0.218**
	=	**0.3451 L**
	=	**0.345 L or 345 mL (3SF)**

(b)   Calculate the pH of the aqua regia solution upon initial mixing of the two acids.   (3 marks)

n(H⁺ total)	**=**	**n(HCl) + n(HNO$_3$)**
	=	**0.07524 + 0.02508**
	=	**0.10032 mol**

C(H⁺ total)	**=**	**n/V**
	=	**0.10032 / 0.510**
	=	**0.1967 mol L^{-1}**

pH	**=**	**-log[H⁺]**
	=	**-log 0.1967**
	=	**0.706196**
	=	**0.706 (3SF)**

After the chemist had finished his laboratory work, 125 mL of the aqua regia remained. Due to its extremely reactive nature, aqua regia needs to be neutralised before disposal. If 42.0 mL of 0.545 mol L^{-1} potassium hydroxide (KOH) solution was added to this beaker of aqua regia;

(c)   Would this be sufficient to neutralise the aqua regia solution? Support your answer with calculations, including the final pH of the mixture. (You may assume no decomposition of aqua regia has occurred before the KOH is added.)   (6 marks)

n(H$^+$)   =   cV
=   0.1967 x 0.125
=   0.024588 mol

n(OH$^-$) = n(KOH)   =   cV
=   0.545 x 0.042
=   0.02289 mol

since n(H$^+$ total) is greater than n(OH$^-$) total, H$^+$ is in excess
n(xs H$^+$)   =   0.024588 - 0.02289
=   0.001698 mol

c(xs H$^+$)   =   n/V
=   0.001698 / 0.167
=   0.0101677 mol L^{-1}

pH   =   -log[H$^+$]
=   -log 0.0101677
=   1.99278
=   1.99   (3SF)

Therefore the KOH is not sufficient to neutralise the aqua regia

In Latin, aqua regia means "royal water" and it was given this name because of its ability to dissolve the noble metals such as gold and platinum. During World War II, a Hungarian chemist used aqua regia to dissolve the gold Nobel prizes of two physicists, in order to hide the gold and prevent the medals being confiscated by German soldiers.

The mechanism by which aqua regia dissolves gold is a two-step process involving both acids present in the mixture. During this reaction, the metallic gold is converted to the (+3) oxidation state as the complex ion, $[AuCl_4]^-$.

The overall equation for the reaction of aqua regia with gold is given below.

$$Au(s) \ + \ 3\,HNO_3(aq) \ + \ 4\,HCl(aq) \ \rightarrow \ [AuCl_4]^-(aq) \ + \ H_3O^+(aq) \ + \ 3\,NO_2(g) \ + \ 2\,H_2O(l)$$

(d)   Use oxidation numbers to demonstrate which acid component of aqua regia is the oxidising agent (oxidant).   (2 marks)

-     **HNO_3 is the oxidising agent**
-     **The oxidation number of N changes from +5 to +4**
      (no oxidation number changes occur to the atoms in HCl)

After World War II, the Hungarian chemist returned to his laboratory to find the jars of aqua regia untouched. He then precipitated the gold out of the solution and returned it to the Nobel Foundation. The medals were recast and presented again to the two physicists.

The gold was extracted from the aqua regia mixture by bubbling sulfur dioxide (SO_2) gas through the solution. This produced sulfate ions (SO_4^{2-}), whilst separating the $[AuCl_4]^-$ complex ion into solid gold and aqueous chloride ions.

(e)   Write oxidation and reduction half-equations for this process.   (4 marks)

Oxidation half-equation	**$SO_2(g) \ + \ 2\,H_2O(l) \ \rightarrow \ SO_4^{2-}(aq) \ + \ 4\,H^+(aq) \ + \ 2\,e^-$**
Reduction half-equation	**$[AuCl_4]^-(aq) \ + \ 3\,e^- \ \rightarrow \ Au(s) \ + \ 4\,Cl^-(aq)$**

Question 36   **(17 marks)**

Ellagic acid is found in fruits and vegetables such as raspberries, strawberries, walnuts and pomegranates. It has been shown to have antioxidant and anticancer properties and has been studied for its potential use as a treatment for viral and bacterial infections, inflammation, some chronic diseases and as a skin anti-ageing agent.

The structure of ellagic acid is shown below.
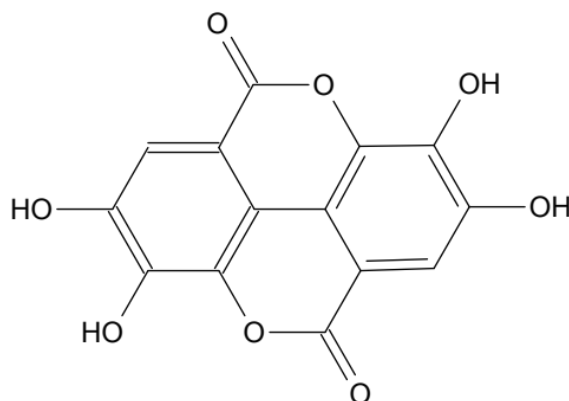
Ellagic acid is a tetraprotic acid.

$Ka_1 = 2.042 \times 10^{-7}$ $Ka_2 = 3.548 \times 10^{-8}$ $Ka_3 = 2.455 \times 10^{-10}$ $Ka_4 = 3.162 \times 10^{-12}$

(a)   Define the term polyprotic (multiprotic).   (1 mark)

    more than one acidic / ionisable hydrogen per molecule

A professor of biochemistry was investigating the concentration of ellagic acid in various fruits and vegetables, by titrating the acid against a sodium hydroxide standard, NaOH(aq). Using the value of Ka_1 provided;

(b)   Suggest a suitable indicator for use in this titration. Justify how you made this choice. (Note that chemical equations are not required.)   (3 marks)

    -    **the value of Ka_1 is very small (well below 1) indicating ellagic is a weak acid**
    -    **therefore the salt produced in this titration would be basic, due to hydrolysis of the anion from the weak acid**
    -    **therefore an indicator such as phenolphthalein would be suitable**

53.70 g of raspberries were liquefied by pulverising and dissolving in an appropriate solvent. The liquid raspberry mixture was made up to 100.0 mL in a volumetric flask. 20.00 mL aliquots were then taken and titrated against a standard 3.802×10^{-3} mol L^{-1} NaOH solution. The titration equation is given below.

$$C_{14}H_6O_8(aq) + 4\ NaOH(aq) \rightarrow 4\ H_2O(l) + Na_4C_{14}H_2O_8(aq)$$
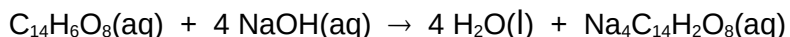
If the concentration of ellagic acid is known to be 40.06 mg per 100.0 g of raspberries;

(c)   Determine the theoretical value of the average titre that the professor should obtain. (Assume all sources of error were minimised and ellagic acid is the only compound in the raspberries that reacts in the titration).   (6 marks)

m(ellagic in 53.70 g sample of raspberries)   **=   53.70 / 100 x 40.06**
                                                                                =   21.51222 mg

                                                                                =   0.02151222 g

n(ellagic)   =   m/M
              =   0.02151222 / 302.188
              = 7.1188×10^{-5} mol
              =   n(ellagic present in 100 mL vol flask)

n(ellagic in 20 mL aliquot)   = 7.1188×10^{-5} x 20/100
                                                    = 1.42376×10^{-5} mol

n(NaOH required from burette to neutralise)   =   4 x n(ellagic)
                                                                          = $4 \times 1.42376 \times 10^{-5}$
                                                                          = 5.695056×10^{-5} mol

V(NaOH)   =   n/c
             = 5.695056×10^{-5} / 3.802×10^{-3}
             =   0.014979 L
             =   0.01498 L   OR   14.98 mL   (4SF)

A class of biochemistry students was attempting to replicate their professor's titration. The results of four student groups (A, B, C and D) are shown in the table below. The data recorded shows the four closest titres obtained by each group and does not include any preliminary or 'rough' trials performed.

	Titre 1	Titre 2	Titre 3	Titre 4
A	14.90	15.00	14.95	15.10
B	14.05	14.05	14.10	14.05
C	11.95	11.85	11.90	11.80
D	16.05	16.25	16.10	16.35

(d)   Select two (2) of the student groups above and use their data to distinguish between the terms 'accurate' and 'precise'.   (4 marks)

- **group A is the most accurate**
- **since their results give an average of 14.99 mL which is closest to 14.98 mL**

- **group B is the most precise**
- **since their results have the smallest range / smallest confidence interval / lowest variation in results**

(e)   Which student group is most likely to have incorrectly rinsed their burette with distilled water before use? State and explain whether this is a random or systematic error.   (3 marks)

- **group D**
- **systematic error**
- **this error would produce consistently high titres since rinsing with distilled water would dilute the NaOH(aq) in the burette**

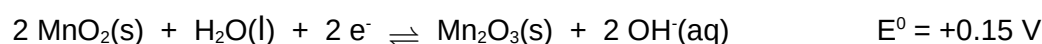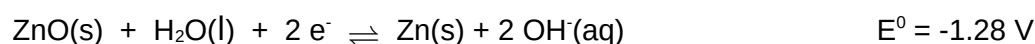**Question 37**   **(16 marks)**

The alkaline battery (or alkaline cell) is so named due to the potassium hydroxide electrolyte used, which contrasts with the acidic electrolyte originally used in the older Leclanché-style cells. It is currently the most commonly produced type of battery worldwide.

The alkaline battery is a non-rechargeable cell, which comes in a range of sizes and is used to power devices such as torches, cameras, radios, lights and toys.

The anode is composed of powdered zinc whilst the cathode is a manganese(IV) oxide paste mixed with carbon powder. The electrolyte, as stated previously, is an aqueous solution with a concentration of 25-40% potassium hydroxide (KOH). The cell produces an EMF of around 1.5 V.

The relevant half-equations for the alkaline battery are as follows;

$$ZnO(s) \ + \ H_2O(l) \ + \ 2 \ e^- \ \rightleftharpoons \ Zn(s) + 2 \ OH^-(aq) \qquad\qquad E^0 = -1.28 \ V$$

$$2 \ MnO_2(s) \ + \ H_2O(l) \ + \ 2 \ e^- \ \rightleftharpoons \ Mn_2O_3(s) \ + \ 2 \ OH^-(aq) \qquad\qquad E^0 = +0.15 \ V$$

(a)   Write the overall equation for the alkaline cell.   (2 marks)

$Zn(s) \ + \ 2 \ MnO_2(s) \ \rightarrow \ Mn_2O_3(s) \ + \ ZnO(s)$
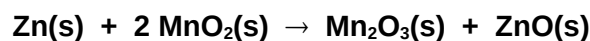
(-1 if unbalanced or state symbols missing)

Both half-equations involve OH^-(aq) ions, indicating the alkaline electrolyte present in the cell.

(b)   How does the overall reaction support the statement that "potassium hydroxide solution is not consumed in the reaction".   (2 marks)

  - **there is 2 mol of OH⁻ on reactants and products side of the overall equation**
  - **these cancel, showing no overall consumption of OH⁻ in the process**

(c)   Explain why both the anode and cathode have been designed to contain compounds in **powdered** form.   (2 marks)

  - **this increases the surface area available**
  - **which in turn increases the frequency of collisions for a faster reaction rate / increases the reaction rate and the rate of electron flow / allows a higher current flow without a drop in voltage**

(d)   Is the alkaline battery best classified as a primary, secondary or fuel cell? Justify your
       answer.   (2 marks)

       - **primary**
       - **not rechargeable**

The diagram below shows a partially labelled cross section of an alkaline cell being used to power
a single light globe.
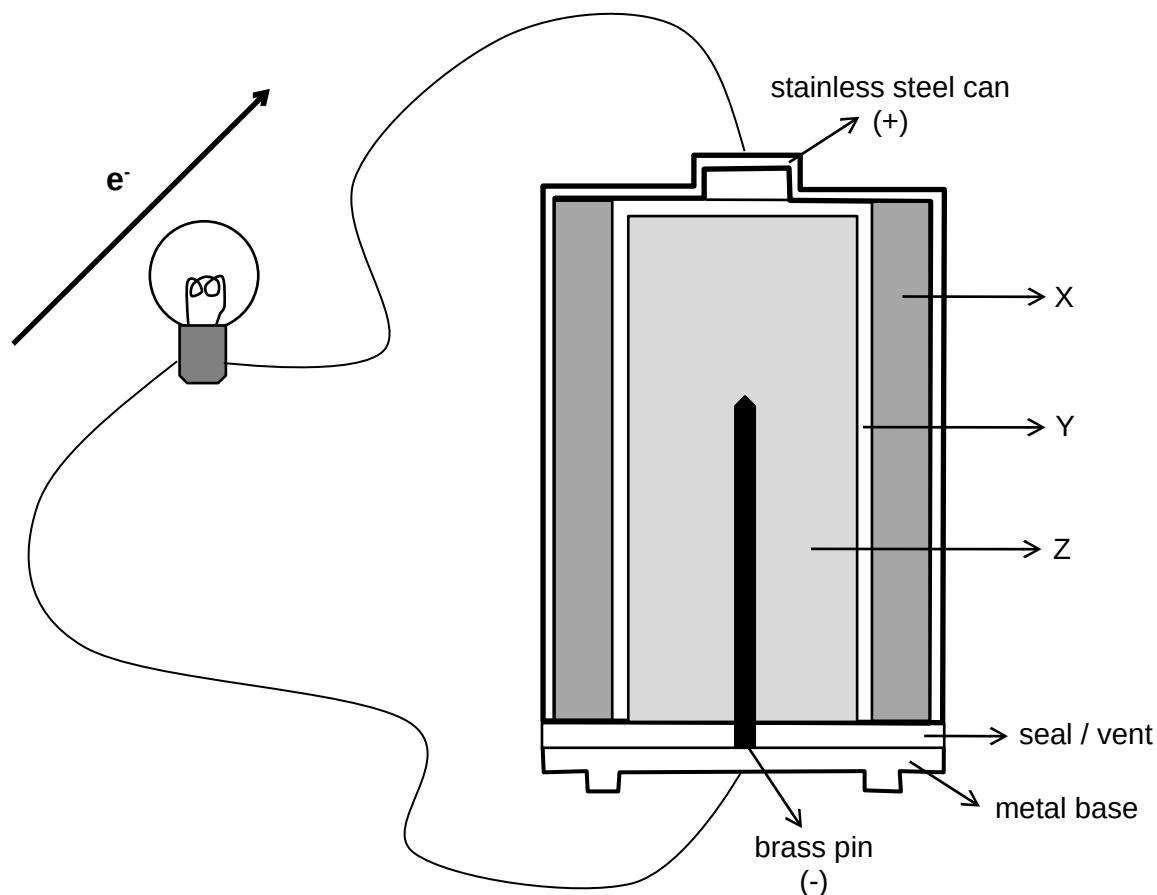
(e)   On the diagram, label the direction of electron flow.   (1 mark)

(f)   Which of the letters (X,Y, Z) functions as a salt bridge? Justify your answer.   (2 marks)

       - **Y**
       - **the function of the salt bridge is to separate (whilst allowing ion flow between)
         the two half cells and prevent the anode and cathode from coming into contact
         (X and Z are the cathodic and anodic chemicals, separated by Y)**

The concentration of KOH(aq) electrolyte in a particular alkaline cell was formulated to be 35.0% by weight (i.e. 35.0 g of KOH per 100 g of solution). If the density of the KOH(aq) electrolyte is measured as 1.35 g mL^{-1};

(g)   Calculate the pH of the electrolyte.   (5 marks)

Since there is 35 g KOH in 100 g solution;

n(KOH in 35g)	**=**	**m/M**
	=	**35.0 / 56.108**
	=	**0.623797 mol**

V(KOH if 100 g present)	**=**	**m/ρ**
	=	**100 / 1.35**
	=	**74.07407 mL**

c(KOH)	**=**	**n/V**
	=	**0.623797 / 0.07407407**
	=	**8.42126 mol L^{-1}**

[H$^+$]	**=**	**1.0 x 10^{-14} / [OH$^-$]**
	=	**1.0 x 10^{-14} / 8.42126**
	=	**1.18747 x 10^{-15} mol L^{-1}**

pH	**=**	**-log [H$^+$]**
	=	**-log 1.18747 x 10^{-15}**
	=	**14.92538**
	=	**14.9 (3SF)**

Question 38   **(13 marks)**

Hydrogen sulfide (H_2S) is a colourless gas often called "rotten egg gas" due to its characteristically unpleasant odour. It is found in volcanic gas and natural gas and is often produced when organic matter decomposes.

Hydrogen sulfide can be used in the production of many different compounds, one of which is hydroiodic acid. This is done, as illustrated in the reversible equation below, by bubbling $H_2S(g)$ through a sample of iodine water, $I_2(aq)$. This produces hydroioidic acid as well as elemental sulfur.

$$H_2S(g) \ + \ I_2(aq) \ \rightleftharpoons \ 2\,HI(aq) \ + \ S(s)$$
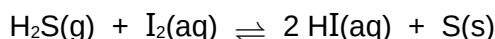
(a)   Write observations for this reaction.   (2 marks)

- **colourless gas smelling of rotten eggs dissolves in brown solution (rotten egg smell will fade)**
- **brown colour of solution fades to some extent and yellow precipitate/solid forms**

Some students wanted to optimise the production of hydroiodic acid and designed the following investigation to study the reaction in more detail.

1. Four (4) separate aliquots of iodine water were placed in individual conical flasks and stoppered.

2. Each aliquot was placed in a water bath with a different temperature and warmed until they reached either 30 °C, 40 °C, 50 °C or 60 °C.

3. A sample of $H_2S(g)$ was then bubbled into each aliquot of $I_2(aq)$.

4. The conical flasks were kept in the water baths to maintain their temperature during the reaction.

5. The reaction was allowed to proceed until equilibrium was established in each flask.

6. The solid sulfur residue was then isolated from each flask by filtration.

7. The sulfur was washed, dried and weighed.

The results obtained by the students in this investigation are shown in the graph below.
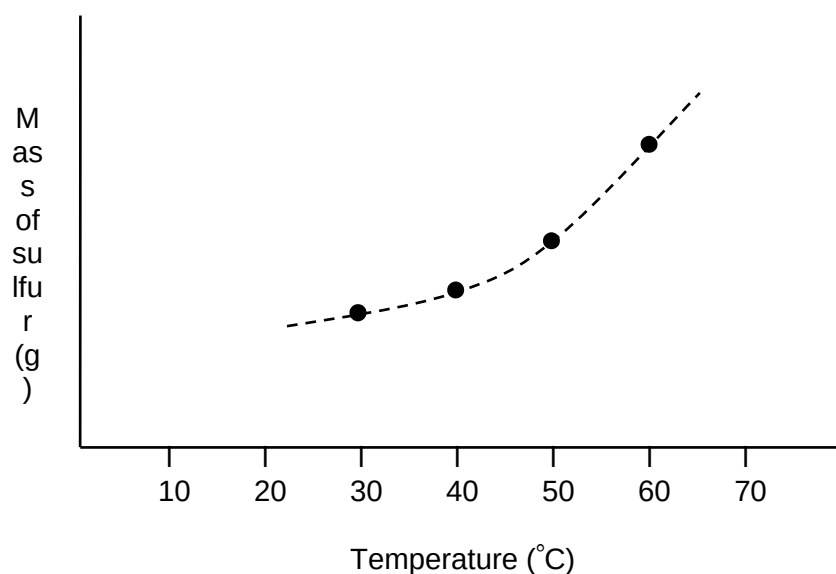
(b)   For the investigation described above state;   (4 marks)

    (i)   the independent variable   **reaction temperature**

    (ii)   the dependent variable   **mass of sulfur**

    (iii)   two controlled variables   **moles of H_2S**

                                               moles of I_2   **(award any other relevant)**

(c)   Use the data to decide whether the forward reaction is exothermic or endothermic. Justify
       your answer.   (3 marks)

-    **endothermic**
-    **an increase in temperature favours the endothermic direction**
-    **since there is an increase in products, the forward reaction must be favoured as
     temperature increases**

The students then decided to set up the same reaction at room temperature in a cylinder with a movable syringe (see diagram below). They allowed the system to establish equilibrium.

Then the students quickly moved the syringe upwards (see diagram below) to increase the volume of the system. They observed the system over time and noted that once equilibrium had re-established, there was less solid sulfur visible. The temperature of the system remained constant throughout this experiment.
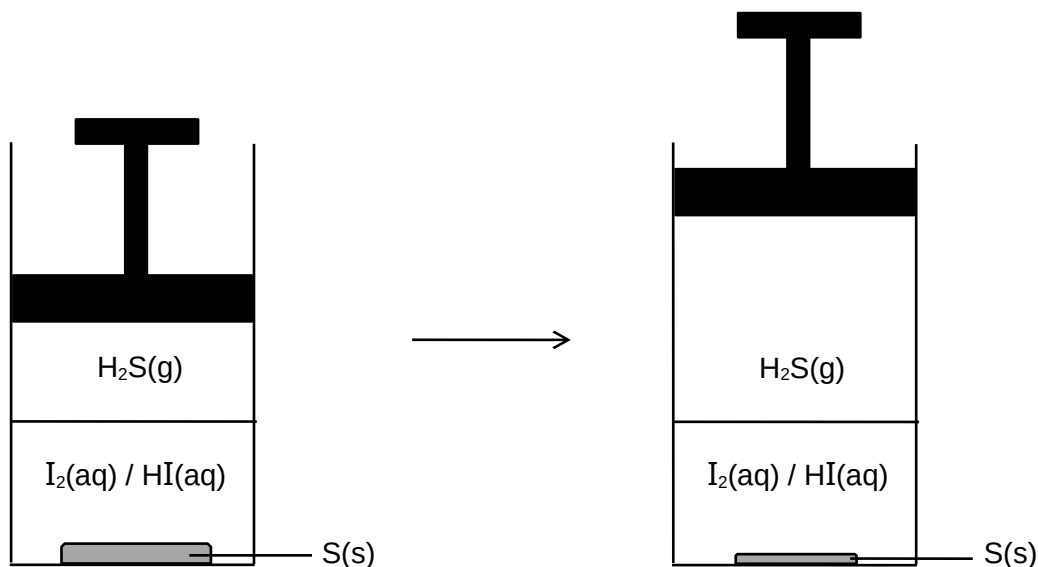
One student wrote the following conclusion in her laboratory book;

"Since less product is present, the reverse reaction must have been favoured and this would decrease the value of K (the equilibrium constant) for the reaction."

(d)   Comment on the accuracy of the student's statement. Refer to collision theory and reaction rates to support your answer.   (4 marks)

- **"reverse reaction must have been favoured" is correct**
- **with an increased volume, both the forward and reverse reaction rates decrease due to fewer collisions between particles**
- **however, the reverse reaction would decrease less (and therefore be favoured, resulting in less S visible) because the reverse reaction does not involve collisions between gas particles**

- **"decrease the value of K" is incorrect, as question states a constant temperature is maintained**

End of questions