Insert School Logo

CHEMISTRY
UNIT 3
2019

Name: _____

Teacher: _____

TIME ALLOWED FOR THIS PAPER
Reading time before commencing work: ten minutes
Working time for the paper: three hours

MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

To be provided by the supervisor:
This Question/Answer Booklet
Multiple-choice Answer Sheet
Chemistry Data Book

To be provided by the candidate:
Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, eraser, correction tape/fluid, ruler, highlighters

Special items: up to three non-programmable calculators approved for use in the WACE examinations

IMPORTANT NOTE TO CANDIDATES
No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Multiple-choice	25	25	50	/50	/25
Section Two: Short answer	8	8	60	/70	/35
Section Three: Extended answer	5	5	70	/80	/40
					/100

Instructions to candidates

1.   Answer the questions according to the following instructions.

Section One: Answer all questions on the separate Multiple-choice Answer Sheet provided. For each question shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Sections Two and Three: Write your answers in this Question/Answer Booklet.

2.   When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.

3.   You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

4.   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.

5.   The Chemistry Data Book is **not** handed in with your Question/Answer Booklet.

Section One: Multiple-choice   **25%   (50 marks)**

This section has **25** questions. Answer **all** questions on the separate Multiple-choice Answer Sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 50 minutes.

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1.   Consider the equilibrium system below.

$$2\ NO_2(g)\ \rightleftharpoons\ N_2O_4(g)$$
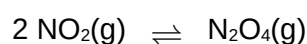
        If the concentrations of $NO_2(g)$ and $N_2O_4(g)$ were equal at a particular temperature, the value of K would be

        (a)   greater than 1.
        (b)   less than 1.
   (c)   equal to 1.
        (d)   unable to be determined.

Questions 2 and 3 relate to the electrolysis of molten magnesium oxide.

Consider the electrolysis of molten magnesium oxide, $MgO(l)$, using inert graphite electrodes.

2.   Which of the following statements is **not** correct regarding this cell?

        (a)   Magnesium is produced at the cathode.
        (b)   Oxygen gas is produced at the positive electrode.
        (c)   Electrons move from the anode to the cathode.
        (d)   Oxide ions are repelled by the anode.

3.   For every 1 mole of oxygen gas produced by this cell, the number of moles of magnesium metal produced would be

        (a)   0.5 moles.
        (b)   1.0 moles.
        (c)   1.5 moles.
        (d)   2.0 moles.

4.   Which of the following ideas regarding acid-base theory is attributed to the work of BrØnsted and Lowry?

        (a)   Bases produce $OH^-(aq)$ ions in solution.
        (b)   Bases are proton donors.
        (c)   Acidic solutions contain $H_3O^+(aq)$ ions.
        (d)   Strong acids completely ionise in solution.

Questions 5, 6 and 7 refer to the following information.

Consider the reversible reaction involving the hexaaquairon(III) ion shown below. Assume the reaction is at equilibrium and the K_c value is approximately 1 at 25 °C.

$$[Fe(H_2O)_6]^{3+}(aq) + H_2O(l) \rightleftharpoons [Fe(H_2O)_5OH]^{2+}(aq) + H_3O^+(aq)$$
colourless   deep orange
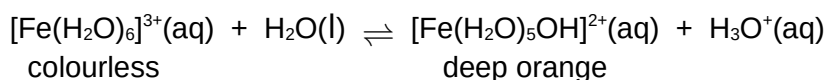
If 20 drops of 0.5 mol L^{-1} HCl(aq) solution was added to this system and a new equilibrium was allowed to establish;

5.   Which is the **best** observation for this?

   (a)   Colourless solution becomes deep orange.
   (b)   Deep orange solution becomes colourless.
   (c)   Orange solution darkens in colour.
   (d)   Orange solution fades in colour.

6.   At the new equilibrium, which of the following statements is **correct**?

   (a)   The rate of the forward reaction is increased.
   (b)   The rate of the forward reaction is decreased.
   (c)   The rate of the forward reaction is unchanged.
   (d)   The rate of the forward reaction is zero.

7.   Which species will **not** have an increase in the number of moles present?

   (a) $[Fe(H_2O)_6]^{3+}(aq)$
   (b) $H_2O(l)$
   (c) $[Fe(H_2O)_5OH]^{2+}(aq)$
   (d) $H_3O^+(aq)$

8.   Some students were carrying out an investigation on the corrosion of iron (Fe). They half-filled seven (7) test tubes, each with a different solution. Then the students placed an iron nail into each solution and left the test tubes to sit for 48 hours. When they returned, the students rated the amount of rust they could see on a scale from 0 (no rust visible) to 5 (large amounts of orange-brown rust visible). Their results are shown in the table below.

	Tap water	Deionised water	0.01 mol L^{-1} NaCl(aq)	0.02 mol L^{-1} NaCl(aq)	0.05 mol L^{-1} NaCl(aq)	0.02 mol L^{-} Cr$_2$O$_7^{2-}$(aq)	0.01 mol L^{-1} NaOH(aq)
Amount of rust (0-5)	2	1	3	4	5	3	0

Which of the following hypotheses is supported by this data?

   (a)   The presence of electrolytes causes corrosion.
   (b)   The rate of corrosion is inversely proportional to electrolyte concentration.
   (c)   An increase in NaCl(aq) concentration increases the rate of corrosion.
   (d)   Corrosion is a redox process and involves the transfer of electrons.

Questions 9 and 10 refer to the process of ocean acidification.

Ocean acidification is likely to have many negative consequences for our marine environments. One group of organisms particularly affected are calcifying species.

The four equations below summarise the chemical reactions involved in the process of ocean acidification.

1. $H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$

2. $HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$

3. $CO_2(g) \rightleftharpoons CO_2(aq)$

4. $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$

9. Place these equations in the correct order to show the series of chemical reactions involved in ocean acidification.

   (a)   3, 2, 1, 4
   (b)   3, 1, 4, 2
   (c)   3, 4, 1, 2
   (d)   4, 3, 2, 1

10. Which of the following does **not** contribute to the problems faced by calcifying species as a direct result of ocean acidification?

   (a)   A decrease in ocean $CO_3^{2-}(aq)$ concentration.
   (b)   A decrease in ocean $Ca^{2+}(aq)$ concentration.
   (c)   An increase in ocean $H_3O^+(aq)$ concentration.
   (d)   A decrease in the presence of $CaCO_3(s)$.

11. Which of these substances could be found on the standard reduction potential table?

   (a)   1.5 mol L^{-1} HCl(aq) at 25 °C.
   (b)   100 kPa $H_2(g)$ at 0 °C.
   (c)   101.3 kPa $H_2S(g)$ at 0 °C.
   (d)   1.0 mol L^{-1} NaCl(aq) at 25 °C.

12. The K_w of pure water at 10 °C is 2.92×10^{-15}. Which of the following statements must therefore be **correct** regarding water at 10 °C?

   (i)   The $[OH^-] = 5.40 \times 10^{-8}$ mol L^{-1}.
   (ii)   The $[OH^-] < [H_3O^+]$.
   (iii)   The pH of the water is 7.27.
   (iv)   The water is slightly basic.
   (v)   The autoionisation of water is exothermic.

   (a)   (i) and (iii) only.
   (b)   (i), (ii) and (v) only.
   (c)   (iii) and (iv) only.

(d)   (ii), (iii) and (iv) only.

Questions 13 and 14 relate to the information and graph given below.

The rate of decomposition of solid calcium carbonate was being investigated.

$$CaCO_3(s) + heat \rightleftharpoons CaO(s) + CO_2(g)$$
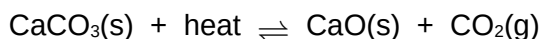
A graph was drawn to show how the moles of $CO_2(g)$ changes over time, as the reaction establishes equilibrium in a closed system. This is represented by the **solid line** on the graph below.
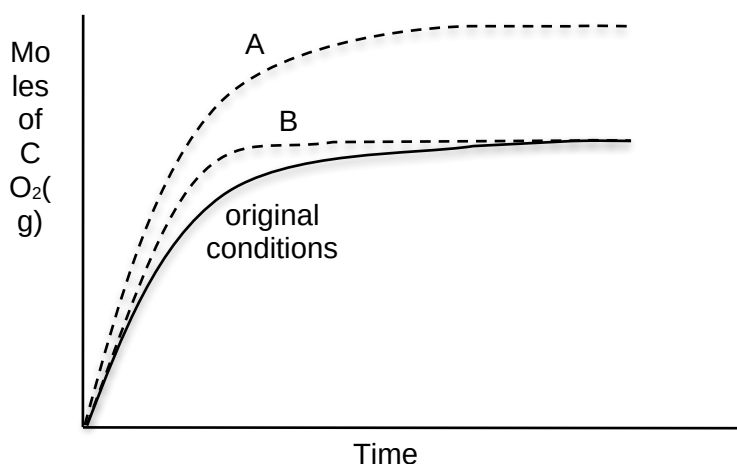
Consider the effect of individually altering (i.e. only changing one at a time) the following conditions and carrying out the reaction again.

        (i)   Increasing the mass of $CaCO_3(s)$.
        (ii)   Increasing the subdivision of $CaCO_3(s)$.
        (iii)   Increasing the temperature of the system.
        (iv)   Adding an appropriate reaction catalyst.

13.   Which of these alterations could result in the curve labelled A?

    (a)   (i) only
   (b)   (ii) only
    (c)   (iii) only
    (d)   (iv) only

14.   Which of these alterations could result in the curve labelled B?

    (a)   (i) and (ii) only
    (b)   (ii) and (iii) only
    (c)   (ii) and (iv) only
    (d)   (iii) and (iv) only

15.   Which of these lists contains species showing oxygen in **three different** oxidation states?

(a)	O_2	H_2O_2	MgO
(b)	F_2O	H_2O	SO_4^{2-}
(c)	H_2O_2	SO_4^{2-}	MgO
(d)	H_2O	O_2	SO_4^{2-}

16.   Consider the following pieces of glassware, both of which are used for measuring liquid volumes.

50 mL measuring cylinder   25 mL pipette

50 mL ± 0.5mL
Ex 20°C ± 0.5mL

25 mL ± 0.03 mL
Ex 20°C ± 0.03 mL
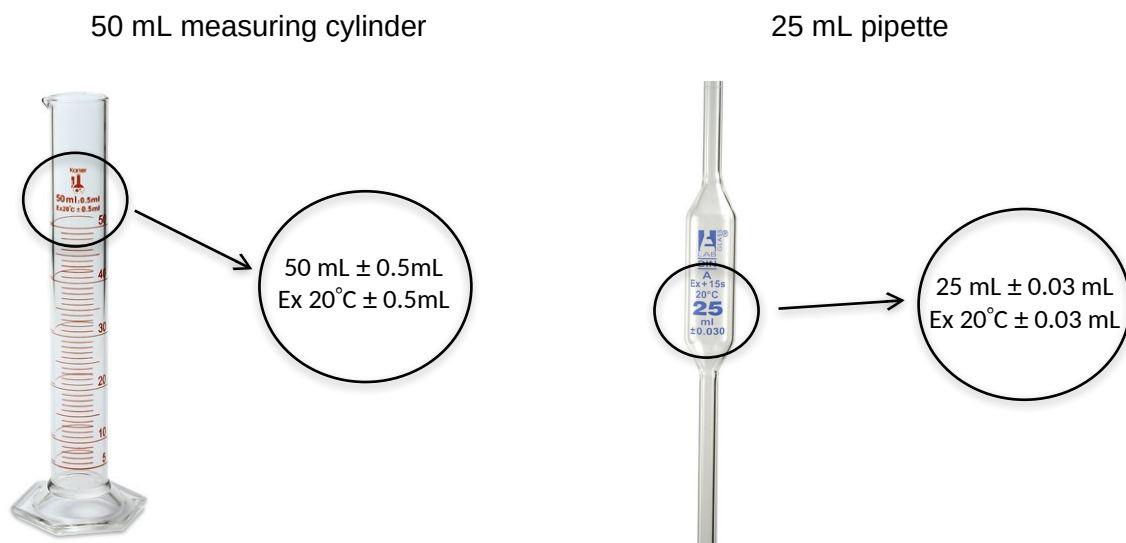
If each of these pieces of equipment was used to measure a 50 mL aliquot of water at 20 °C, the most accurate recordings possible are

	50 mL measuring cylinder	**25 mL pipette**
(a)	50 ± 0.5 mL	50 ± 0.03 mL
(b)	50 ± 0.5 mL	50 ± 0.06 mL
(c)	50 ± 1.0 mL	50 ± 0.03 mL
(d)	50 ± 1.0 mL	50 ± 0.06 mL

Questions 17 and 18 refer to the following equilibrium system.

Consider the following reversible gaseous system. Assume the reaction is at equilibrium.

$$CO_2(g) \ + \ 4 H_2(g) \ \rightleftharpoons \ CH_4(g) \ + \ 2 H_2O(g) \ + \ heat$$
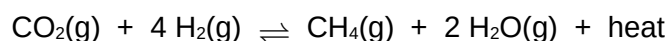
17.   Increasing the temperature of the system would

(a)   increase the yield of $CH_4(g)$.
(b)   increase the average kinetic energy of the particles.
(c)   increase the activation energy.
(d)   increase the heat of reaction.

18.   A chemist devised a way to remove methane from the system as it forms. This would

(a)   increase the rate of the forward reaction.
(b)   decrease the yield.
(c)   increase the rate of the reverse reaction.
(d)   create an open system.

Questions 19, 20 and 21 relate to the data below.

Four (4) different beakers were set up, each containing a different salt solution. A piece of cobalt metal was then placed in each. The beakers contained the combinations shown in the table.

A	B	C	D
$Co(s) + Cd^{2+}(aq)$	$Co(s) + Zn^{2+}(aq)$	$Co(s) + Sn^{2+}(aq)$	$Co(s) + Fe^{2+}(aq)$

19.   In which of the beaker(s) would the metal donate electrons?

(a)   C
(b)   A and B
(c)   B and C
(d)   A, B and D

20.   The strongest reducing agent is

(a) $Sn^{2+}(aq)$
(b) $Co(s)$
(c) $Fe^{2+}(aq)$
(d) $Zn^{2+}(aq)$

21.   In how many of the beakers would a spontaneous reaction occur (under standard conditions)?

(a)   1
(b)   2
(c)   3
(d)   4

22.   Which of the following are homogeneous equilibrium systems?

(i) $HCOOH(l) + CH_3CH_2OH(l) \rightleftharpoons HCOOCH_2CH_3(l) + H_2O(l)$
(ii) $SbCl_5(g) \rightleftharpoons SbCl_3(g) + Cl_2(g)$
(iii) $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\ OH^-(aq)$

(a)   (ii) only
(b)   (i) and (ii) only
(c)   (ii) and (iii) only
(d)   (i) and (iii) only

23.   Use the standard reduction potential table to determine the correct ionic equation for the reaction between acidified aqueous sodium dichromate and hydrogen peroxide solution.

(a) $H_2O_2(aq) + 6\ H^+(aq) + Cr_2O_7^{2-}(aq) \rightarrow O_2(g) + 2\ Cr^{3+}(aq) + 3\ H_2O(l)$
(b) $Cr_2O_7^{2-}(aq) + 8\ H^+(aq) + 3\ H_2O_2(aq) \rightarrow 2\ Cr^{3+}(aq) + 7\ H_2O(l) + 3\ O_2(g)$
(c) $3\ H_2O_2(aq) + Cr_2O_7^{2-}(aq) + 6\ H^+(aq) \rightarrow 7\ H_2O(l) + 3\ O_2(g) + Cr^{3+}(aq)$
(d) $Cr_2O_7^{2-}(aq) + H_2O_2(aq) + 2\ H^+(aq) \rightarrow O_2(g) + 2\ Cr^{3+}(aq) + 3\ H_2O(l)$

24.   In which of these equations would water be labelled as the conjugate acid?

(a) $HSO_4^-(aq) + H_2O(l) \rightleftharpoons SO_4^{2-}(aq) + H_3O^+(aq)$

(b) $CH_3COO^-(aq) + H_2O(l) \rightleftharpoons CH_3COOH(aq) + OH^-(aq)$

(c) $PO_4^{3-}(aq) + H_3O^+(aq) \rightleftharpoons H_2O(l) + HPO_4^{2-}(aq)$

(d) $HC_2O_4^-(aq) + OH^-(aq) \rightleftharpoons H_2O(l) + C_2O_4^{2-}(aq)$

25.   Consider the rate graph below, showing a system establishing equilibrium.
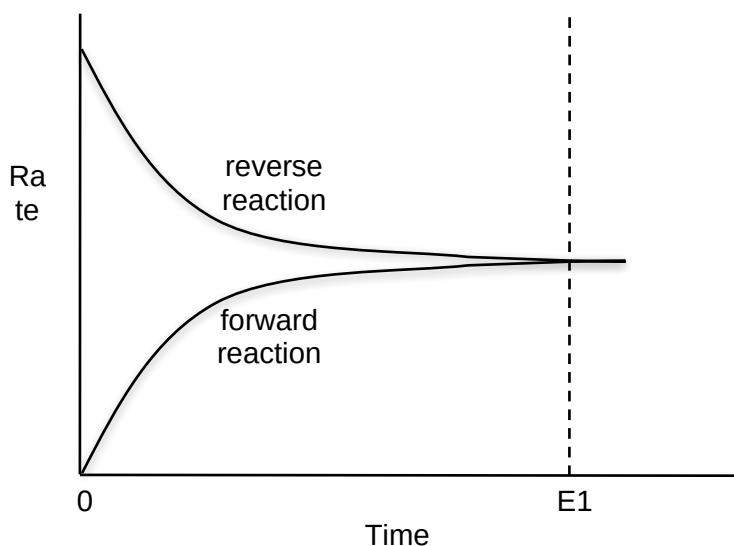
Which statements are **correct** regarding this graph?

(i)   At Time 0, the forward reaction rate is zero.
(ii)   At Time E1, the forward reaction rate is zero.
(iii)   From Time 0 to E1, the forward reaction rate is increasing.
(iv)   From Time 0 to E1, the reverse reaction rate is greater than the forward reaction rate.
(v)   At Time E1, the reverse reaction rate reaches a maximum.

(a)   (i), (ii) and (iv) only
(b)   (i), (iii) and (iv) only
(c)   (ii), (iv) and (v) only
(d)   (iii), (iv) and (v) only

End of Section One

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

This section has **8** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.

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: 60 minutes.

Question 26   **(7 marks)**

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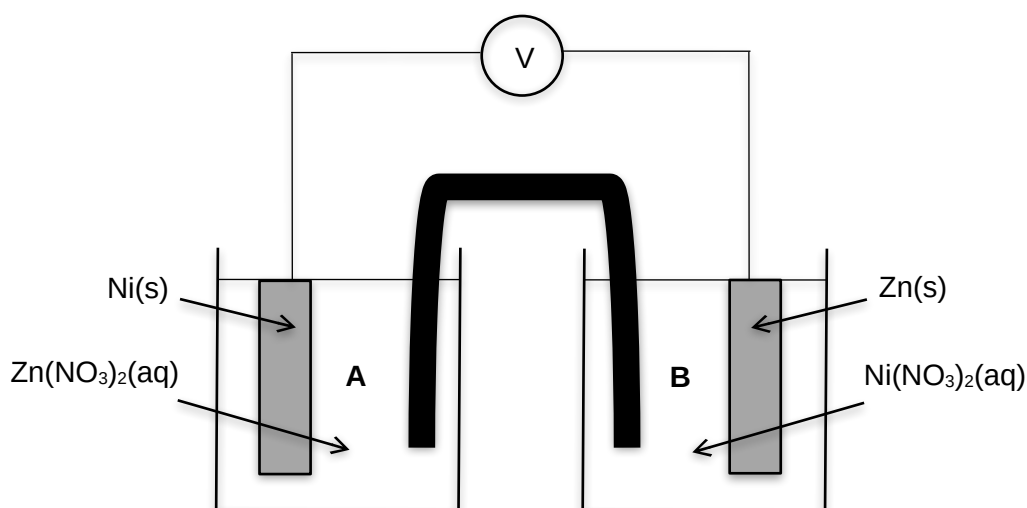
No voltage was recorded for this cell because it was incorrectly set up.

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

A	
B	

(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)

_____

_____

_____

_____

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)

_____

_____

(d)   What is the maximum EMF that could be recorded for this cell if it was operating under standard conditions?   (1 mark)

_____

_____

Question 27 **(10 marks)**

Read the following passage regarding the pH of soils.

Soil pH is a very important factor that contributes to the healthy growth of a plant. A soil pH that is too acidic or too alkaline can affect the ability of a plant to take up nutrients such as nitrogen, phosphorus and sulfur. There are many fertilisers and other chemicals that can be added to soils to alter the pH to the desired level.

Potash, which contains potassium chloride (KCl), increases the water uptake of a plant and improves the yield of a crop.

Many fertilisers contain nitrogen and phosphorus in the form of compounds such as ammonium nitrate (NH_4NO_3) or calcium dihydrogenphosphate ($Ca(H_2PO_4)_2$). These are used to improve the growth and health of plants.

Many farmers also add agricultural lime to their soil, which consists of pulverised limestone ($CaCO_3$), to decrease water runoff.

(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.

_____

_____

_____

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

_____

_____

_____

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)

_____

_____

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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.

$$H\textit{Ind}(aq) \ + \ H_2O(l) \ \rightleftharpoons \ \textit{Ind}^-(aq) \ + \ H_3O^+(aq)$$
$$\quad\text{red} \qquad\qquad\qquad \text{green}$$
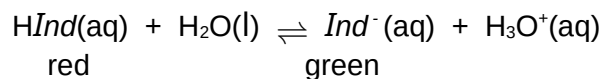
A few drops of red cabbage indicator were added to separate samples of 0.1 mol L⁻¹ HCl(aq) and 0.1 mol L⁻¹ NaOH(aq).

(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)

_____

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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)

(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)

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)

(d)   A small piece of potassium metal is placed in a large glass bowl filled with water. (2 marks)

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
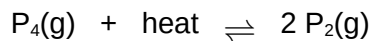   standard.   (2 marks)

        _____

        _____

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

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.

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

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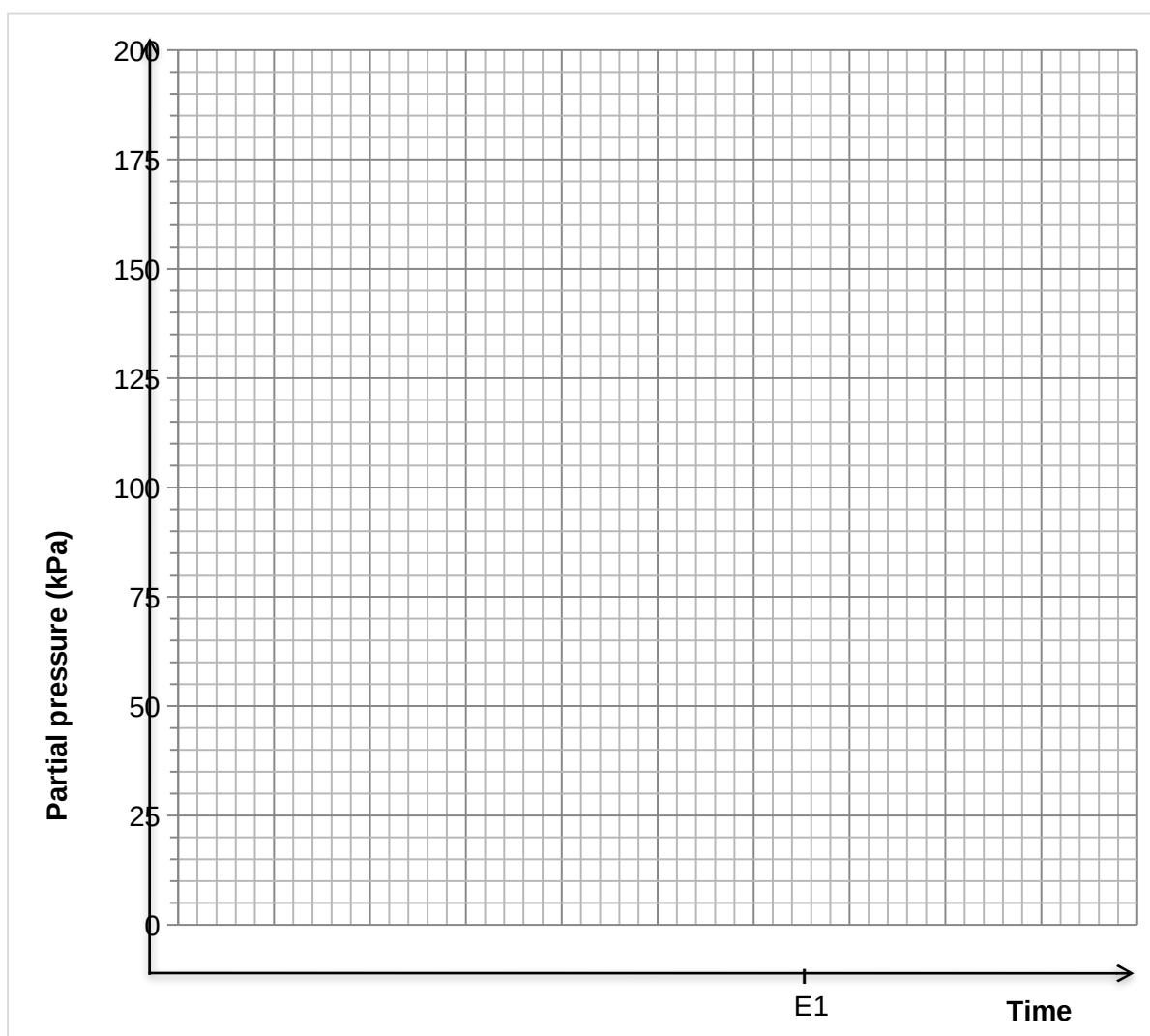
(b)   Write the equilibrium constant (K) expression for this reaction.   (1 mark)

(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		
Total volume increased		

Question 31   **(10 marks)**

The final stage of copper refining involves the electrochemical process illustrated below.
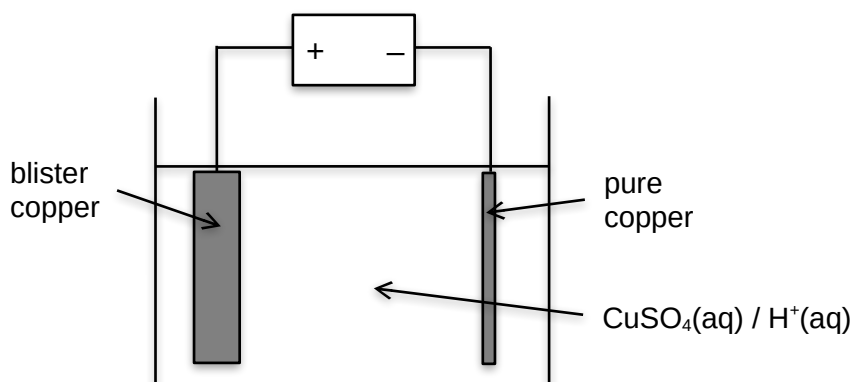
(a)   Write the overall equation for this electrochemical cell.   (1 mark)

(b)   Is this a galvanic or electrolytic cell? Justify your answer.   (2 marks)

(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)

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)

_____

_____

_____

_____

_____

Question 32 **(9 marks)**

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

$HNO_2(aq)$ / $H_2O(l)$	$HCl(aq)$ / $NaCl(aq)$	$NaCl(aq)$ / $H_2O(l)$	$HNO_2(aq)$ / $KNO_2(aq)$

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.

	Solution	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	
B	
C	
D	

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

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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		$E^0_{(red)}$ =
Anode half-equation		$E^0_{(ox)}$ =
Overall equation		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)

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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)

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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).

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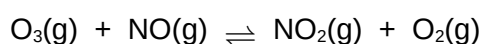
The reaction between ozone and nitric oxide is referred to as 'chemiluminescent' because it produces light. Whilst nitrogen dioxide is a brown gas, the other gases involved in this reaction are colourless.

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)

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Progress of reaction
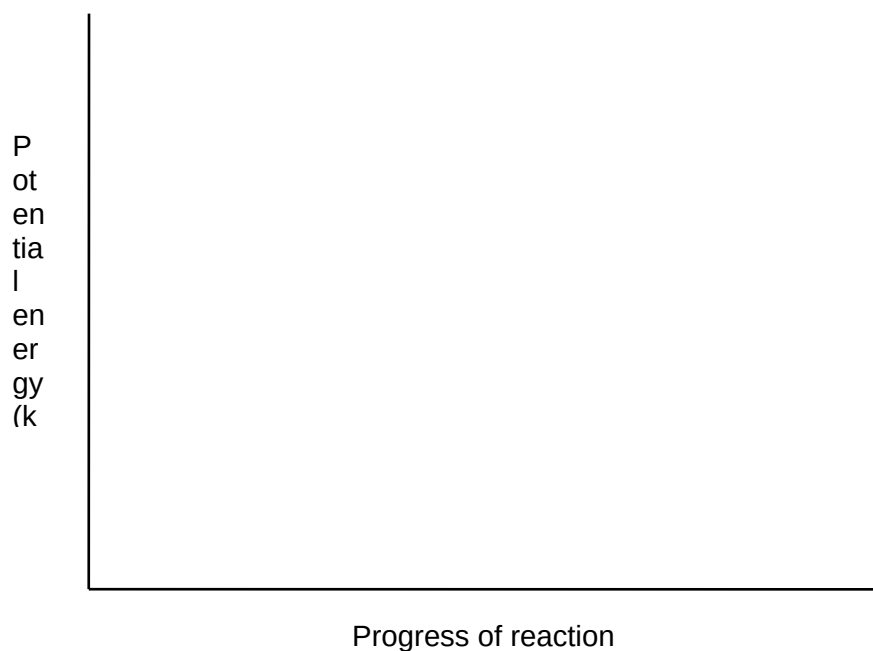
Considering the activation energy values provided;

(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)

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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.

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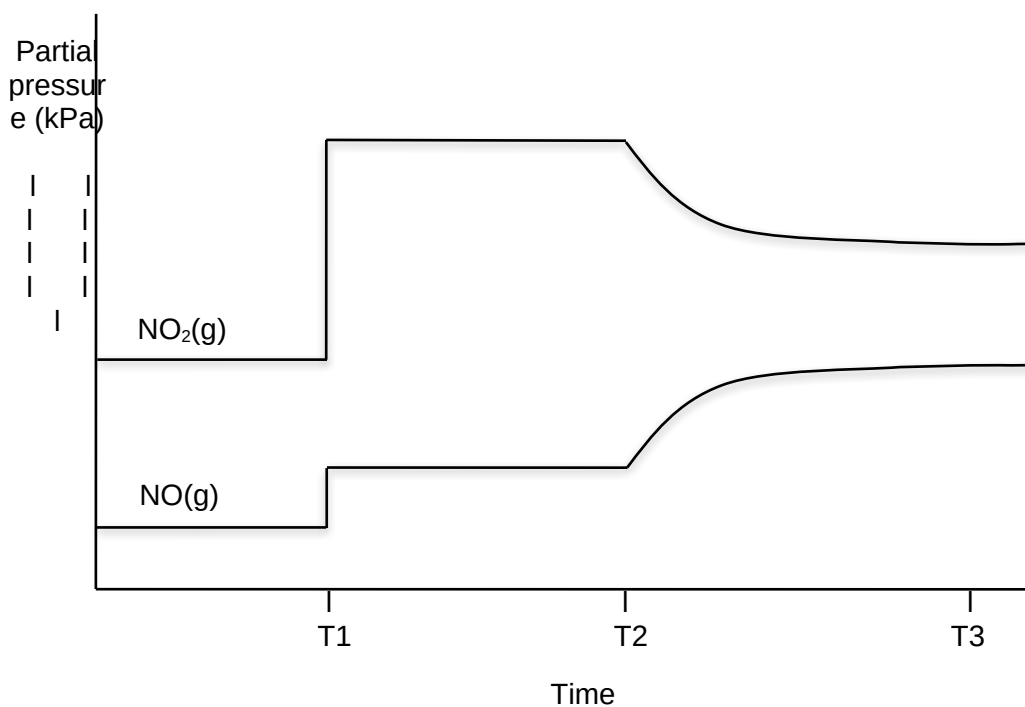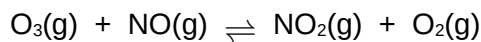
(c)   State the change imposed at T1. Give any corresponding observations.   (3 marks)

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

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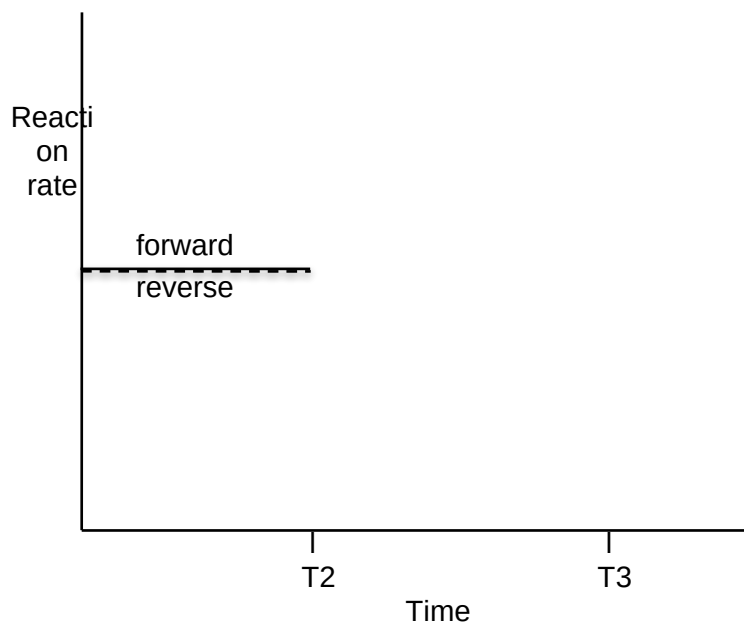
(f)   State **one other** change that could have been made to the system which would have resulted in the partial pressure changes observed (see original graph on previous page) between T2 and T3. Justify your answer.   (3 marks)

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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)

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

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)

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)

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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	
Reduction half-equation	

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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.
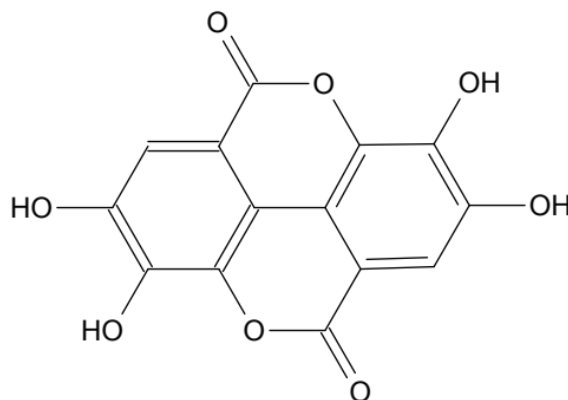
Ellagic acid is a tetraprotic acid.

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

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

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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)

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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.

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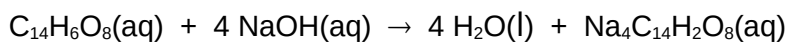
If the concentration of ellagic acid is known to be 40.06 mg per 100.0 g of raspberries;

(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)

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)

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(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)

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Question 37   **(16 marks)**
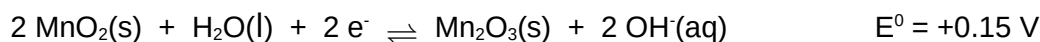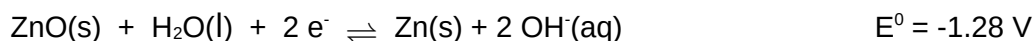
The alkaline battery (or alkaline cell) is so named due to the potassium hydroxide electrolyte used, which contrasts with the acidic electrolyte originally used in the older Leclanché-style cells. It is currently the most commonly produced type of battery worldwide.

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;

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

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

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

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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)

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

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

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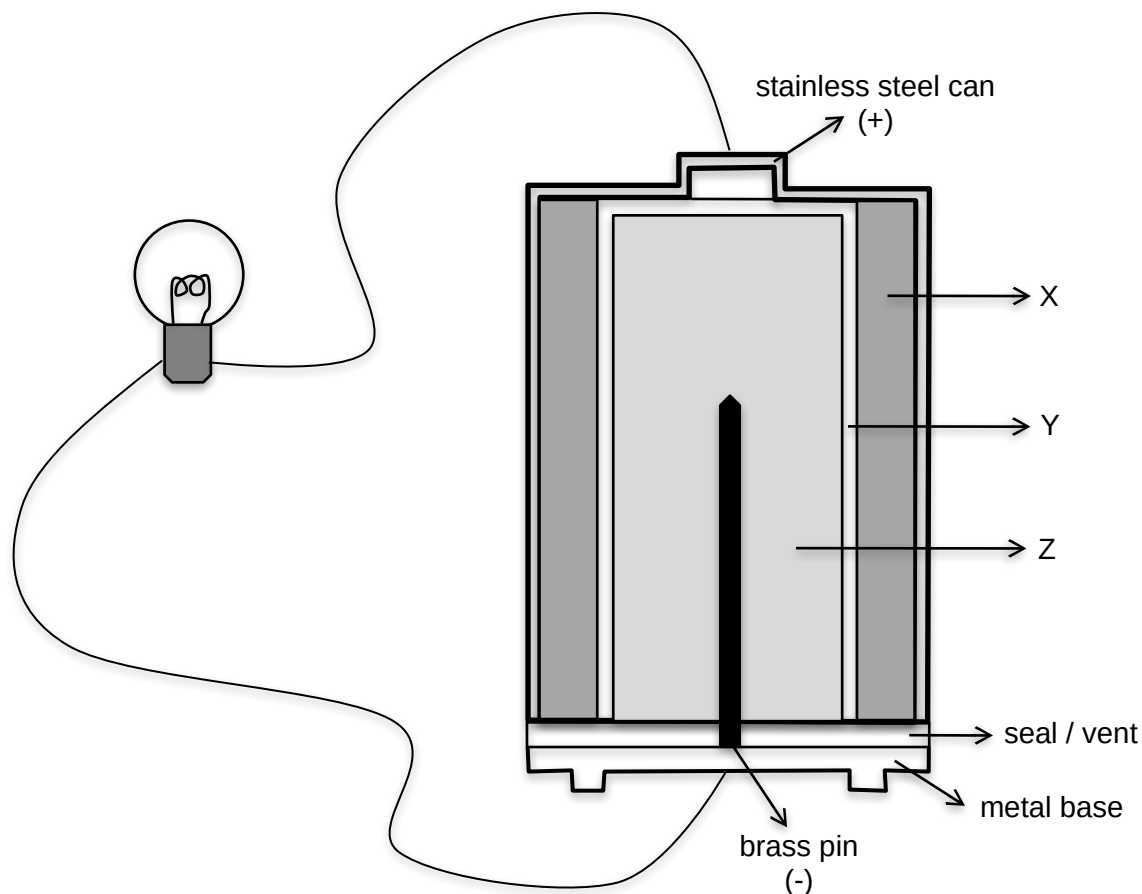
(e)   On the diagram, label the direction of electron flow.   (1 mark)

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

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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)

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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.

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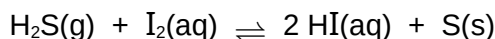
(a)   Write observations for this reaction.   (2 marks)

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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.
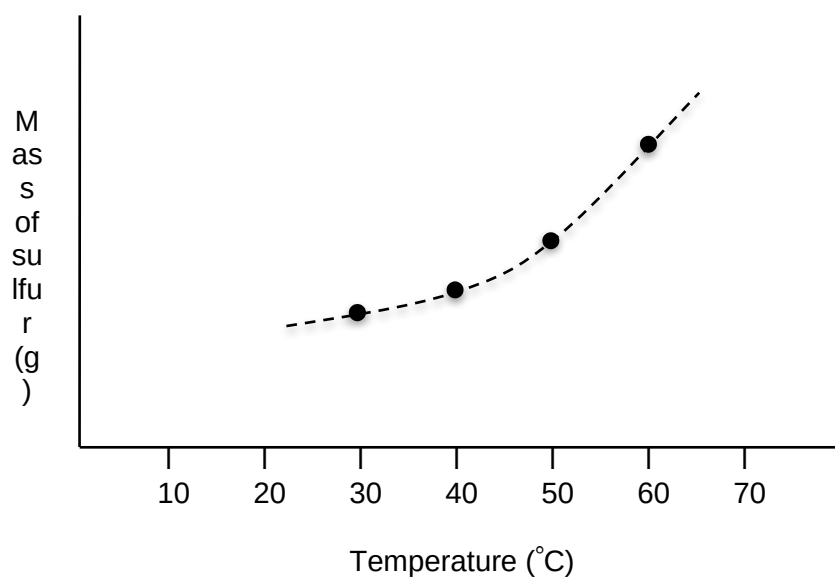

(b)   For the investigation described above state;   (4 marks)

    (i)   the independent variable

    (ii)   the dependent variable

    (iii)   two controlled variables

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

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.
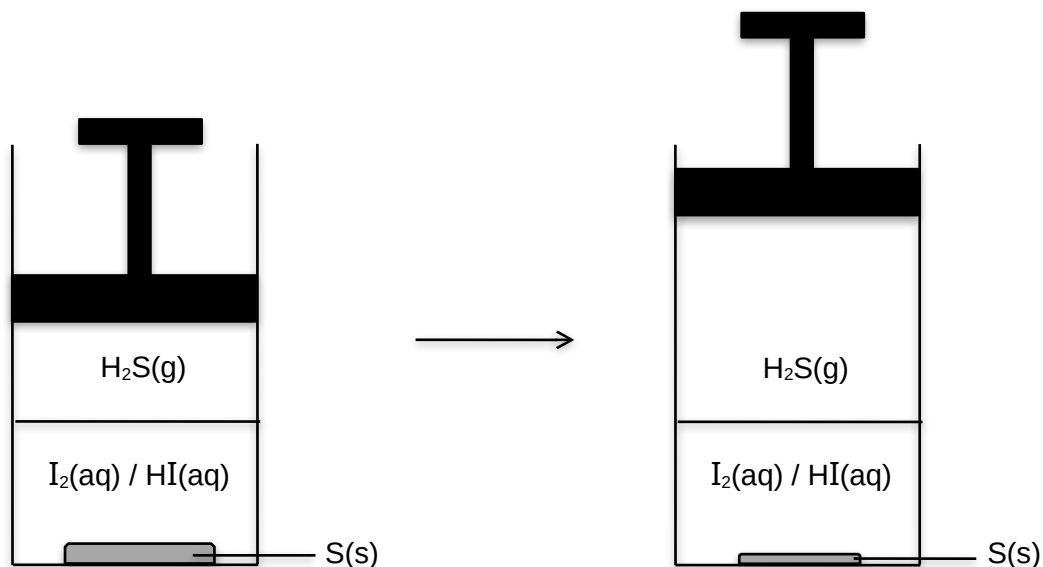
One student wrote the following conclusion in her laboratory book;

"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)

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End of questions

Spare answer page

Question number: _____