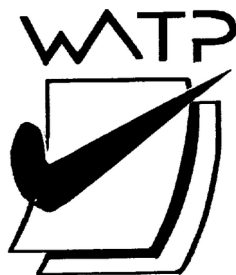


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CHEMISTRY

UNIT 3 & 4

2019

MARKING GUIDE

Section One: Multiple-choice

(50 marks)

1	a <input type="checkbox"/> b <input type="checkbox"/> c <input checked="" type="checkbox"/> d <input type="checkbox"/>
2	a <input type="checkbox"/> b <input checked="" type="checkbox"/> c <input type="checkbox"/> d <input type="checkbox"/>
3	a <input type="checkbox"/> b <input type="checkbox"/> c <input checked="" type="checkbox"/> d <input type="checkbox"/>
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11	a <input checked="" type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d <input type="checkbox"/>
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16	a <input type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d <input checked="" type="checkbox"/>
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19	a <input type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d <input checked="" type="checkbox"/>
20	a <input checked="" type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d <input type="checkbox"/>

(2 marks per question)

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.

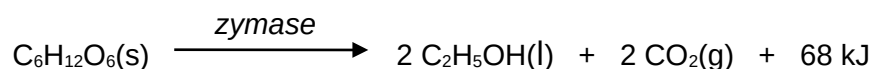
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- 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.

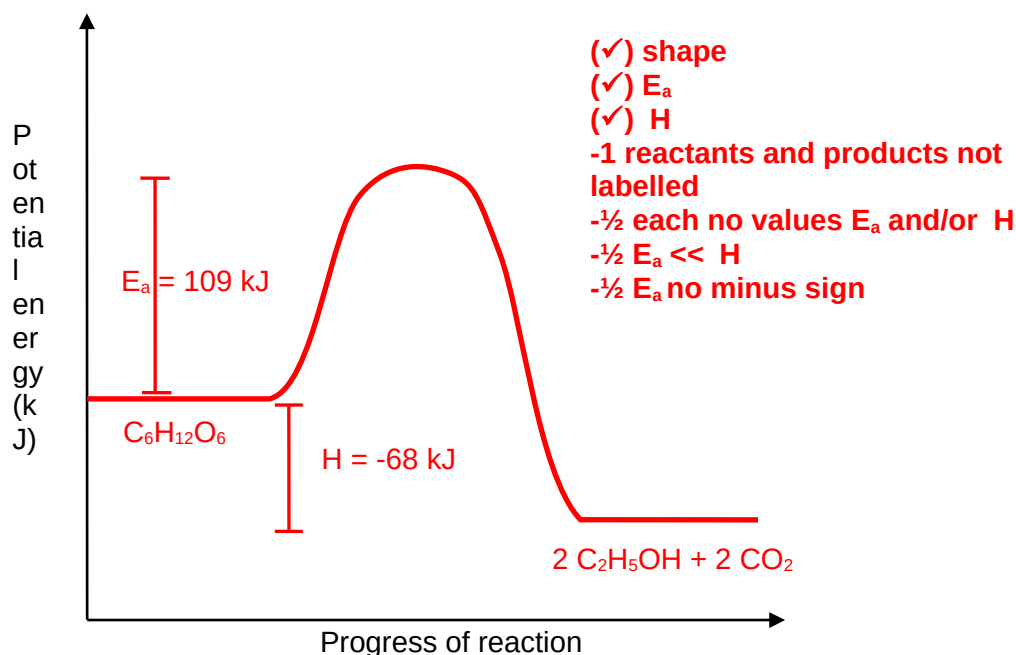
Question 26**(12 marks)**

The production of ethanol by fermentation of glucose in the presence of the enzyme *zymase* can be represented by the chemical equation below.



The activation energy for this reaction is 109 kJ.

- (a) Sketch a labelled energy profile diagram for this reaction. Label the heat of reaction and the activation energy. (3 marks)

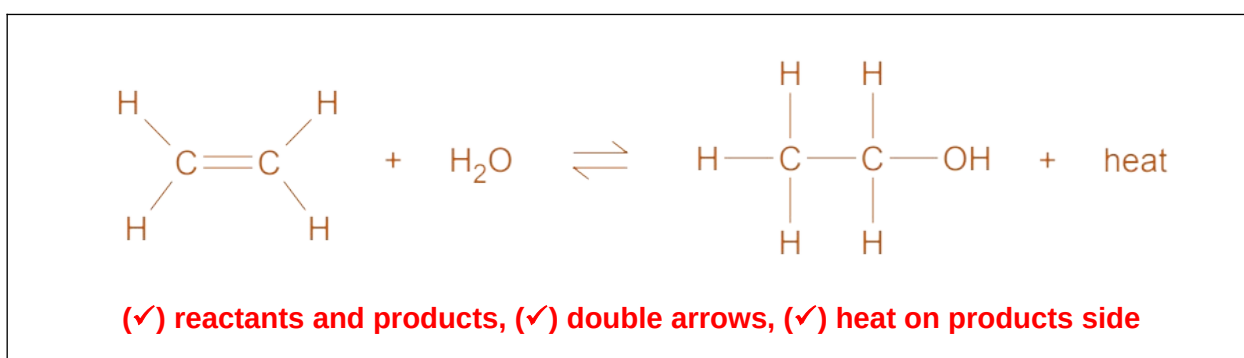


- (b) What is an enzyme? Briefly describe the function of an enzyme in terms of the collision theory. (3 marks)

- Enzymes are biological catalysts which increase reaction rate (✓)
- They provide an alternate reaction pathway with a lower activation energy (✓)
- Therefore, a greater proportion of particles have sufficient kinetic energy to reach activation energy and so frequency of successful collisions increases (which increases reaction rate) (✓)

An alternate method for producing ethanol involves the addition reaction of an alkene. This reaction is reversible and exothermic in the forward direction.

- (c) Write a balanced chemical equation for this reaction. Use full structural formula for any organic substances and include the heat of reaction. (3 marks)

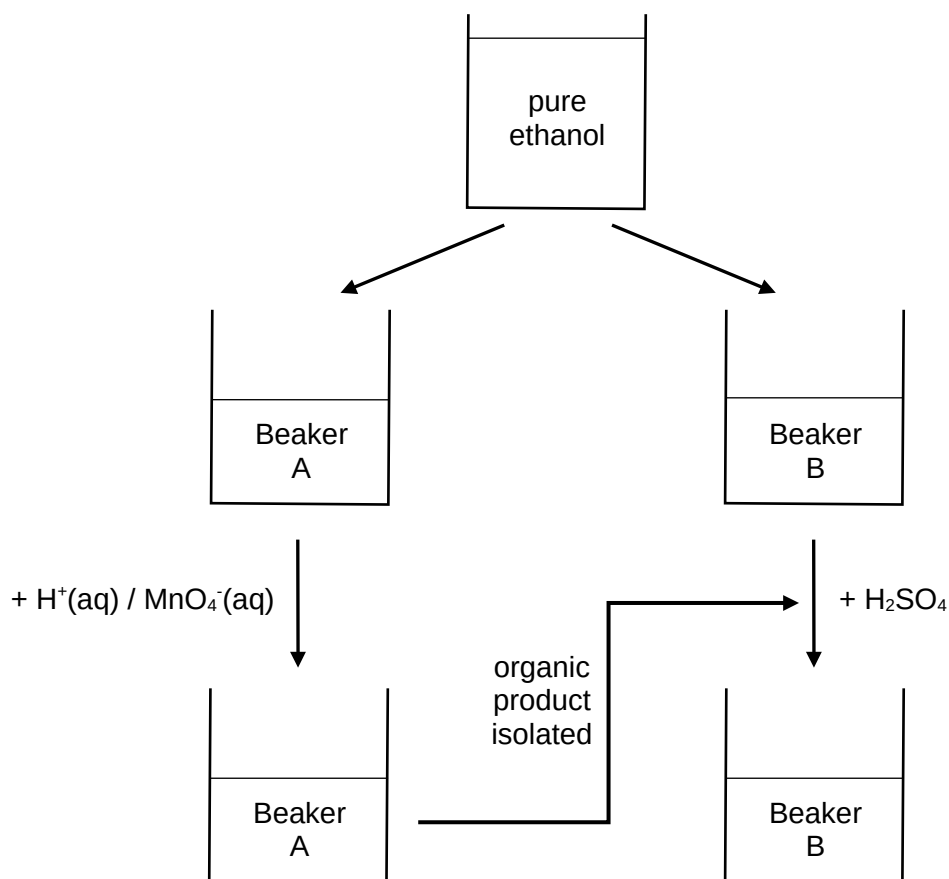


Industrially, the addition reaction that produces ethanol is carried out under acidic conditions, in the presence of phosphoric acid.

- (d) Considering the principles of green chemistry, state one advantage of using an enzyme catalyst rather than a phosphoric acid catalyst. (1 mark)

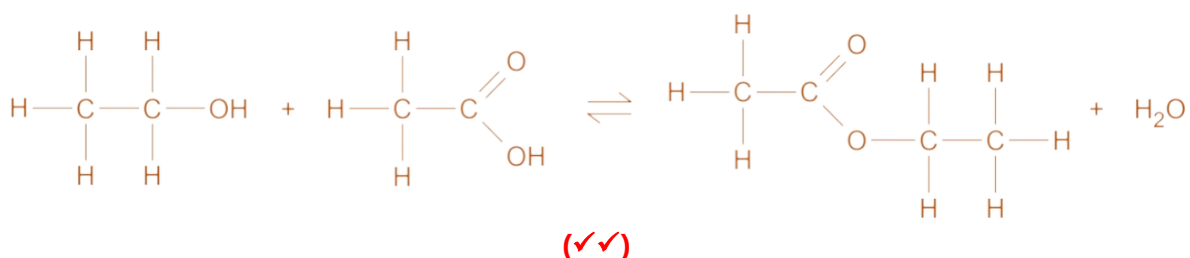
- Less hazardous chemical synthesis / safer chemicals and products / minimise potential for accidents / safer solvents and reaction conditions / increase energy efficiency (lower temperature and pressure requirements) (✓ any one)

A sample of pure ethanol was collected and divided into two beakers, A and B.



Some acidified potassium permanganate was added to Beaker A, and the reaction was allowed to proceed to completion. The organic product from this reaction was then isolated and added into Beaker B, along with a few drops of concentrated sulfuric acid. Beaker B was gently warmed.

(e) Write a balanced chemical equation for the reaction occurring in beaker B. (2 marks)



Question 27

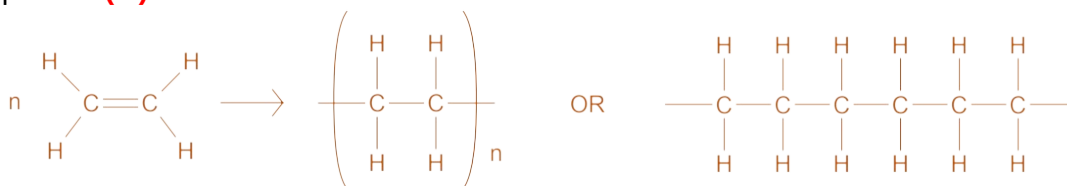
(6 marks)

Polyethene is the world's most common plastic and accounts for approximately one third of the total plastic produced globally each year.

- (a) Discuss the polymerisation process by which polyethene forms. Include a chemical equation in your answer. (3 marks)

- This is an addition polymerisation where double bonds in the monomer units are broken, forming single bonds (✓)
- Monomers link together to form long repeating polymer chains (✓)

Equation: (✓)



The melting points of two common forms of the polymer, low density polyethene (LDPE) and high density polyethene (HDPE), are shown below.

	LDPE	HDPE
Melting point range	105-115 °C	120-180 °C

- (b) Explain the difference in melting point of LDPE and HDPE. (3 marks)

- LDPE has (more) branches compared to the relatively straight chained HDPE which means the molecules can't pack together as closely / there is less surface area contact between the molecules (✓)
- This results in weaker dispersion forces in LDPE compared to HDPE (✓, -½ if only mentions intermolecular forces)
- This requires less energy to overcome and so possesses a lower melting point than HDPE (✓)

(Must compare to HDPE at least once to gain full marks otherwise -1)

OR

- HDPE consists of long unbranched chains which means the molecules can pack together closely / there is more surface area contact between the molecules compared to the more branched LDPE (✓)
- This results in stronger dispersion forces in HDPE compared to LDPE (✓, -½ if only mentions intermolecular forces)
- This requires more energy to overcome and so possesses a higher melting point than LDPE (✓)

(Must compare to LDPE at least once to gain full marks otherwise -1)

Question 28**(12 marks)**

Consider the data regarding the four hydrohalic acids in the table below.

Hydrohalic acid	Formula	K_a
Hydrofluoric acid	HF(aq)	6.6×10^{-4}
Hydrochloric acid	HCl(aq)	approx. 1.0×10^6
Hydrobromic acid	HBr(aq)	approx. 1.0×10^9
Hydroiodic acid	HI(aq)	approx. 1.0×10^{10}

- (a) Write the K_a expression for hydroiodic acid. (1 mark)



- (b) Considering all of the K_a values given in the table, classify HI as a strong or weak acid. Justify your answer. (3 marks)

- A large K_a indicates a greater proportion of products rather than reactants (\checkmark)
- A strong acid has a high concentration of H_3O^+ (or a greater degree of ionisation) (\checkmark)
- HI is, therefore, a strong acid (\checkmark)

All of the hydrohalic acids are classified as monoprotic acids.

- (c) Define the term 'monoprotic'. (1 mark)

- Contains one acidic / ionisable hydrogen per molecule OR donates one proton per molecule (\checkmark)

(Do not accept contains only one hydrogen/proton... CH_3COOH is monoprotic but contains 4 Hs, etc)

- (d) Select an appropriate acid from the table and describe how a buffer solution could be produced using this acid. Your answer should include; (7 marks)
- the definition of a buffer solution
 - a brief description of how the buffer solution would be made
 - the chemical equation for the buffer solution
 - a brief description, using Le Chatelier's principle, of how the buffer solution would respond to the addition of a small volume of 0.1 mol L^{-1} nitric acid (noting that equations are not required).
- A buffer is an aqueous solution that is a mixture of a weak acid and conjugate base (or weak base and conjugate acid) (✓)
- It resists a change in pH upon addition of small volumes of acid / base (✓)
- Add 1 mol L^{-1} HF to 1 mol L^{-1} NaF solution (the concentration of NaF should be equal or similar to the concentration of HF and relatively high) (✓)
- $\text{HF} + \text{H}_2\text{O} \rightleftharpoons \text{F}^- + \text{H}_3\text{O}^+$ OR $\text{HF} + \text{OH}^- \rightleftharpoons \text{F}^- + \text{H}_2\text{O}$ (✓)
- Adding HNO_3 increases the $[\text{H}_3\text{O}^+]$ (✓)
- Equilibrium shifts left/favours the reverse reaction to reduce the increased $[\text{H}_3\text{O}^+]$ (i.e. counteract change imposed). (✓)
- This then reduces the $[\text{H}_3\text{O}^+]$ so that it almost returns to its original concentration and in doing so maintains the pH (✓)
- 1 mark if used HI or HBr or HCl but follow through with marking.

Question 29**(7 marks)**

Write balanced chemical equations which represent each of the procedures described below. Include state symbols, i.e. (s), (l), (g) and (aq), in your answer.

- (a) A few drops of acidified sodium dichromate solution are added to a test tube containing colourless propan-2-ol. (2 marks)

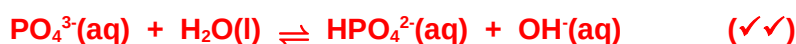


Overall:



(✓✓) final equation, -1 if minor mistake such as equilibrium arrow, states missing/incorrect, etc

- (b) A sample of solid potassium phosphate was dissolved in a beaker of distilled water. When 2 drops of universal indicator were added the solution turned a blue colour. (3 marks)



-1 if minor mistake such as one way arrow, states missing/incorrect, etc
If combined



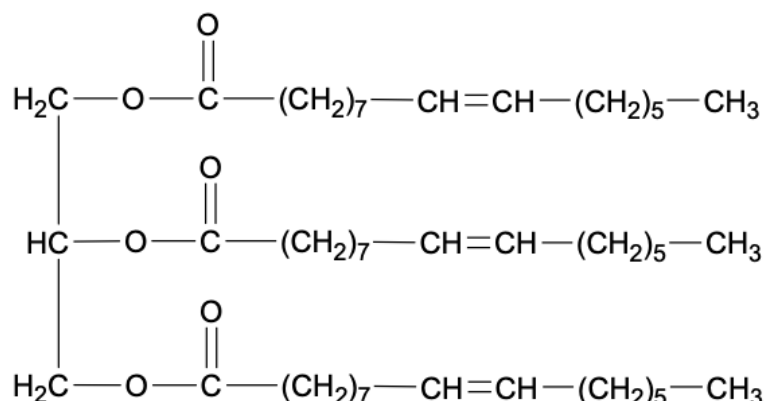
- (c) A piece of nickel metal was placed into a beaker containing a solution of zinc nitrate. (2 marks)

No observable change

Question 30

(6 marks)

Consider the triglyceride shown below.



- (a) Complete the table below, showing how this triglyceride can be converted into soap. Give the name or formula of the reactant that can be added to the triglyceride to form soap and draw the structure of the resulting soap formed. (3 marks)

Name or formula of reactant to be added	Sodium hydroxide, NaOH (OR KOH etc) (✓)
Structural diagram of soap	<p>$\text{CH}_3 - (\text{CH}_2)_5 - \text{CH} = \text{CH} - (\text{CH}_2)_7 - \text{COO}^- \text{Na}^+$</p> <p>(✓✓)</p> <p>Note: structure can be given with or without cation. -1 if minor error such as one incorrect H, covalent bond shown between COO and Na etc</p>

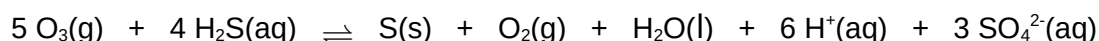
- (b) Complete the table below, showing how this triglyceride can be converted into biodiesel. Give the name or formula of the reactant that can be added to the triglyceride to form biodiesel and draw the structure of the resulting biodiesel formed. (3 marks)

Name or formula of reactant to be added	Methanol, CH₃OH (OR ethanol / propanol etc) (✓)
Structural diagram of biodiesel	<p>$\text{CH}_3 - (\text{CH}_2)_5 - \text{CH} = \text{CH} - (\text{CH}_2)_7 - \text{COOCH}_3$</p> <p>(✓✓)</p> <p>Note: if ethanol/propanol used, alkyl group must correspond. -1 if minor error such as one incorrect H, no double bond shown etc</p>

Question 31

(12 marks)

Consider the following closed system which is at equilibrium.



- (a) Write the equilibrium constant expression for this reaction. (2 marks)

$$K = \frac{[\text{O}_2] [\text{H}^+]^6 [\text{SO}_4^{2-}]^3}{[\text{O}_3]^5 [\text{H}_2\text{S}]^4}$$

(✓✓)

-1 if minor error such as one incorrect index

- (b) When changes are imposed to this equilibrium system, describe and justify how the direction of the equilibrium shift could be **visibly observed**. (2 marks)

- Equilibrium shift to the right would be evidenced by an increase in solid yellow mass (✓)
- Equilibrium shift to the left would be evidenced by a decrease in solid yellow mass (✓)

(✓ for suggesting 'increased/decreased effervescence/production of gas' with correct left (more effervescence) and right (less effervescence) description)

- (c) Consider the effect of imposing the following changes on the system. Complete the table below by stating;
- in which direction, if any, an equilibrium shift would occur, and
 - how the forward reaction rate will differ from the original equilibrium once the new equilibrium has been re-established. (4 marks)

	Equilibrium shift (left, right, no change)	Rate of forward reaction (increase, decrease, no change)
distilled H ₂ O is added to the system	Right (✓)	Decrease (✓)
volume of system is decreased (at constant temperature)	Right (✓)	Increase (✓)

A small volume of 2 mol L⁻¹ sodium sulfate, Na₂SO₄, solution was added to the original equilibrium.

- (d) Explain, in terms of the collision theory and reaction rates, the effect this change would have on the equilibrium position. (4 marks)

- Adding Na₂SO₄ increases the concentration of SO₄²⁻ (✓)
- This causes increased frequency of collisions between product particles/ particles on the left of the equilibrium (✓)
- This initially increases the rate of the reverse reaction relative to the forward reaction shifting the equilibrium left (✓)
- The forward reaction rate then begins to increase until the new equilibrium is established (✓)

Question 32

(6 marks)

When solid red phosphorus, P(s), is mixed with sodium chlorite solution, NaClO₂(aq), this results in the formation of the aqueous salt disodium pyrophosphate, Na₂H₂P₂O₆, in addition to hydrochloric acid.

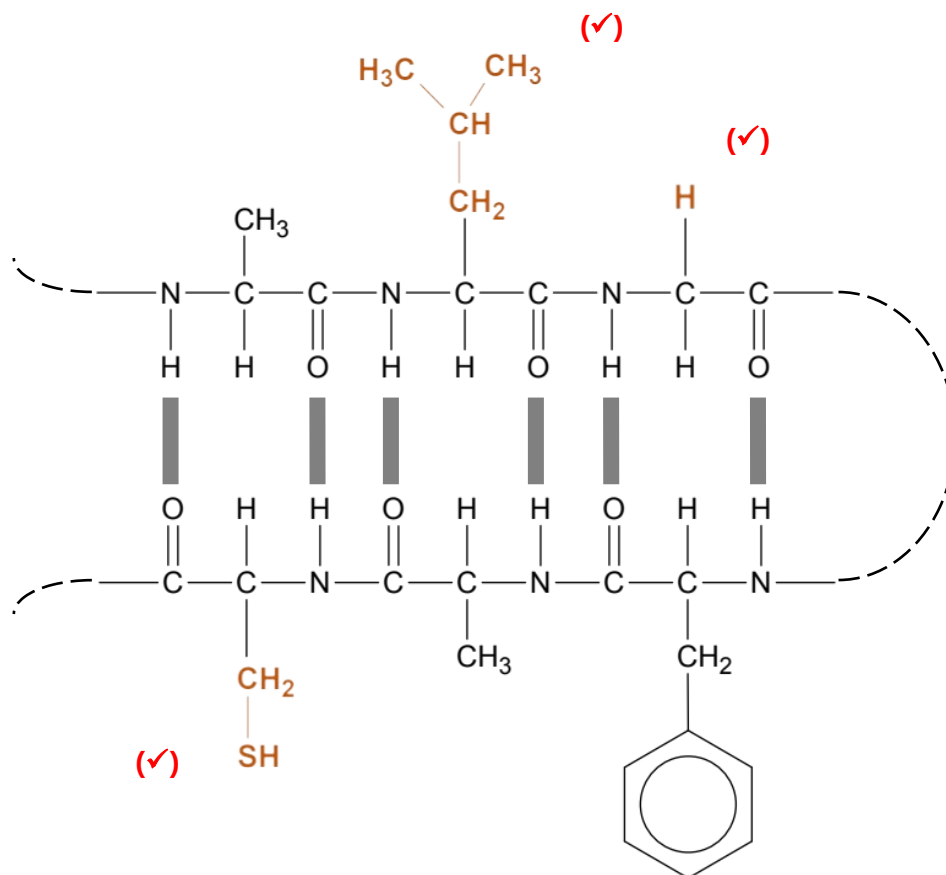
Write the oxidation and reduction half-equations, and an overall balanced redox equation for this reaction.

Oxidation half-equation	$2\text{P(s)} + 6\text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{P}_2\text{O}_6^{2-}(\text{aq}) + 10\text{H}^+(\text{aq}) + 8\text{e}^-$ (✓✓)
Reduction half-equation	$(\text{ClO}_2^-(\text{aq}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow \text{Cl}^-(\text{aq}) + 2\text{H}_2\text{O(l)}) \times 2$ (✓✓) IF $\text{ClO}_2^-(\text{aq}) + 5\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow \text{HCl(aq)} + 2\text{H}_2\text{O(l)}$ (✓)
Overall redox equation	$2\text{P(s)} + 2\text{H}_2\text{O(l)} + 2\text{ClO}_2^-(\text{aq}) \rightarrow \text{H}_2\text{P}_2\text{O}_6^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{Cl}^-(\text{aq})$ (✓✓) OR FT $2\text{P(s)} + 2\text{H}_2\text{O(l)} + 2\text{ClO}_2^-(\text{aq}) \rightarrow \text{H}_2\text{P}_2\text{O}_6^{2-}(\text{aq}) + 2\text{HCl(aq)}$ (✓✓)

Question 33

(9 marks)


Consider the **partially** drawn protein fragment below.



- (a) The **partially** completed primary sequence of this protein fragment is given below. Complete the primary sequence. (3 marks)

ala – leu – gly – – – – – **phe** – **ala** – cys (✓ each)

- (b) Complete the drawing of the protein fragment in the diagram above. (3 marks)

Part of the structure of this protein is formed because of the bonds represented by  on the diagram above.

- (c) Do these bonds represent a secondary or tertiary structure? Justify your answer. (3 marks)

- **secondary (beta pleated sheet) (✓)**
- **the hydrogen bonding is between all amino and carbonyl groups (or C=O and H-N) of the polypeptide backbone (✓)**
- **rather than the side chains of the amino acids (as in tertiary) (✓)**

End of Section Two

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.

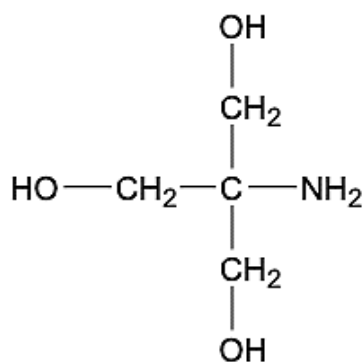
- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 70 minutes.

Question 34**(18 marks)**

The compound tris(hydroxymethyl)aminomethane is generally referred to by its common name 'Tris'. It is a white, crystalline, water-soluble powder.

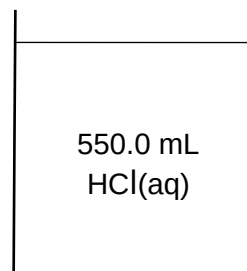
The molecular formula for Tris is $C_4H_{11}NO_3$ and the structural formula is shown below.



Tris is a primary amine and therefore a weak base. It is frequently found as a component of buffers used in molecular biology labs.

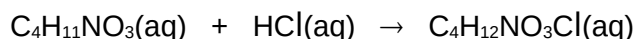
Tris can also function as a primary standard in acid-base titrations.

Some chemistry students found a large beaker on the bench in their laboratory. The beaker contained 550 mL of solution and was labelled HCl(aq). The students decided to determine the concentration of the acid by titrating it against a standardised solution of 0.08482 mol L⁻¹ Tris.



The students took a 20.00 mL sample of the HCl(aq) and diluted it to 250.0 mL in a volumetric flask. They then titrated 25.00 mL aliquots of the diluted HCl(aq) solution and found an average titre of 32.47 mL of Tris was required for equivalence.

The titration equation is given below.



- (a) Name an appropriate indicator for use in this titration. Justify your choice, using a relevant chemical equation to support your answer. (3 marks)

- Methyl orange/bromophenol blue (✓)
- $\text{C}_4\text{H}_{12}\text{NO}_3^+(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{C}_4\text{H}_{11}\text{NO}_3(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ (Cl⁻ is neutral) (✓)
- Equivalence point is in acidic region as $[\text{H}_3\text{O}^+] > [\text{OH}^-]$. Methyl orange has end point in the acidic region. (✓)

- (b) Calculate the concentration of the undiluted HCl(aq) in the beaker. State your answer to the appropriate number of significant figures. (6 marks)

$$\begin{aligned} n(\text{Tris}) &= cV \\ &= 0.08482 \times 0.03247 \\ &= 0.002754105 \text{ mol (✓)} \end{aligned}$$

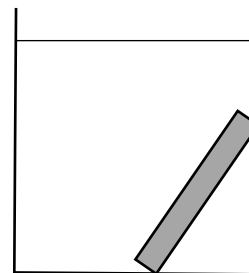
$$n(\text{HCl in 25 mL}) = 0.002754105 \text{ mol (✓)}$$

$$\begin{aligned} n(\text{HCl in 250 mL}) &= 0.002754105 \times 250/25 & \text{OR} & & [\text{HCl}]_{\text{dilute}} &= 0.002754105/25.00 \times 10^{-3} \\ &= 0.027541054 \text{ mol (✓)} & & & &= 0.1101642 \text{ mol L}^{-1} \text{ (✓)} \end{aligned}$$

$$\begin{aligned} n(\text{HCl in 25 mL}) &= n(\text{HCl in 250 mL}) & [\text{HCl}]_{\text{initial}} &= 0.1101642 \times 250/20 \text{ (✓)} \\ &= 0.027541054 \text{ mol (✓)} & &= 1.3770527 \\ & & &= 1.377 \text{ mol L}^{-1} \text{ (4sf) (✓✓)} \end{aligned}$$

$$\begin{aligned} [\text{HCl}] &= 0.027541054 / 20.00 \times 10^{-3} \\ &= 1.3770527 \\ &= 1.377 \text{ mol L}^{-1} \text{ (4 sf) (✓✓)} \end{aligned}$$

After talking with the laboratory technician, the students learned that the original beaker of acid had **previously been used to dissolve and remove the scale, $\text{CaCO}_3(\text{s})$** , off a small section of pipe. The pipe had been soaked in the acid for 3 hours to remove all traces of scale, according to the reaction below.



By weighing the pipe before and after it was soaked in the acid, the laboratory technician was able to determine that the mass of scale removed from the pipe was $12.730 \pm 0.010 \text{ g}$.

- (c) Calculate the **maximum** concentration of the original $\text{HCl}(\text{aq})$, before the pipe had been placed into the solution. You may assume the entire mass of the scale was composed of $\text{CaCO}_3(\text{s})$ and the volume of the acid remained constant at 550.0 mL throughout. (6 marks)

$$\begin{aligned} m(\text{CaCO}_3 \text{ maximum}) &= 12.73 + 0.01 \\ &= 12.74 \text{ g } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{CaCO}_3) &= m / M \\ &= 12.74 / 100.09 \\ &= 0.127285443 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{HCl req. to remove scale}) &= 2 \times n(\text{CaCO}_3) \\ &= 2 \times 0.127285 \\ &= 0.254570886 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{HCl in 550 mL after soaking pipe}) &= cV \\ &= 1.377 \times 0.550 \\ &= 0.75735 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{HCl at start}) &= 0.254571 + 0.7573 \\ &= 1.011920886 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} c(\text{HCl before soaking}) &= n / V \\ &= 1.011948 / 0.550 \\ &= 1.839856156 \text{ mol L}^{-1} \\ &= 1.840 \text{ mol L}^{-1} \text{ (4 sf) } (\checkmark) \end{aligned}$$

The laboratory technician knew that the build-up of scale in the water pipes at school was most likely caused by hard water.

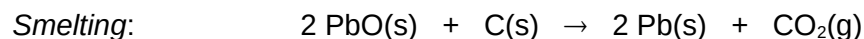
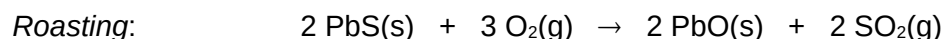
- (d) Define 'hard water' and explain why detergents are used in preference to soaps when cleaning in hard water (note that chemical equations are not required). (3 marks)

- High concentration of $\text{Ca}^{2+}/\text{Mg}^{2+}$ (\checkmark)
- Soaps react with $\text{Ca}^{2+}/\text{Mg}^{2+}$ to produce a precipitate (scum) which makes them ineffective (\checkmark)
- Detergents do not form a precipitate and so are still able to function and clean (\checkmark)

Question 35**(15 marks)**

Galena is one of the most common lead-containing ores. It is comprised of a large proportion of the mineral lead (II) sulfide, PbS, as well as small amounts of other metals such as silver, zinc, copper, bismuth, cadmium and antimony.

The extraction of lead from galena ore can be represented by the following equations.



The first step involves roasting the crushed galena in the presence of oxygen gas over a lengthy period of time, which results in conversion of lead (II) sulfide to lead (II) oxide. Following this, the lead (II) oxide is smelted to produce lead metal.

A particular sample of galena ore was found to contain 89.3% lead (II) sulfide. An 8.62×10^6 g quantity of this ore was crushed and roasted in a furnace where the pressure and temperature were maintained at 470.0 kPa and 540.0 °C respectively. Air was injected into the chamber at a rate of 1.75×10^5 L per hour, for a period of 18 hours. The air was comprised of 21.0% oxygen gas.

(a) Determine the limiting reagent for the 'roasting' step.

(8 marks)

$$\begin{aligned} m(\text{PbS}) &= (89.3/100) \times (8.62 \times 10^6) \\ &= 7.697660 \times 10^6 \text{ g } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{PbS}) &= (7.698 \times 10^6)/239.27 \\ &= 3.217143812 \times 10^4 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} V(\text{air}) &= (1.75 \times 10^5) \times 18 \\ &= 3150000 \text{ L } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{air}) &= (470 \times 3150000) / (8.314 \times 813.15) (\checkmark) \\ &= 2.189917354 \times 10^5 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{O}_2) &= n(\text{air}) \times 0.21 \\ &= 4.598826444 \times 10^4 \text{ mol } (\checkmark) \end{aligned}$$

Mole ratio

PbS		O₂
=	$3.217 \times 10^4 / 2$	= $4.599 \times 10^4 / 3$
=	$1.608571906 \times 10^4 \text{ mol } (\text{working } \checkmark)$	= $1.532942148 \times 10^4 \text{ mol}$

$\therefore \text{O}_2$ is limiting reagent as there is less present on a mole-to-mole basis. (\checkmark)

If 5.91 tonnes of lead metal was produced from this sample of galena;

- (b) Calculate the percentage yield of the overall process for this particular sample of ore. (4 marks)

$$\begin{aligned} n(\text{Pb theoretical}) &= \frac{2}{3} \times n(\text{O}_2) \\ &= \frac{2}{3} \times 45988.26444 \\ &= 3.065884296 \times 10^4 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} m(\text{Pb theoretical}) &= nM \\ &= 30658.84 \times 207.2 \\ &= 6.3525122561 \times 10^6 \text{ g } (\checkmark) \end{aligned}$$

$$\begin{aligned} \% \text{ yield} &= \frac{(5.91 \times 10^6 (\checkmark))}{6.3525 \times 10^6} \times 100 \\ &= 93.03405892 \% \\ &= 93.0 \% (3 \text{ sf}) (\checkmark) \end{aligned}$$

The waste sulfur dioxide gas produced by the roasting of galena ore can be used to make sulfuric acid via the Contact process. The process of converting sulfur dioxide gas into sulfuric acid can be represented by three chemical equations, one of which is given in the table below.

- (c) Write two (2) balanced chemical equations to complete the series of steps, illustrating the conversion of sulfur dioxide to sulfuric acid. (3 marks)

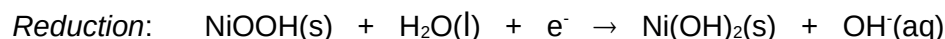
Step 1	$2 \text{ SO}_2(\text{g}) + \text{O}_2(\text{g}) \xrightleftharpoons{\text{V}_2\text{O}_5} 2 \text{ SO}_3(\text{g}) (\checkmark\checkmark)$
Step 2	$\text{SO}_3(\text{g}) + \text{H}_2\text{SO}_4(\text{l}) \rightarrow \text{H}_2\text{S}_2\text{O}_7(\text{l}) (\checkmark)$
Step 3	$\text{H}_2\text{S}_2\text{O}_7(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2 \text{ H}_2\text{SO}_4(\text{l})$

Question 36

(19 marks)

The nickel-iron battery was developed by Thomas Edison in the early 1900s. It is a rechargeable battery that was originally designed for use in electric vehicles. Though not common today, it is still used in some railway vehicles found in the London Underground and the New York City Subway.

The nickel-iron battery contains a nickel oxide-hydroxide electrode and an iron electrode. The relevant half-equations for the **discharge** of the cell are shown below.



The nickel-iron battery contains an alkaline electrolyte composed of a mixture of 240.0 g L^{-1} KOH(aq) and 50.0 g L^{-1} LiOH(aq) .

- (a) Calculate the pH of the electrolyte used in the nickel-iron battery. Assume a 1.00 L volume. (6 marks)

$$\begin{aligned} n(\text{KOH}) &= m / M \\ &= 240 / 56.108 \\ &= 4.277464889 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{LiOH}) &= m / M \\ &= 50 / 23.948 \\ &= 2.087857024 \text{ mol } (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{OH}^- \text{ total}) &= 4.277465 + 2.087857 \\ &= 6.365321913 \text{ mol } (\checkmark) \end{aligned}$$

$$[\text{OH}^-]_{\text{r}} = 6.365321913 \text{ mol L}^{-1} (\checkmark)$$

OR

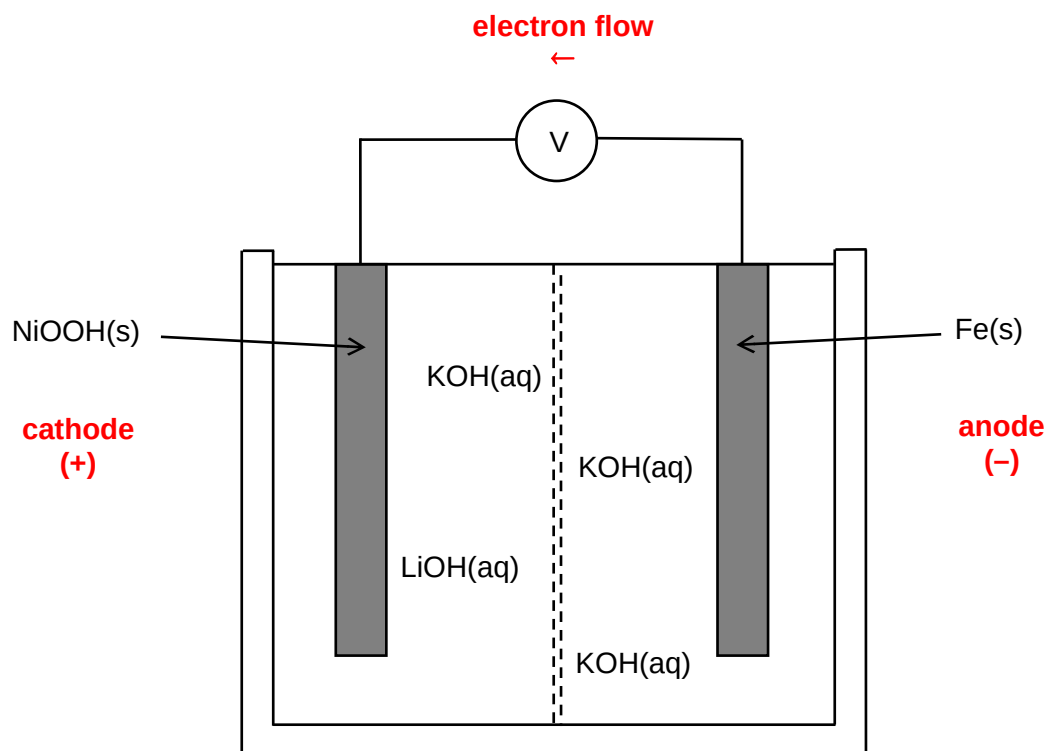
$$\begin{aligned} [\text{H}_3\text{O}^+] &= (1.0 \times 10^{-14}) / [\text{OH}^-] \\ &= (1.0 \times 10^{-14}) / 6.365322 \\ &= 1.571012451 \times 10^{-15} \text{ mol L}^{-1} (\checkmark) \end{aligned}$$

$$\begin{aligned} \text{pOH} &= -\log [\text{OH}^-] \\ &= -\log (6.365321913) \\ &= -0.803820372 (\checkmark) \end{aligned}$$

$$\begin{aligned} \text{pH} &= -\log [\text{H}_3\text{O}^+] \\ &= -\log (1.571 \times 10^{-15}) \\ &= 14.80382037 \\ &= 14.8 \text{ (3 sf)} (\checkmark) \end{aligned}$$

$$\begin{aligned} \text{pH} &= 14 - \text{pOH} \\ &= 14 - (-0.80382) \\ &= 14.80382037 \\ &= 14.8 \text{ (3 sf)} (\checkmark) \end{aligned}$$

Consider the following diagram of the nickel-iron battery.



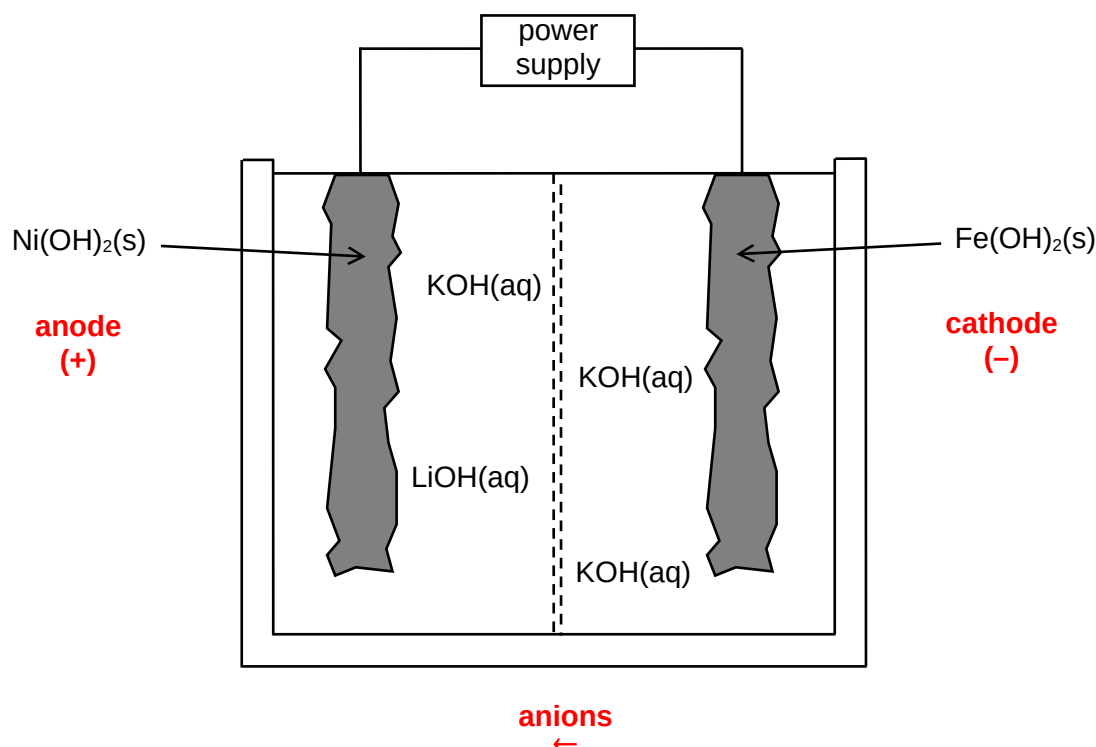
- (b) Label the
- anode and cathode (✓)
 - polarity (sign) of each electrode (✓)
 - direction of electron flow (✓)
- (3 marks)

As mentioned, the nickel-iron battery is rechargeable. One of the main modern uses of the nickel-iron battery is to store surplus electricity produced by solar panels and wind turbines. The surplus electricity causes the nickel-iron battery to recharge and the energy is then stored as chemical potential energy until required.

- (c) Write the overall equation for the recharging process. (2 marks)



Consider the following diagram of the nickel-iron battery, during the **recharging process**.



- (d) Label the
- anode and cathode (✓)
 - polarity (sign) of each electrode (✓)
 - direction of anion flow (✓)
- (3 marks)

Recent research has investigated the use of nickel-iron batteries as “battolysers”. This name refers to the ability of the cell to function as both a battery (galvanic cell) and an electrolyser (electrolytic cell).

- (e) Briefly describe the difference between a ‘galvanic cell’ and an ‘electrolytic cell’, in terms of the redox processes occurring. (2 marks)

- galvanic cells use a spontaneous redox reaction to produce electrical energy from chemical potential energy (✓ –½ no mention of spontaneous redox)
- electrolytic cells use electrical energy to drive a non-spontaneous redox reaction to produce chemical potential energy (✓ –½ no mention of non-spontaneous redox)

Once the nickel-iron battery is fully recharged, the overcharging process results in electrolysis of the water present in the electrolyte, producing hydrogen and oxygen gases. The half-equations for the production of hydrogen and oxygen gas are shown in the table below.

- (f) Complete the table, by naming the electrode (NiOOH or Fe) where each of these 'overcharging' reactions take place. (1 mark)

Half-equation	Electrode (NiOOH or Fe)
$2 \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{H}_2(\text{g}) + 2 \text{OH}^-(\text{aq})$	Fe
$4 \text{OH}^-(\text{aq}) \rightarrow \text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{e}^-$	NiOOH

(✓ all or nothing)

The ability of the nickel-iron battery to be discharged, recharged and produce hydrogen and oxygen gas by electrolysis, has resulted in research into its potential use in fuel cell cars.

- (g) State **two** differences between fuel cells and primary/secondary cells. (2 marks)

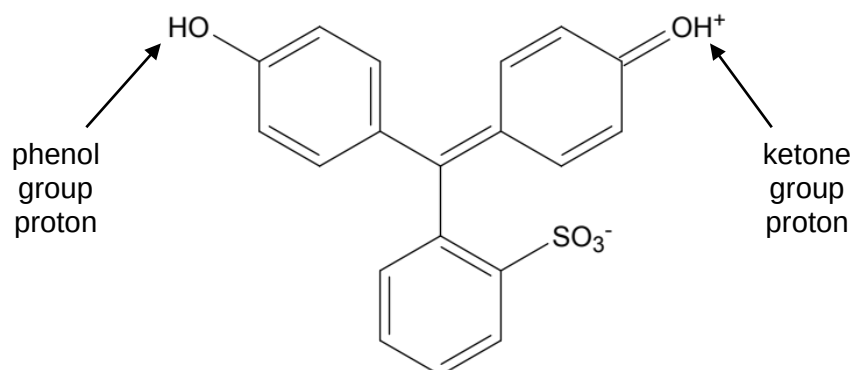
- Fuel cell requires continuous external supply of reactants, primary/secondary cells do not (✓)
- Fuel cells produce a constant voltage, voltage in primary/secondary cells drops over time (✓)
- etc

(any 2 appropriate statements but must refer to both fuel cell and primary/secondary cells to get full mark)

Question 37

(15 marks)

Phenol red is a pH indicator commonly used in molecular biology laboratories. When found as a crystalline solid, the molecular formula of phenol red is $C_{19}H_{14}O_5S$ and the structure is shown below.



When solid, and in solution below pH 1.2, phenol red exists in zwitterion form, as shown in the diagram above. In this case, the compound appears as red crystals or an orange-red solution.

Once the pH of a solution containing phenol red rises above 1.2, the proton from the ketone group is lost, and the colour of the solution becomes yellow.

If the pH is raised higher still, to a level greater than 7.7, a second proton is lost from the phenol group. This causes the colour of the indicator to change again, to a bright pink (fuchsia).

- (a) What is a 'zwitterion'? State how the physical appearance of phenol red, as a crystalline solid, is related to its existence in zwitterion form. (2 marks)

- A zwitterion is a species with both a positive and negative charge but no/neutral overall charge (✓)
- It is a crystalline structure due to presence of ionic bonding (✓)

- (b) Use the information given to complete the table below regarding the three forms of phenol red indicator. (2 marks)

	Molecular formula
pH < 1.2	$C_{19}H_{14}O_5S$
$1.2 < \text{pH} < 7.7$	$C_{19}H_{13}O_5S^-$
pH > 7.7	$C_{19}H_{12}O_5S^{2-}$

One of the three forms of phenol red was isolated and analysed as follows.

A 1.232 g sample of the indicator was combusted in pure oxygen and produced 2.908 g of carbon dioxide gas and 0.4385 g of water vapour. A **separate** 2.198 g sample of the indicator was treated to convert all the sulfur to sulfur dioxide gas. This produced 170.0 mL of sulfur dioxide, which was collected at a pressure of 132.0 kPa and temperature of 435.15 K.

- (c) Determine the empirical formula of this sample. **Identify which form** of phenol red has been isolated and state the colour it would appear in solution. Full working must be shown. (11 marks)



$$\begin{aligned} n(\text{CO}_2) &= 2.908/44.01 \\ &= 0.066075891 \text{ mol} = n(\text{C}) (\checkmark) \end{aligned}$$

$$\begin{aligned} \% \text{ C} &= ((0.066 \times 12.01)/1.232) \times 100 \\ &= 64.41326794 \% (\checkmark) \end{aligned}$$

$$\begin{aligned} n(\text{H}_2\text{O}) &= 0.4385/18.016 \\ &= 0.024339476 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{H}) &= 2 \times n(\text{H}_2\text{O}) \\ &= 0.048678952 \text{ mol} (\checkmark) \end{aligned}$$

$$\begin{aligned} \% \text{ H} &= ((0.0487 \times 1.008)/1.232) \times 100 \\ &= 3.982823349 \% (\checkmark) \end{aligned}$$

$$\begin{aligned} \text{C}_x\text{H}_y\text{O}_z\text{S}_w &\rightarrow \text{WSO}_2 \\ n(\text{SO}_2) &= PV / RT \\ &= (132 \times 0.170) / (8.314 \times 435.15) \\ &= 0.0062026 \text{ mol} = n(\text{S}) (\checkmark) \end{aligned}$$

$$\begin{aligned} \% \text{ S} &= ((0.0062 \times 32.07)/2.198) \times 100 \\ &= 9.049927841 \% (\checkmark) \end{aligned}$$

$$\begin{aligned} \% \text{ O} &= 100 - (64.41 + 3.98 + 9.05) \\ &= 22.55398087 \% (\checkmark) \end{aligned}$$

	C	H	O	S
m in 100 g	64.4133	3.98282	22.55395	9.049928
n	64.4133 / 12.01	3.98282 / 1.008	22.55395 / 16	9.049928 / 32.07
	= 5.3633056	= 3.9512103	= 1.409622	= 0.2821929
ratio	5.3633056 / 0.2821929	3.9512103 / 0.2821929	1.409622 / 0.2821929	0.2821929 / 0.2821929
	≈ 19	≈ 14	≈ 5	≈ 1

(✓✓ must show working for number of moles and ratio as minimum)

Therefore EF is $\text{C}_{19}\text{H}_{14}\text{O}_5\text{S}$ (✓)

Therefore orange-red solution (✓)

OR

$$\begin{aligned}
 n(\text{C}) &= n(\text{CO}_2) \\
 &= 2.908 / 44.01 \\
 &= 0.06607 \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 m(\text{C}) &= 0.06607 \times 12.01 \\
 &= 0.79357 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{H}) &= 2 \times n(\text{H}_2\text{O}) \\
 &= 2 \times 0.4385 / 18.016 \\
 &= 0.04867 \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 m(\text{H}) &= 0.04867 \times 1.008 \\
 &= 0.049068 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{S in 2.198 g sample}) &= n(\text{SO}_2) \\
 &= PV / RT \\
 &= (132 \times 0.170) / (8.314 \times 435.15) \\
 &= 0.0062026 \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{S in 1.232 g sample}) &= (1.232 / 2.198) \times 0.0062026 \\
 &= 0.0034766 \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 m(\text{S}) &= 0.0034766 \times 32.07 \\
 &= 0.11149 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 m(\text{O}) &= 1.232 - m(\text{C}) - m(\text{H}) - m(\text{S}) \\
 &= 0.27796 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{O}) &= 0.27797 / 16 \\
 &= 0.017372 \text{ mol}
 \end{aligned}$$

	C	H	O	S
n	0.06607	0.04867	0.017372	0.0034766
ratio	0.06607 / 0.0034766	0.04867 / 0.0034766	0.01737 / 0.0034766	0.0034766 / 0.0034766
	≈ 19	≈ 14	≈ 5	≈ 1

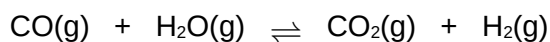
Therefore EF is $\text{C}_{19}\text{H}_{14}\text{O}_5\text{S}$

Therefore orange-red solution

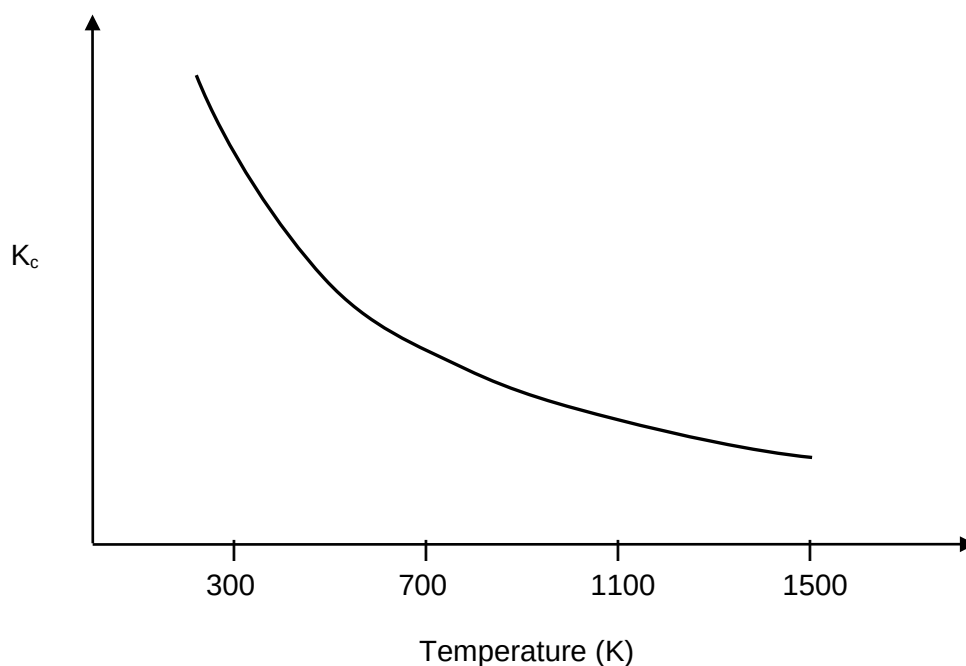
Question 38**(13 marks)**

The 'water-gas shift reaction' or just 'shift reaction' is a common and extremely important industrial process used to manufacture hydrogen. The hydrogen produced is used in many ways, such as the production of ammonia via the Haber-Bosch process.

The shift reaction is an equilibrium process and can be represented by the following equation.



The graph below shows the relationship between temperature and K_c for the shift reaction.



- (a) Using the information provided in the graph, state whether the forward reaction is exothermic or endothermic as written. Justify your answer. (4 marks)
- As the temperature of the system is increased, the value of K_c decreases (✓)
 - This corresponds to an increase in the concentration of reactants (OR a decrease in the ratio of product to reactant concentration) (✓)
 - The equilibrium shifts to favour the endothermic reaction which is the reverse reaction in this case (✓)
 - Therefore, the forward reaction is exothermic (✓)

On an industrial scale, the shift process utilises two stages. The first is a 'high temperature shift' which is carried out at 310-450 °C. This is then followed by a 'low temperature shift' which occurs at temperatures of 200-250 °C.

(b) Briefly explain the main advantage of using a; (4 marks)

(i) high temperature shift.

- Increases both the forward and reverse reaction rates as the average kinetic energy of the particles increases (✓)
- A greater proportion of particles have kinetic energy greater than activation energy which increases frequency of successful collisions (✓)
- ½ mark only if reaction rate is increased

(i) low temperature shift.

- Reduces the rate of both forward and reverse reactions but reduces the reverse (endothermic) more (✓)
- This means the forward reaction is occurs at a greater rate relative to reverse reaction and so yield of H₂ is increased (✓)
- ½ mark only if yield is increased

A pressure of 10 - 20 atmospheres is used in the shift process. This is considered to be **relatively low** in industrial terms.

(c) By referring to reaction rate, equilibrium yield and operating cost, explain why this choice of relatively low pressure is preferred over using a much higher pressure. (5 marks)

- A low pressure results in a decrease in the frequency of collisions (✓)
- Which reduces the rate of both the forward and reverse reactions (✓)

OR

- A high pressure results in an increase in the frequency of collisions (✓)
- Which increases the rate of both the forward and reverse reactions (✓)
- There are two moles of gaseous particles on both sides of the chemical equation (✓)
- Therefore, no effect on yield (✓)
- Pressure is kept relatively low to decrease cost (and maximise profits) (✓)

Also, award marks for relevant statements/discussions such as 'It is likely that an increased pressure may not substantially increase the reaction rate, or increase it enough to make it economically viable to maintain these conditions' etc.

End of Exam