Insert School Logo

CHEMISTRY

UNIT 3

2021

Name: _____

Teacher: _____

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: 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 calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination

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 material. 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 examination
Section One Multiple-choice	25	25	50	/ 25	/ 25
Section Two Short answer	11	11	60	/ 80	/ 35
Section Three Extended answer	5	5	70	/ 90	/ 40
					/ 100

Instructions to candidates

1. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

2. 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. Do not use erasable or gel pens. 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.

3. When calculating numerical answers, show your working or reasoning clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. Express numerical answers to the appropriate number of significant figures and include appropriate units where applicable.

4. 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.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

6. The Chemistry Data Book is not to be handed in with your Question/Answer booklet.

Section One: Multiple-choice **25% (25 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. Which of the following factors would increase the reaction rate, by increasing the proportion of successful collisions between reactant particles?

   (a) Increasing the concentration of reactant species.
   (b) Decreasing the volume of a gaseous system.
   (c) Increasing the subdivision of a solid reactant.
   (d) Increasing the temperature of a reacting system.

2. A 500 mL sample of a 1.0 mol L^{-1} solution must meet the following criteria;

   (i) Have a pH below 7.
   (ii) Can be completely neutralised by the addition of 0.5 moles of NaOH(s).
   (iii) Have a K_a value less than 1.

   The solution could be

   (a) NH_3(aq).
   (b) HCl(aq).
   (c) CH_3COOH(aq).
   (d) H_2SO_3(aq).

Questions 3 and 4 refer to the equilibrium below.

Consider the following physical equilibrium involving pure ethanol.

$$CH_3CH_2OH(l) \rightleftharpoons CH_3CH_2OH(g)$$

3. If this system had established equilibrium, which of the following would be correct?

   (a) The rate of evaporation would equal the rate of condensation.
   (b) The rate of evaporation would be greater than the rate of condensation.
   (c) The rate of condensation would be greater than the rate of evaporation.
   (d) The rate of evaporation and condensation would be zero.

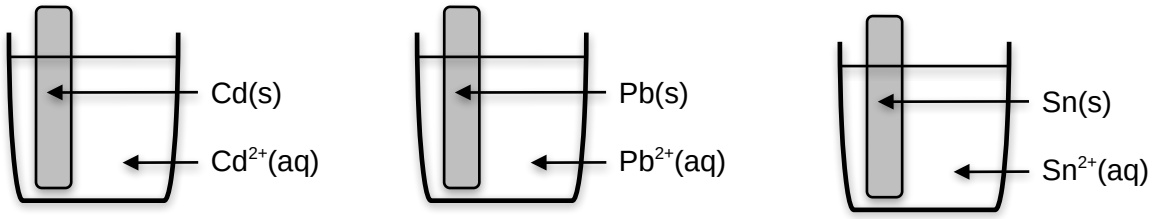
4. If the temperature of this system was increased by 5 ˚C, this would

   (a) have no effect on the position of equilibrium.
   (b) decrease the rate of condensation.
   (c) decrease the rate of evaporation.
   (d) increase the value of K_c.

5. In which of the following acid-base titrations, would the reaction mixture **not** be a good conductor of electricity at the equivalence point?

(a) Hydrochloric acid and sodium hydroxide.
(b) Sulfuric acid and barium hydroxide.
(c) Ethanoic acid and ammonia.
(d) All of the above.

Questions 6 and 7 refer to the three (3) half-cells pictured below, which were set up under standard conditions.



6. Which of the species in the half-cells above represent the strongest oxidising and reducing agents (oxidant and reductant)?

	Oxidising agent	**Reducing agent**
(a)	Cd	Pb^{2+}
(b)	Pb	Cd^{2+}
(c)	Cd^{2+}	Pb
(d)	Pb^{2+}	Cd

Two of these half-cells are connected to form a functioning galvanic cell.

7. Which piece of equipment would **not** be required?

(a) Salt bridge
(b) Power pack
(c) Wires
(d) Electrical load (e.g. globe, voltmeter, resistor)

8. Consider the following data regarding the monoprotic acids below.

HSO_4^-(aq) $K_a = 1.3 \times 10^{-2}$ at 25 °C

$HC_2O_4^-$(aq) $K_a = 5.4 \times 10^{-5}$ at 25 °C

Compare 0.2 mol L^{-1} solutions of both $NaHSO_4$(aq) and $NaHC_2O_4$(aq). The $NaHC_2O_4$(aq) solution would have a

(a) higher concentration of Na^+(aq).
(b) higher conductivity.
(c) higher pH.
(d) higher concentration of anions with a -2 charge.

Questions 9, 10 and 11 refer to the following equilibrium system.

Consider the following gaseous system, which has established equilibrium at 85 ˚C.

$$\underset{\textit{colourless}}{CO(g)} + \underset{\textit{red}}{Br_2(g)} \rightleftharpoons \underset{\textit{colourless}}{COBr_2(g)} + \text{heat}$$

9. If the volume of the system was halved, it would be observed that

(a) the red colour would gradually lighten.
(b) the red colour would gradually darken.
(c) the red colour would immediately darken and then gradually lighten.
(d) the red colour would immediately lighten and then gradually darken.

The reacting system was then cooled from 85 ˚C to 35 ˚C, to **condense** the $COBr_2$.

10. When compared to the system at 85 ˚C, at 35 ˚C the system would contain

(a) a smaller mass of $COBr_2$.
(b) a larger mass of $COBr_2$.
(c) the same mass of $COBr_2$.
(d) the comparative mass of $COBr_2$ cannot be predicted from this information.

11. Once the system had been cooled to 35 ˚C, it was then classified as

(a) an open system, because some of the $COBr_2$ had condensed.
(b) an open system, because there were fewer gas particles.
(c) a closed system, because the position of equilibrium had not changed.
(d) a closed system, because the number of atoms in the system had not changed.

12. A chemistry student attempted to identify a 0.5 mol L^{-1} salt solution by performing several chemical tests.

(i) A few drops of universal indicator were added to a sample of the solution, and the mixture turned blue.
(ii) A few drops of 2 mol L^{-1} HCl(aq) were added to a separate sample of the solution, and this resulted in bubbles of colourless, odourless gas forming.

The identity of the salt solution could be

(a) $NaCH_3COO(aq)$.
(b) $KHCO_3(aq)$.
(c) LiF(aq).
(d) $NH_4NO_3(aq)$.

13. The Hall-Heroult process involves the electrolysis of molten alumina, $Al_2O_3(l)$, with carbon electrodes. During this process

(a) aluminium ions would be oxidised at the cathode.
(b) aluminium metal would form at the anode.
(c) oxide ions would move towards the negative electrode.
(d) oxide ions would lose electrons.

Questions 14 and 15 refer to the lead-acid accumulator.

14. The following equation represents the discharge reaction occurring in a lead-acid accumulator.

$$PbO_2(s) + 2\ SO_4^{2-}(aq) + 4\ H^+(aq) + Pb(s) \rightarrow 2\ PbSO_4(s) + 2\ H_2O(l)$$

Which statement regarding this chemical process is **not** correct?

(a) The oxidation number of Pb(s) changes by 2.
(b) The $PbO_2(s)$ electrode would have a positive polarity.
(c) The $H^+(aq)$ ions would migrate towards the $PbO_2(s)$ electrode.
(d) The Pb(s) electrode acts as the oxidising agent.

15. The lead-acid accumulator **cannot** be classified as a

(a) primary cell.
(b) secondary cell.
(c) galvanic cell.
(d) electrolytic cell.

16. Consider the data shown in the table below, which relates to a particular reversible reaction.

	Uncatalysed reaction	Catalysed reaction
E_a(forward) (kJ mol^{-1})	551	**W**
E_a(reverse) (kJ mol^{-1})	**X**	129
H(forward) (kJ mol^{-1})	+373	**Y**
H(reverse) (kJ mol^{-1})	**Z**	

The correct values of W, X, Y and Z are

	W	**X**	**Y**	**Z**
(a)	502	178	+373	- 373
(b)	924	178	- 373	+373
(c)	244	924	- 422	- 373
(d)	502	422	+373	+924

17. Which of the acidic solutions below could be completely neutralised by the addition of 1 mole of $NH_3(aq)$?

(i) 1 mole of $CH_3COOH(aq)$
(ii) 1 mole of $H_2SO_4(aq)$
(iii) 1 mole of $HCl(aq)$
(iv) 1 mole of $H_2CO_3(aq)$

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

Questions 18 and 19 refer to the information below.

An aqueous solution was formed by dissolving an equal number of moles of $Zn(NO_3)_2(s)$ and $Cr(NO_3)_3(s)$ into water.

Ten drops of concentrated NaOH(aq) was added to this mixture. The following equations relate to the subsequent equilibria that were established.

$$Zn^{2+}(aq) + 4\ OH^-(aq) \rightleftharpoons Zn(OH)_4^{2-}(aq) \qquad K_c = 4.6 \times 10^{17}$$

$$Cr^{3+}(aq) + 4\ OH^-(aq) \rightleftharpoons Cr(OH)_4^-(aq) \qquad K_c = 8.0 \times 10^{29}$$

18. Whilst the system was moving to establish equilibrium, which of the following statements would be correct regarding the equilibria above?

(a) The forward reaction rates were continually increasing.
(b) The reverse reaction rates were continually decreasing.
(c) The forward reaction rates were faster than their respective reverse reaction rates.
(d) The reverse reaction rates were faster than their respective forward reaction rates.

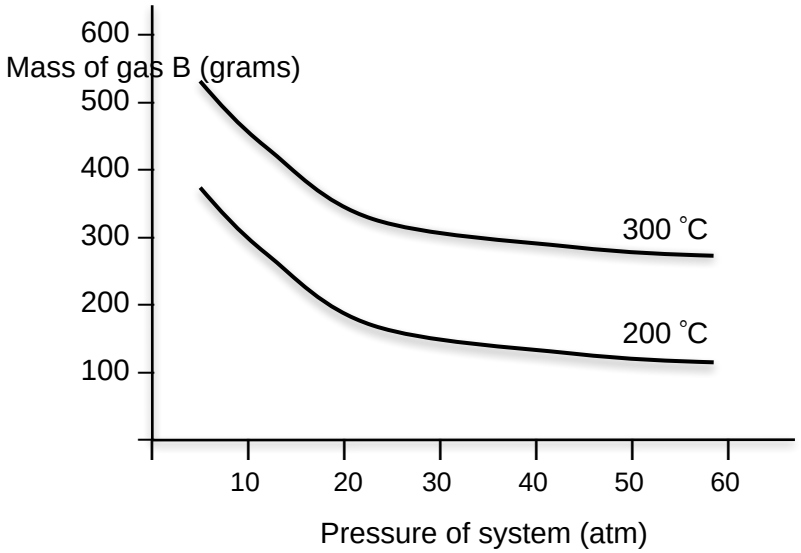
19. Once all equilibria had been established, which of the following would be correct?

(a) $[Zn^{2+}(aq)] < [Cr^{3+}(aq)]$
(b) $[Cr^{3+}(aq)] < [H_3O^+(aq)]$
(c) $[Zn^{2+}(aq)] < [OH^-(aq)]$
(d) $[Zn(OH)_4^{2-}(aq)] < [Cr(OH)_4^-(aq)]$

20. A particular gaseous equilibrium can be represented by the following equation;

$$a\ A(g) \rightleftharpoons b\ B(g)$$

The graph below shows how the mass of gas B present at equilibrium changes with different conditions of temperature and pressure.



Using the data provided in this graph, which of the following must be true for this reaction?

(a) a > b, H is positive.
(b) a > b, H is negative.
(c) a < b, H is positive.
(d) a < b, H is negative.

21. Consider the following substance;

$$H_3N^+ – CH_2 – CH_2 – COO^-$$

Select the correct conjugate species for this substance.

	Conjugate acid	**Conjugate base**
(a)	$H_3N^+ – CH_2 – CH_2 – COOH$	$H_2N – CH_2 – CH_2 – COO^-$
(b)	$H_2N – CH_2 – CH_2 – COO^-$	$H_3N^+ – CH_2 – CH_2 – COOH$
(c)	$H_2N – CH_2 – CH_2 – COOH$	$HN^- – CH_2 – CH_2 – COO^-$
(d)	$H_3N^+ – CH_2 – CH_2 – COOH_2^+$	$H_2N – CH_2 – CH_2 – COOH$

22. An acid-base indicator must

(a) only display two different colours.
(b) change colour in response to pH.
(c) distinguish an acid from a base.
(d) be highly soluble in water.

23. The hydrogen fuel cell can be designed with either an acidic or alkaline electrolyte. The oxidation and reduction half-equations for both variations of this cell are given below.

Acidic: $O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l)$
$H_2(g) \rightarrow 2\ H^+(aq) + 2\ e^-$

Alkaline: $O_2(g) + 2\ H_2O(l) + 4\ e^- \rightarrow 4\ OH^-(aq)$
$H_2(g) + 2\ OH^-(aq) \rightarrow 2\ H_2O(l) + 2\ e^-$

Consider the following characteristics;

(i) The EMF under standard conditions is +1.23 V.
(ii) The overall cell equation is $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$
(iii) The $O_2(g)$ enters the cell at the cathode.

Which type of hydrogen fuel cell possesses all three of these characteristics?

(a) Acidic only.
(b) Alkaline only.
(c) Both acidic and alkaline.
(d) Neither acidic nor alkaline.

Questions 24 and 25 refer to the following chemicals.

Consider the four (4) pairs of chemicals listed below.

(i) $Pb(s)$ and $Cd(NO_3)_2(aq)$
(ii) $Sn(s)$ and $Ni(NO_3)_2(aq)$
(iii) $Ni(s)$ and $Pb(NO_3)_2(aq)$
(iv) $Cd(s)$ and $Sn(NO_3)_2(aq)$

24. If these chemical combinations were mixed in separate beakers, which would result in a metal displacement reaction?

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

Four (4) separate galvanic cells were then set up, using the chemicals listed above.

25. Which combination of chemicals would have produced the galvanic cell with the highest EMF under standard conditions?

(a) $Pb(s) / Pb^{2+}(aq)$ and $Cd(s) / Cd^{2+}(aq)$
(b) $Sn(s) / Sn^{2+}(aq)$ and $Ni(s) / Ni^{2+}(aq)$
(c) $Ni(s) / Ni^{2+}(aq)$ and $Pb(s) / Pb^{2+}(aq)$
(d) $Cd(s) / Cd^{2+}(aq)$ and $Sn(s) / Sn^{2+}(aq)$

End of Section One

Section Two: Short answer **35% (80 marks)**

This section has 11 questions. Answer **all** questions. Write your answers in the spaces provided.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 60 minutes.

Question 26 **(7 marks)**

Consider the combustion of ethane gas, $C_2H_6(g)$.

(a) Write balanced chemical equations representing the combustion of ethane gas, in both excess and limited oxygen environments. (4 marks)

Excess oxygen	
Limited oxygen	

(b) Use oxidation numbers to demonstrate which process results in the complete oxidation of ethane. (3 marks)

Question 27 **(6 marks)**

Consider the following gaseous equilibrium system.

$$2\ NO_2(g) \rightleftharpoons N_2O_4(g) + \text{heat}$$

brown *colourless*

Complete the following table by stating how each of the imposed changes would affect;

(i) the rate of the forward reaction,
(ii) the position of equilibrium, and
(iii) the concentration of $NO_2(g)$.

Note: consider the effect of each imposed change in isolation.

	Increase in temperature of system	Increase in volume of system
Rate of forward reaction (increase, decrease, no change)		
Position of equilibrium (shift left, shift right, no change)		
Concentration of $NO_2(g)$ (increase, decrease, no change)		

Question 28 **(9 marks)**

A chemistry student poured 325 mL of 0.55 mol L^{-1} hydrochloric acid, HCl(aq), into a beaker. They then added 200 drops of 2.0 mol L^{-1} nitric acid, HNO_3(aq), whilst measuring the pH of the mixture throughout.

(a) Calculate the initial pH of the hydrochloric acid solution. (1 mark)

(b) Calculate the pH of the mixture, after the 200 drops of nitric acid was added. (6 marks)
Note: 1 drop = 0.05 mL.

The student concluded that the solution was a buffer, since the pH change caused by the additional 200 drops of nitric acid had been minimal. However, their teacher said this was incorrect, and the solution was **not** a buffer.

(c) Use relevant chemical theory to justify the teacher's statement, with reference to the results obtained. (2 marks)

Question 29 **(8 marks)**

The sulfur cycle involves the transformation of sulfur atoms through various oxidation states. Hydrogen sulfide (H_2S) released from hydrothermal vents can be converted to elemental sulfur (S_8) by photosynthetic green and purple bacteria. The elemental sulfur is then converted to sulfate (SO_4^{2-}). Another type of bacteria transforms the sulfate into sulfite (SO_3^{2-}), and then finally back into hydrogen sulfide, where the cycle can begin again.

Write four (4) half-equations representing the steps in the sulfur cycle described above, assuming acidic conditions. Classify each step as a reduction (R) or oxidation (O) process.

	Half-equation	R / O
1		
2		
3		
4		

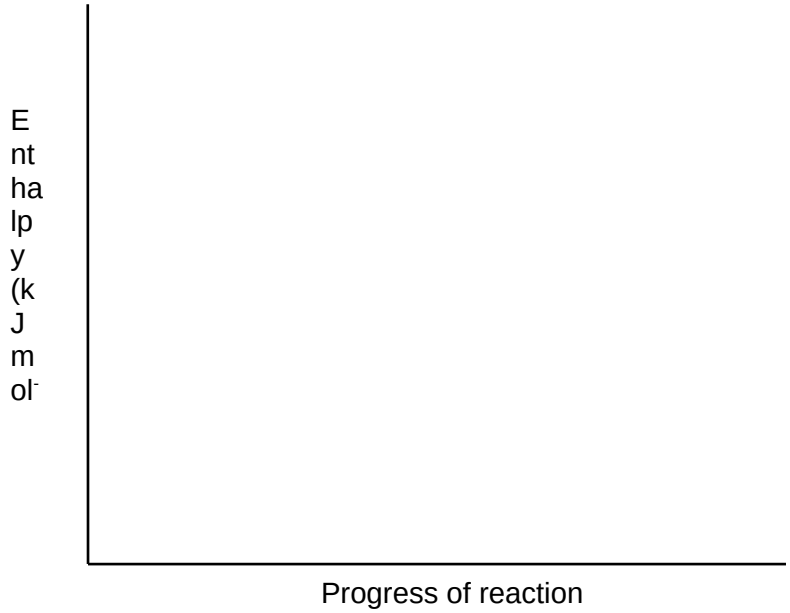
Question 30 **(9 marks)**

Consider the information provided in the table below, which relates to a particular reaction that is taking place at 25 ˚C.

E_a	=	8 kJ
H	=	-33 kJ mol^{-1}
K	=	$\frac{1}{[Pb^{2+}]\,[I^-]^2}$
K_c	=	2.27×10^8

(a) Write a balanced chemical equation for the reaction occurring. (2 marks)

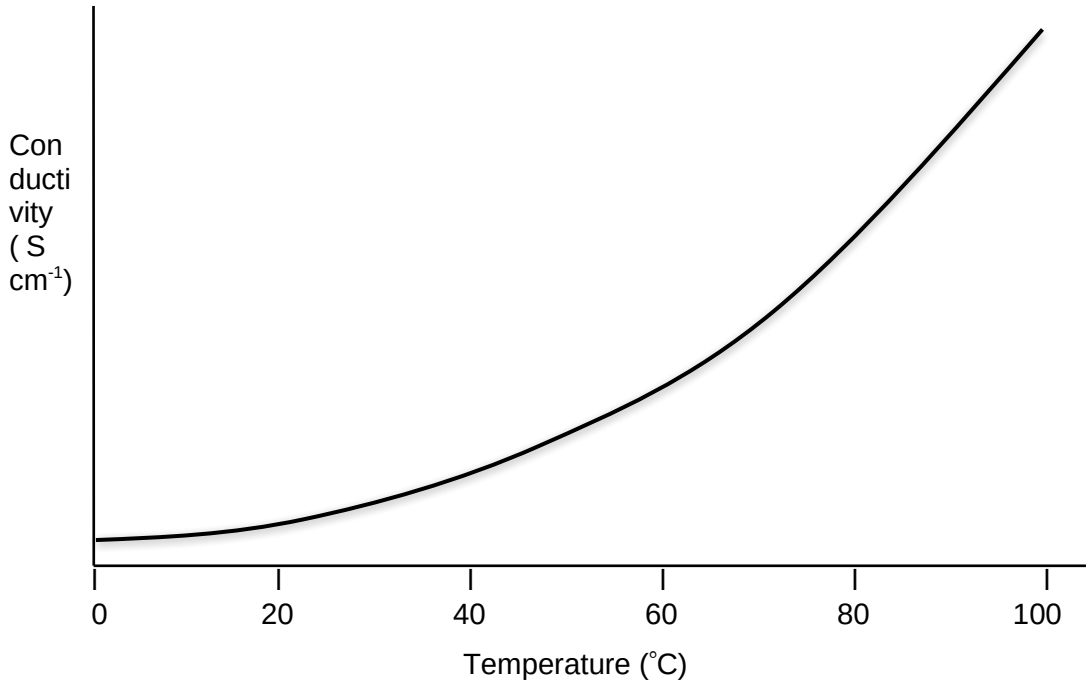
(b) Sketch an energy profile diagram for this reaction on the axes below. Label the activation energy and change in enthalpy. (5 marks)



(c) Comment, with justification, on the likely reversibility of this reaction at 25 ˚C. (2 marks)

Question 31 **(5 marks)**

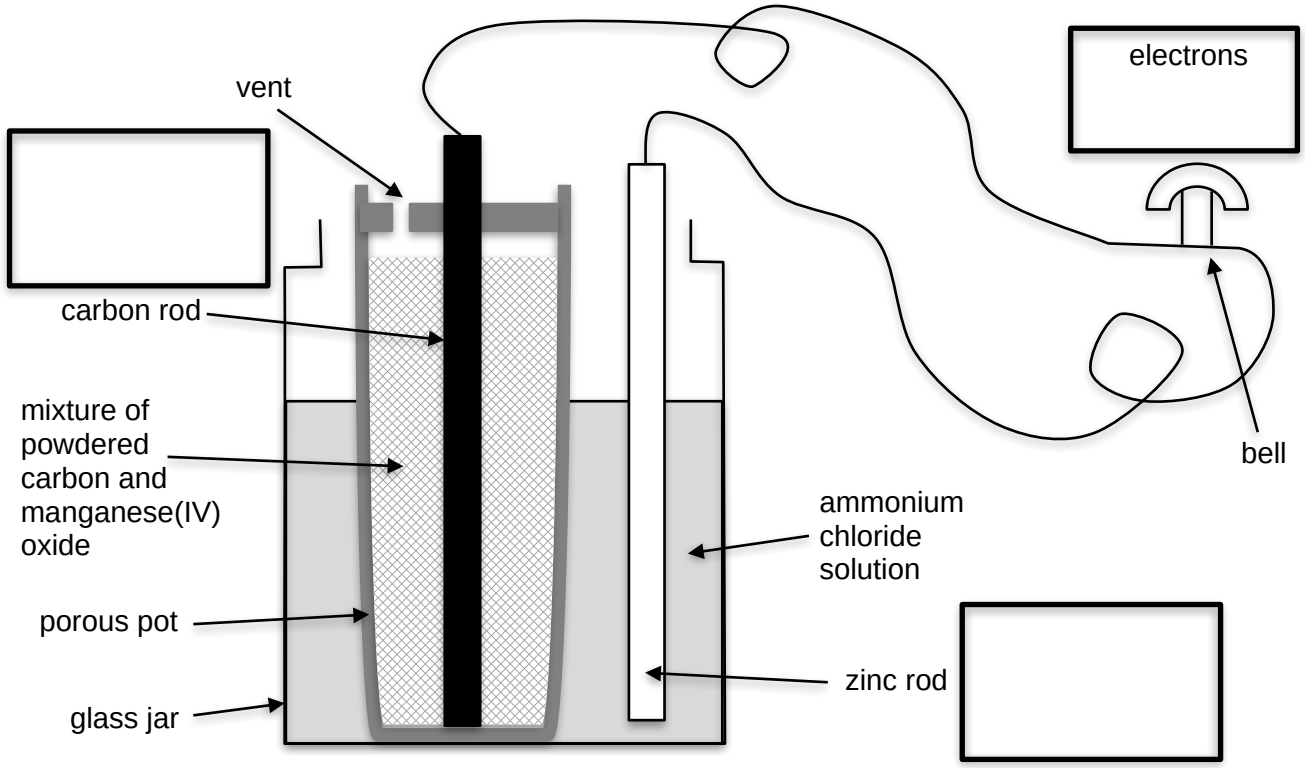
The following graph illustrates the relationship between the temperature of pure water and its electrical conductivity.



Describe, with reference to relevant chemical theory, what information the data represented in the graph provides, regarding the enthalpy change of the autoionisation of water. Include a relevant chemical equation in your answer.

Question 32 **(9 marks)**

The Leclanché cell was invented and patented in 1866. It was a primary cell, that was later developed into the dry cell. The Leclanché cell was very successful and quickly became used to power early telephones and electric bells. The diagram below shows the original Leclanché design.



The relevant half-equations are given in the table below.

$MnO_2(s) + 2\ NH_4^+(aq) + 2\ e^- \rightarrow Mn_2O_3(s) + 2\ NH_3(aq) + H_2O(l)$	$E^0(red)$ =
$Zn(s) \rightarrow Zn^{2+}(aq) + 2\ e^-$	$E^0(ox)$ =

(a) Define a primary cell. (1 mark)

(b) In the boxes on the diagram above, label the

- anode and cathode,
- polarity of each electrode, and
- direction of electron flow. (3 marks)

(c) The Leclanché cell provides an EMF of +1.4 V. If this EMF was produced under standard conditions, complete the table above by adding in the E^0 values. (2 marks)

(d) Which component on the diagram above is acting as the 'salt bridge'? Describe the functions of this component. (3 marks)

_____

_____

_____

_____

_____

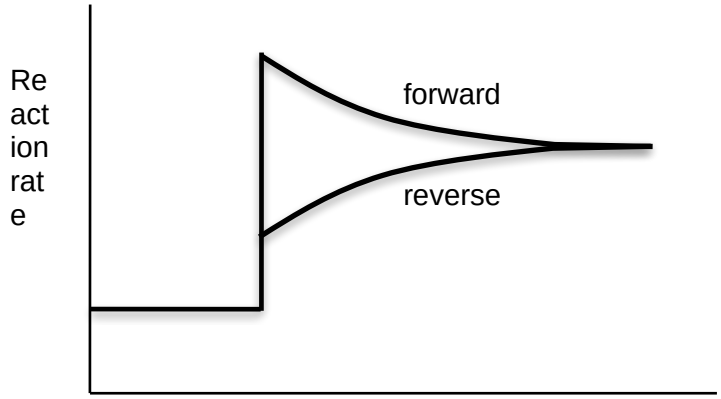
_____

Question 33 **(6 marks)**

The following gaseous system had established equilibrium.

$$N_2(g) + O_2(g) + 181\ kJ \rightleftharpoons 2\ NO(g)$$

A change was then imposed on the system, the effect of which is represented by the graph below.



(a) Which of the changes below was imposed on the system? (circle your choice) (1 mark)

addition of nitrogen gas to the system	decrease in total volume of the system	increase in temperature of the system

(b) Justify why you **did not choose** the two remaining options. (2 marks)

(c) Explain the resultant shift that was observed. (3 marks)

Question 34 **(6 marks)**

(a) Write a balanced ionic equation for the chemical reaction that would occur when ethanoic acid is mixed with sodium carbonate solution. (2 marks)

(b) State all observations that would be noted, when several drops of bromine water are added to a beaker containing excess potassium iodide. (2 marks)

(c) Write the equilibrium constant expression for the reaction that would occur, when a piece of barium metal is dropped into a large bowl of warm water. (2 marks)

Question 35 **(7 marks)**

A laboratory technician prepared a primary standard solution by dissolving 4.962 g of powdered acid in distilled water, and then making the solution up to 250.0 mL in a volumetric flask.

A chemistry class was then asked to identify the primary standard, and were told it was either potassium hydrogen phthalate, $KHC_8H_4O_4(s)$, or potassium hydrogen iodate, $KH(IO_3)_2(s)$.

The students took 20.00 mL aliquots of the acidic solution and titrated these against a standard 0.06723 mol L^{-1} NaOH(aq) solution.

The stoichiometry of the neutralisation reaction is the same for each acid, as shown in the following equations. A selection of data comparing the two primary standards is provided in the table below.

Potassium hydrogen phthalate	$KHC_8H_4O_4(s)$	M = 204.22 g mol^{-1}
$KHC_8H_4O_4(aq) + NaOH(aq) \rightarrow C_8H_4O_4KNa(aq) + H_2O(l)$		
Potassium hydrogen iodate	$KH(IO_3)_2(s)$	M = 389.908 g mol^{-1}
$KH(IO_3)_2(aq) + NaOH(aq) \rightarrow NaK(IO_3)_2(aq) + H_2O(l)$		

The students collected the following titration data.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Final (mL)	48.03	42.78	39.45	37.45	31.66
Initial (mL)	18.44	13.91	10.07	8.53	2.73
Titre (mL)					

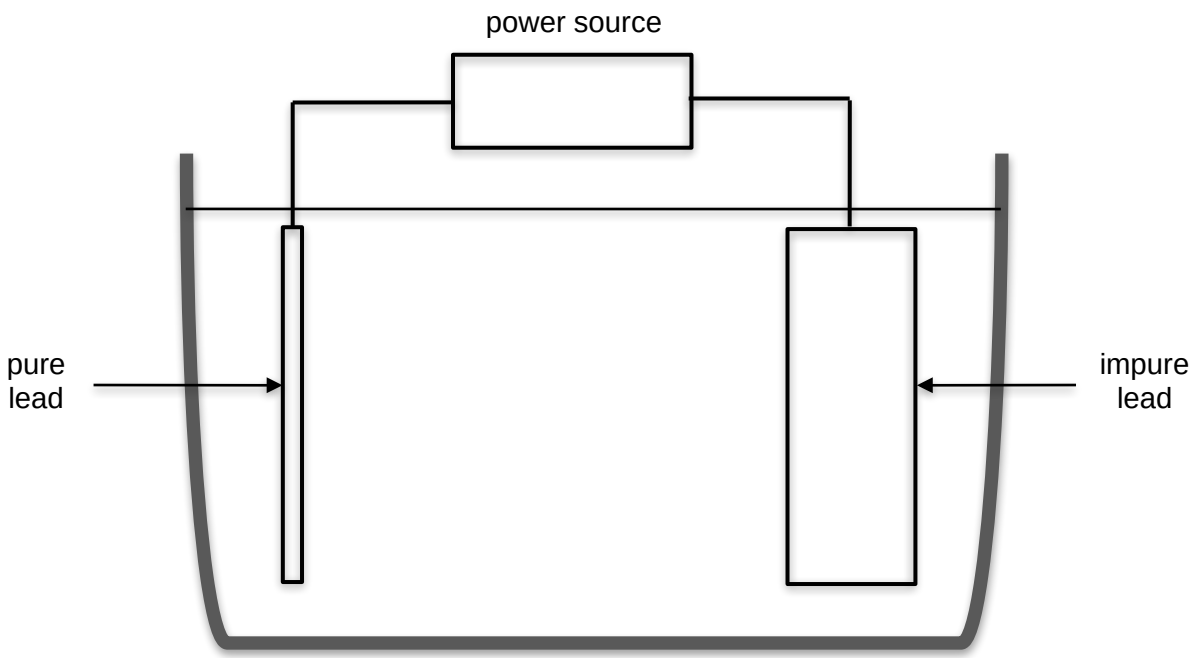
Identify whether the laboratory technician used potassium hydrogen phthalate or potassium hydrogen iodate as the primary standard. Use appropriate calculations to support your answer.

Question 36 **(8 marks)**

The Betts process is an expensive electrorefining technique used to purify lead, when very high purity lead metal is required. In this process, the electrolyte is composed of a lead(II) fluorosilicate and hexafluorosilicic acid mixture, $PbSiF_6(aq)$ / $H_2SiF_6(aq)$. The temperature of the electrolyte is maintained at 45 ˚C and an electric potential of 0.5 V is applied.

The basis of this electrorefining process is very similar to that used for copper metal, with some of the metal impurities entering the electrolyte solution, and some forming an anode mud.

The diagram below is a simplified representation of the Betts process.



(a) On the diagram above, label the

- direction of electron flow through the power source, and
- direction of cation flow. (2 marks)

(b) Write balanced half-equations representing the processes occurring at the cathode and the anode. (2 marks)

cathode	
anode	

(c) State the overall EMF for the reaction occurring, and justify why a voltage is applied. (2 marks)

(d) If copper metal was one of the impurities in the lead, would this likely be found in the electrolyte or the anode mud, once the electrorefining process was complete? Justify your answer. (2 marks)

End of Section Two

Section Three: Extended answer **40% (90 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.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 70 minutes.

Question 37 **(17 marks)**

When solutions of iron(III) nitrate and potassium thiocyanate are mixed, the iron thiocyanate complex ion, $FeSCN^{2+}(aq)$ is formed, and an aqueous equilibrium system is established as shown below.

$$\underset{\textit{very pale brown}}{Fe^{3+}(aq)} + \underset{\textit{colourless}}{SCN^{-}(aq)} \rightleftharpoons \underset{\textit{blood-red}}{FeSCN^{2+}(aq)} + \text{heat}$$

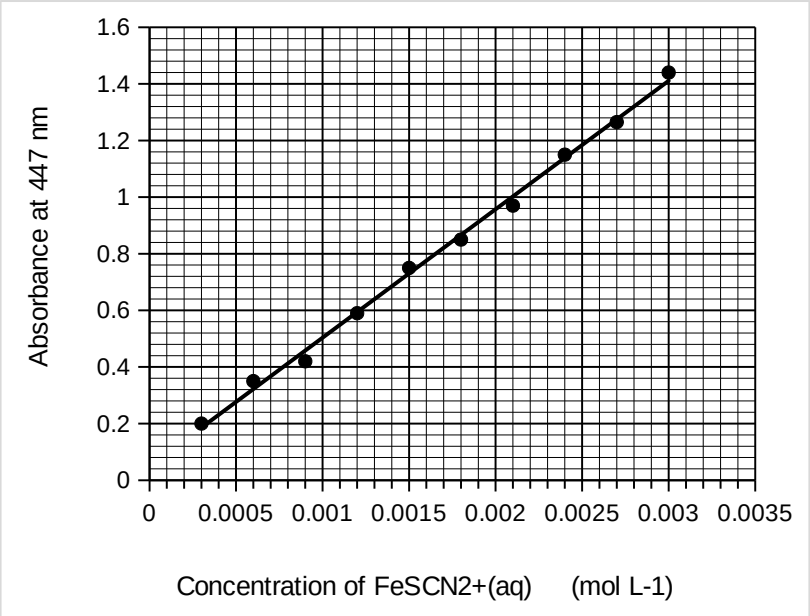
The appearance of the equilibrium mixture is determined by the concentration of $FeSCN^{2+}(aq)$, which displays a characteristic blood-red colour.

Due to the presence of this colour, the concentration of $FeSCN^{2+}(aq)$ can be quantified by measuring the absorbance. A sample of the equilibrium mixture can be taken, and the absorbance is measured using light at 447 nm. This absorbance value is then compared to a calibration curve to determine the concentration of $FeSCN^{2+}(aq)$.

A group of chemistry students set up this equilibrium as described;

1. Samples of $Fe(NO_3)_3(aq)$ and KSCN(aq) were prepared.
2. Aliquots of each solution were then combined so that, once mixed, the initial concentrations were 0.01 mol L^{-1} and 0.006 mol L^{-1} respectively.
3. The mixture was allowed to sit for 10 minutes so equilibrium could be established.
4. A sample of the equilibrium mixture was then taken, and the absorbance was measured at 447 nm using a spectrophotometer.
5. The absorbance was determined to be 0.96.

The calibration curve for $FeSCN^{2+}(aq)$ is shown below.



(a) Determine the concentration of $FeSCN^{2+}(aq)$ present at equilibrium. (1 mark)

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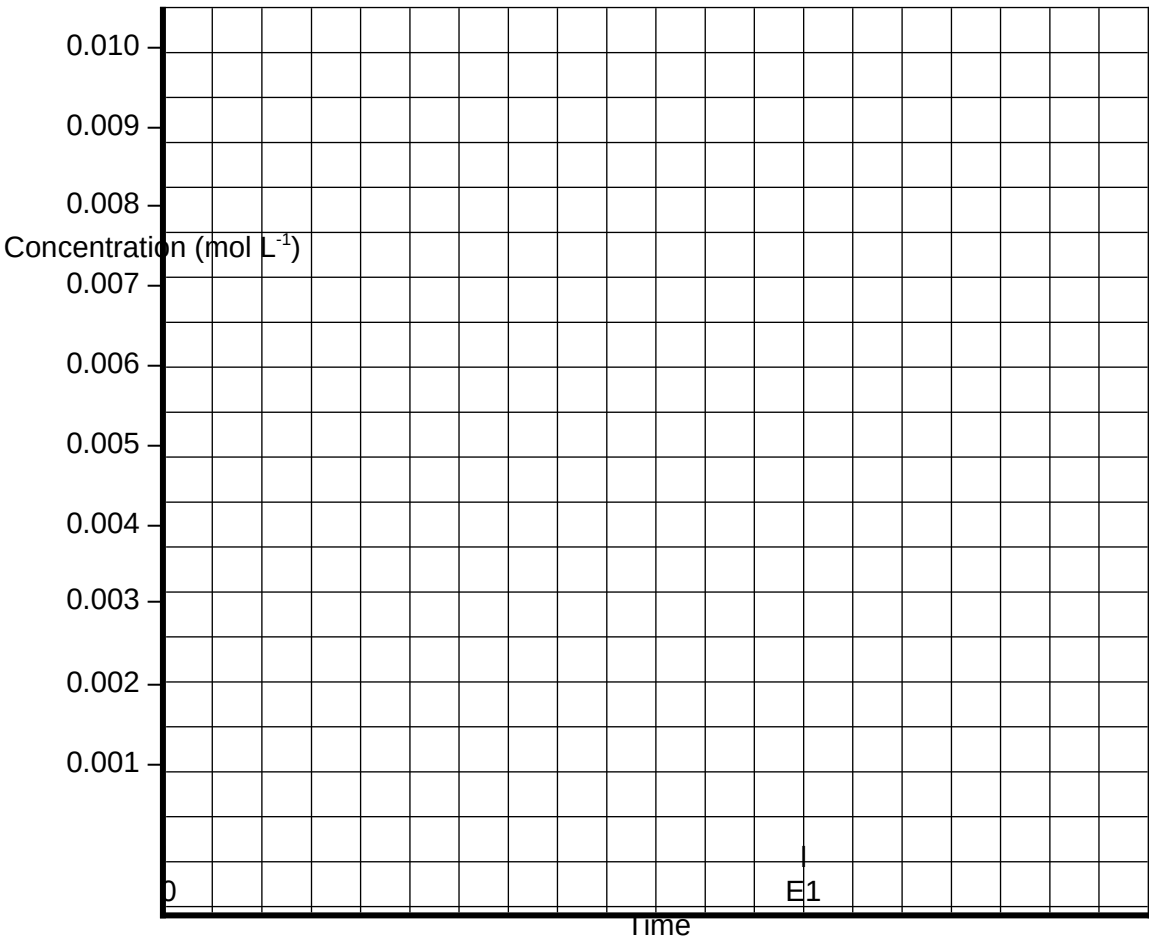
(b) Sketch a graph, including all relevant species, showing the establishment of equilibrium, from Time 0 where the reactants were mixed, to Time E1, where equilibrium was established and maintained. (5 marks)



The students then decided to split their equilibrium mixture into several different beakers, and impose various changes on the system to examine the results. The equilibrium equation is provided again below, for convenience.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq) + heat$$

very pale brown *colourless* *blood-red*

The students' research had also provided them with the following chemical equations, related to the iron thiocyanate equilibrium.

i. $Fe^{3+}(aq) + 6\ F^{-}(aq) \rightleftharpoons FeF_6^{3-}(aq)$

ii. $SCN^{-}(aq) + H_3O^{+}(aq) \rightleftharpoons HSCN(aq) + H_2O(l)$

iii. $Fe^{3+}(aq) + 3\ OH^{-}(aq) \rightleftharpoons Fe(OH)_3(s)$

Firstly, the students used two beakers to investigate the effect of adding acid, $H_3O^{+}(aq)$ and base, $OH^{-}(aq)$ to the original iron thiocyanate equilibrium. They found that in both cases, this shifted the position of the equilibrium to the left.

(c) Justify these results by using Le Chatelier's principle and making reference to any appropriate equations provided. (6 marks)

(d) Describe the observation that would have distinguished between the addition of acid and base to the equilibrium system. (1 mark)

To a separate beaker containing a sample of the iron thiocyanate equilibrium, the students added a few drops of concentrated potassium fluoride, KF(aq).

(e) Explain, in terms of reaction rates, the effect this would have on the equilibrium position.
(4 marks)

Question 38 **(16 marks)**

Coca-Cola was first released in 1886 in the USA. It's current formula still remains a trade secret, but the listed ingredients are;

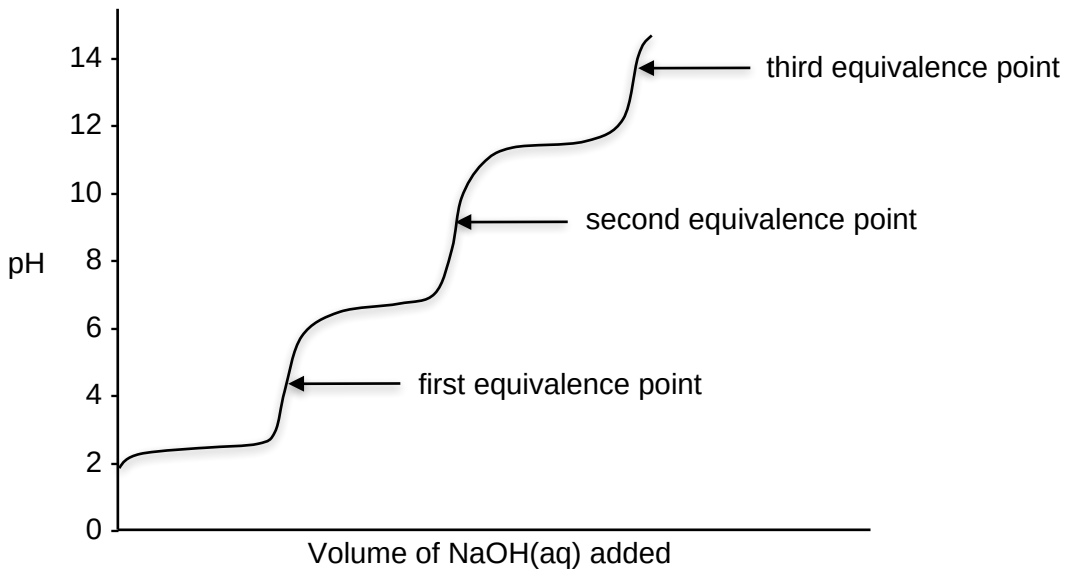
Carbonated water, sugar, caffeine, phosphoric acid, caramel colour, natural flavourings.

Phosphoric acid adds a tangy taste to the Coca-Cola. A chemistry class was assigned the task of determining the concentration of phosphoric acid, $H_3PO_4(aq)$, in Coca-Cola and using this **to determine the phosphorus content** of the soft drink.

Research by the students led to the development of the following method;

1. Take a 150.0 mL aliquot of Coca-Cola.
2. Heat for 20 minutes, to just below the boiling point.
3. Allow to cool.
4. Insert a pH meter into the solution.
5. Titrate against a 0.1005 mol L^{-1} NaOH(aq) standard solution, until a pH of 9.5 is reached.

Phosphoric acid is a weak, triprotic acid. This means there are three different equivalence points for the titration reaction. The titration curve for this reaction is shown below.



The pH at the third equivalence point is too basic to titrate accurately, and so the titration is performed to the **second equivalence point**, according to the following equation;

$$H_3PO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2HPO_4(aq) + 2\ H_2O(l)$$

(a) Explain why the pH at the first equivalence point is acidic, whilst the pH at the second equivalence point is basic. Include relevant chemical equations in your answer. (4 marks)

(b) Suggest one practical reason a pH meter is used to detect the equivalence point, instead of the indicator phenolphthalein. (1 mark)

The students performed the titration and found an average titre of 16.65 mL of NaOH(aq) was required to reach the second equivalence point.

(c) Calculate the milligrams of phosphorus present in a 375 mL can of Coca-Cola. (6 marks)

In Step 2 and 3 of the method, the Coca-Cola is heated and cooled. This causes the following reaction to occur, which removes the carbonic acid present in the soft drink.

$$H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$$

(d) Justify why this step is important for the **validity** of the experiment. (2 marks)

One group of students only heated their Coca-Cola samples for 5 minutes, before performing each titration.

(e) Classify this error as random or systematic. Justify your choice and state the likely effect this would have on the students' calculated phosphorus content. (3 marks)

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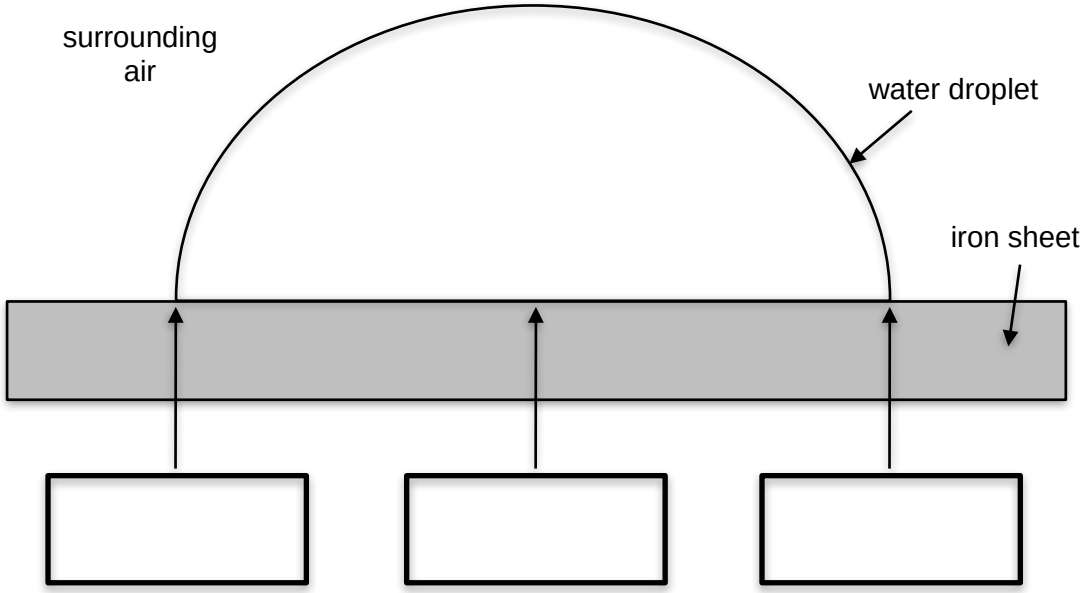
Question 39 **(18 marks)**

Iron is used widely in modern society, in structures such as bridges and buildings, in reinforced concrete as well as piping, and to manufacture cars and ships. The corrosion of iron to form rust is a costly and potentially dangerous problem, and a great deal of money is spent trying to prevent, reduce and repair the damage caused by the corrosion of iron.

The corrosion of iron to form rust involves a sequence of reactions. The process generally begins when iron comes into contact with water and oxygen. The overall equation for the initial redox reaction involved in the corrosion of iron can be represented by the following chemical equation.

$$2\ Fe(s) + O_2(g) + H_2O(l) \rightarrow 4\ OH^-(aq) + 2\ Fe^{2+}(aq)$$

The diagram below shows a close-up view of a water droplet on a sheet of iron.



(a) In the boxes on the diagram, label these sites as cathodic or anodic. (2 marks)

(b) On the diagram above, label the direction of cation and anion flow. Your labels should indicate the **identity** of each ion. (2 marks)

(c) Demonstrate that this reaction is a redox process, using oxidation numbers to support your answer. (2 marks)

The next step in the reaction sequence to form rust, involves the formation of a precipitate.

(d) Write a balanced ionic equation for this step. (1 mark)

The product of this precipitation reaction is further oxidised to solid iron(III) hydroxide, which then dehydrates to form orange-brown rust, $Fe_2O_3.H_2O(s)$. This is illustrated in the chemical equation below.

$$2\ Fe(OH)_3(s) \rightarrow Fe_2O_3.H_2O(s) + 2\ H_2O(l)$$

The mass of a sample of iron sheet was recorded. After a period of time, rust formed on the surface of the iron. All traces of the rust were then scraped off, and the new mass of the iron sheet was recorded. The results are shown in the table below.

Initial mass of iron (g)	84.2 g
Final mass of iron (g)	77.1 g

(e) Calculate the volume of $O_2(g)$ that would have reacted to produce this rust. The partial pressure of $O_2(g)$ in air is 21.2 kPa and the temperature of the air was 19.3 °C. State your answer to the appropriate number of significant figures. (5 marks)

(f) Calculate the maximum mass of rust, $Fe_2O_3.H_2O(s)$, that would have formed from this corrosion. (2 marks)

This experiment was repeated with a galvanised iron sheet (i.e. an iron sheet coated in zinc), which was exposed to identical conditions, for the same period of time. The galvanised iron sheet showed no signs of rust.

(g) Explain these observations. (4 marks)

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Question 40 **(20 marks)**

The buffering capacity of seawater results from the presence of hydrogencarbonate, $HCO_3^-(aq)$ and carbonate, $CO_3^{2-}(aq)$ ions. The chemical equation for this buffer is given below.

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

(a) Define a buffer. (2 marks)

(b) Describe how the large increase in atmospheric $CO_2(g)$ caused by human activity, results in a higher $H_3O^+(aq)$ concentration in seawater. (Note: chemical equations are **not** required in your answer). (3 marks)

(c) Justify, using Le Chatelier's principle, how the hydrogencarbonate / carbonate buffer system in seawater responds to this increase in $H_3O^+(aq)$. (2 marks)

A group of chemistry students collected a sample of seawater and decided to investigate its buffering capacity. They placed two 100 mL samples of the seawater into separate beakers and measured the initial pH.

To one beaker they added 0.005 mol L^{-1} HCl(aq) in 1 mL aliquots, whilst measuring the pH. To the other beaker, they added 0.005 mol L^{-1} NaOH(aq) in 1 mL aliquots, whilst measuring the pH.

Their results are shown in the table below.

		Volume of acid / base added (mL)										
Solution added		0	1	2	3	4	5	6	7	8	9	10
pH	HCl(aq)	8.2	8.2	8.1	8.1	8.0	7.8	7.5	7.0	6.2	5.0	3.0
	NaOH(aq)	8.2	8.2	8.3	8.3	8.4	8.4	8.5	8.5	8.6	8.7	8.9

(d) Plot this data on the same set of axes, using the grid below. (5 marks)

(e) Does seawater contain a higher concentration of HCO_3^-(aq) or CO_3^{2-}(aq)? Justify your answer, by referring to the data collected in this investigation. (4 marks)

In addition to an increased H_3O^+(aq) ion concentration, the increase in atmospheric CO_2(g) also has a negative impact on many marine calcifying species, such as cuttlefish.

(f) State two (2) negative consequences associated with the cuttlefish not being able to form its internal calcium carbonate shell. (2 marks)

(g) Suggest two (2) ways humans can reduce their production of CO_2(g). (2 marks)

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Question 41 **(19 marks)**

Gold is a precious metal that humankind has used for thousands of years. Over the centuries there have been many methods used to extract gold from its ore. Whilst it is a relatively unreactive metal, it does dissolve in alkaline solutions of cyanide. This discovery, in 1783, lead to the development of the 'gold cyanidation' process, which is widely used today.

In the extraction of gold, the ore is first ground and crushed. Water and sodium cyanide solution, NaCN(aq), are then added to form a slurry. This mixture is then left for 16 - 48 hours with a stream of oxygen gas passing through the mixture. During this time 'gold leaching' occurs. This process results in the gold being oxidised to the (+1) oxidation state and dissolving into solution to form the aurocyanide ion.

This process can be represented by the 'Elsner equation'.

$$4\ Au(s) + 8\ CN^-(aq) + O_2(g) + 2\ H_2O(l) \rightarrow 4\ Au(CN)_2^-(aq) + 4\ OH^-(aq)$$

A sample of gold-bearing ore was crushed and placed in a tank, along with 25 kL of leaching solution. The initial concentration of NaCN(aq) in the leach solution was 0.478 g L^{-1}. After 48 hours, this had fallen to 0.083 g L^{-1}.

(a) Calculate the mass of gold that was leached into solution. (6 marks)

(b) Calculate the final pH of the leaching solution. (You may assume that only the $OH^-(aq)$ ions produced are contributing to pH). (4 marks)

There are several techniques used to separate the gold from the leaching solution, one of which is the Merill-Crowe process. Once the slurry has been filtered, zinc dust is then added to the leaching solution to precipitate the gold. The Merill-Crowe process can be represented by the following chemical equation.

$$2\ Au(CN)_2^-(aq) + 3\ Zn(s) \rightarrow 3\ Zn^{2+}(aq) + 8\ CN^-(aq) + 2\ Au(s)$$

(c) State the oxidant and the reductant in this process. (2 marks)

(d) Explain, in terms of the collision theory, why zinc **dust** is used to precipitate the gold out of solution. (3 marks)

Once the gold has been precipitated, filtration is again used to separate the reaction mixture. This results in a solid filtrate composed of Au(s) as well as excess Zn(s).

A solution of sulfuric acid is then added to this Au(s) / Zn(s) mixture.

(e) Explain how this would allow separation of the two metals to occur. Use data from your standard reduction potential table to support your answer. (4 marks)

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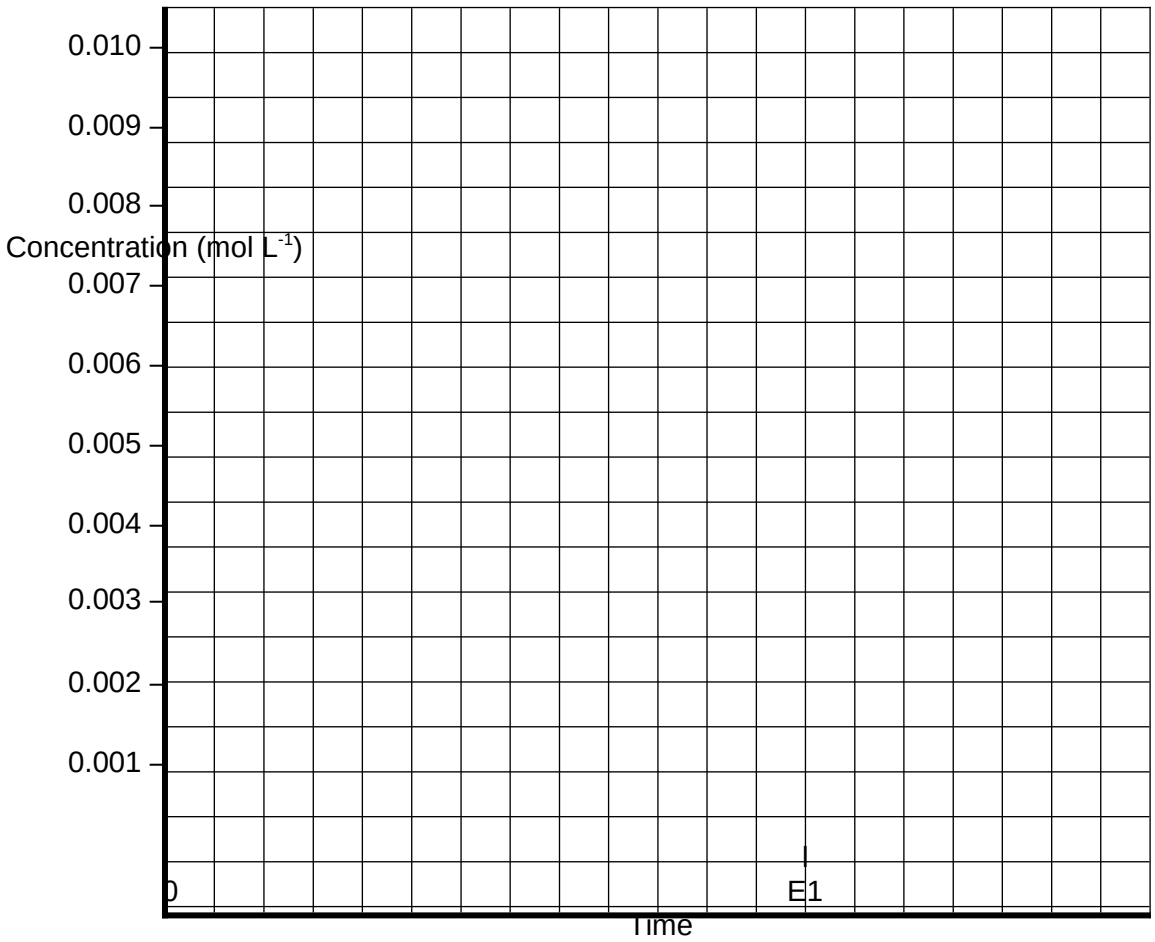
Question 37 (b)



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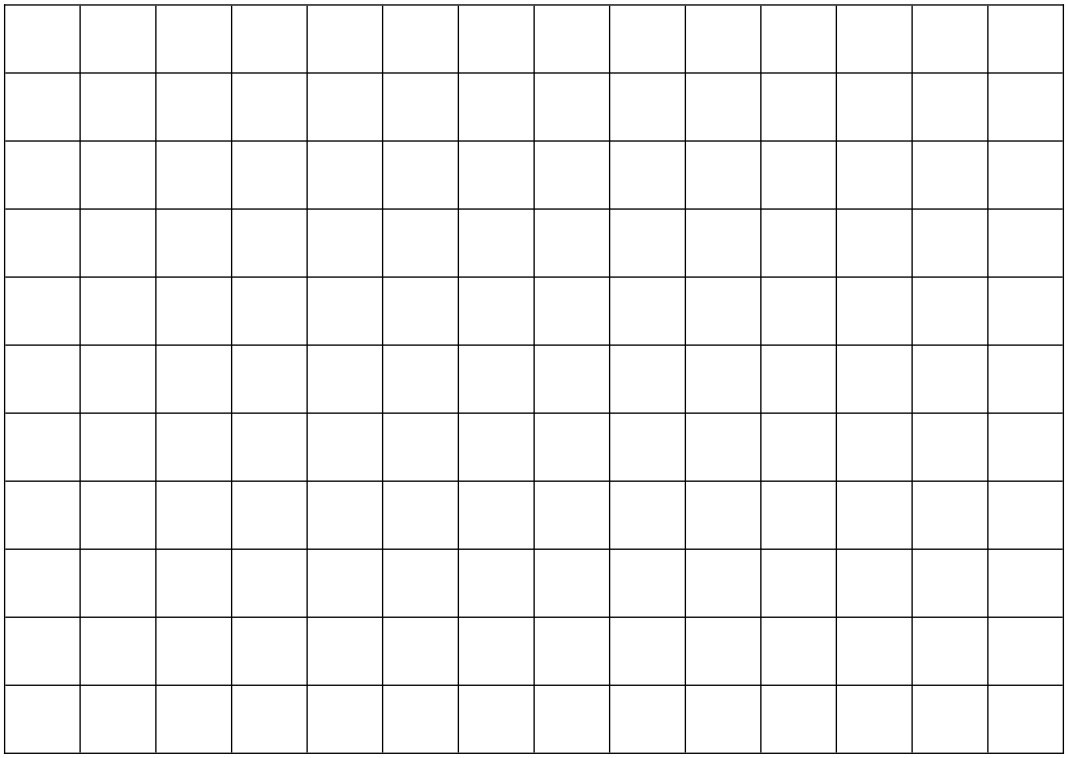
Question 40 (d)