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CHEMISTRY

UNIT 3

2020

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 examination
Section One Multiple-choice	25	25	50	/ 25	/ 25
Section Two Short answer	8	8	60	/ 82	/ 35
Section Three Extended answer	5	5	70	/ 98	/ 40
					/ 100

Instructions to candidates

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

- When calculating numerical answers, show your working or reasoning clearly. Your working should be in sufficient detail to allow your answer 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.
- You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.
- 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.
- The Chemistry Data booklet is not to be handed in with your Question/Answer booklet.

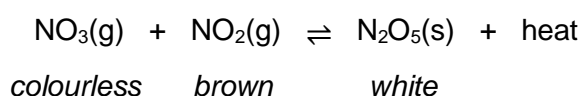
Section One: Multiple-choice**25% (25 marks)**

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.

Questions 1, 2 and 3 relate to the following equilibrium system.

Samples of $\text{NO}_3(\text{g})$ and $\text{NO}_2(\text{g})$ were injected into an empty flask and equilibrium was established according to the following equation.



1. While the system was establishing equilibrium, which of the following would **not** be observed?
 - (a) The brown gas colour fades.
 - (b) A white solid appears.
 - (c) The pressure in the flask increases.
 - (d) The temperature in the flask increases.

2. Which of the following conditions would increase the value of K for this equilibrium?
 - (a) Decreasing the temperature of the system.
 - (b) Increasing the temperature of the system.
 - (c) Decreasing the volume of the system.
 - (d) Increasing the volume of the system.

3. Which of the following conditions would favour a high equilibrium yield of $\text{N}_2\text{O}_5(\text{s})$?
 - (i) Increased concentrations of $\text{NO}_3(\text{g})$ and $\text{NO}_2(\text{g})$
 - (ii) Increased volume of system
 - (iii) Increased subdivision of $\text{N}_2\text{O}_5(\text{s})$
 - (iv) Increased temperature of system
 - (a) (i) only.
 - (b) (ii) only.
 - (c) (i) and (iii) only.
 - (d) (ii) and (iv) only.

4. 'Black powder' is typically composed of solid potassium nitrate and charcoal dust ($\text{C}_7\text{H}_4\text{O}$). When this powder is ignited, the products formed are a mixture of solid potassium carbonate, carbon dioxide gas, water vapour and nitrogen gas.

Identify the element oxidised and reduced in this reaction.

	Oxidised	Reduced
(a)	N	K
(b)	C	N
(c)	O	N
(d)	C	H

5. Compare the four halogens in their elemental form; $\text{F}_2(\text{g})$, $\text{Cl}_2(\text{g})$, $\text{Br}_2(\text{l})$ and $\text{I}_2(\text{s})$. Which of the following statements is **correct**?

- (a) $\text{F}_2(\text{g})$ exists in the highest oxidation state.
- (b) $\text{Cl}_2(\text{g})$ is the strongest reducing agent (reductant).
- (c) $\text{Br}_2(\text{l})$ has the lowest tendency to gain electrons.
- (d) $\text{I}_2(\text{s})$ has the lowest reduction potential.

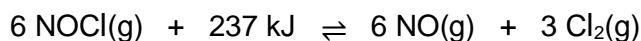
6. Which metal is **least** likely to be found in the anode slime/mud of a cell performing the electrolytic refining of copper metal?

- (a) Au
- (b) Pb
- (c) Ag
- (d) Pt

7. Using a chemical equation, the Arrhenius theory of acids and bases **would be** able to justify the pH of a solution of

- (a) nitric acid.
- (b) ammonia.
- (c) potassium carbonate.
- (d) lithium fluoride.

8. Consider the following equilibrium system.



A chemist wanted to;

- favour the reverse reaction
- decrease the rate of the reverse reaction
- maintain a constant K value

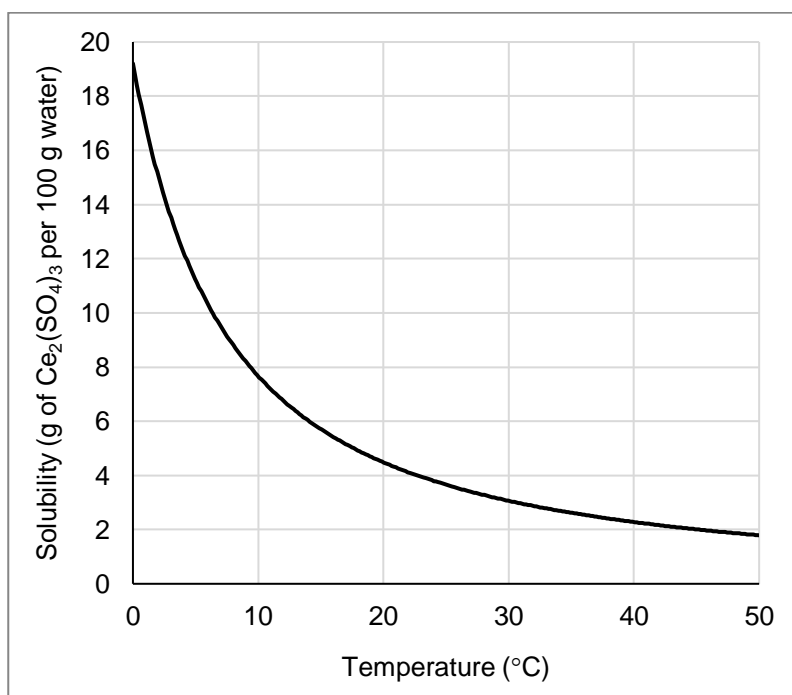
Which change should they impose on the system to satisfy all 3 criteria?

- (a) Decrease the temperature of the system.
- (b) Decrease the volume of the system.
- (c) Remove some $\text{NOCl}(\text{g})$ from the system.
- (d) Add some $\text{NO}(\text{g})$ to the system.

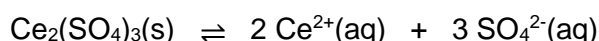
Questions 9 and 10 refer to the following redox reaction.

A small piece of potassium metal was placed into a large bowl of water, which contained a few drops of universal indicator.

9. Which of the following would **not** be observed?
- (a) The silver metal dissolves.
 - (b) A colourless, odourless gas is produced.
 - (c) The solution colour changes from green to orange.
 - (d) Heat is produced.
10. Select the correct statement with regards to the reaction that took place.
- (a) The oxidation number of potassium decreases.
 - (b) The oxidation number of oxygen increases.
 - (c) Hydrogen atoms are oxidised.
 - (d) Water is the oxidising agent (oxidant).
11. Consider the following graph, which provides information regarding the solubility of cerium(III) sulfate, $\text{Ce}_2(\text{SO}_4)_3(\text{s})$, at various temperatures.



An 8 g sample of $\text{Ce}_2(\text{SO}_4)_3(\text{s})$ was added to a beaker containing 100 g of water at 20 °C. Equilibrium was established according to the following equation.



If the temperature of the system is decreased, which of the following is **not** correct?

- (a) The conductivity of the solution would increase.
- (b) The rate of dissociation would increase.
- (c) The forward reaction would be favoured.
- (d) The value of K would increase.

12. The endothermic autoionisation of water can be represented by the equation below.



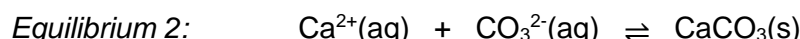
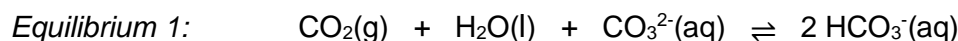
Distilled water at a temperature of 15 °C would have

- (a) a concentration of hydronium ions greater than $1.0 \times 10^{-7} \text{ mol L}^{-1}$.
(b) a concentration of hydroxide ions greater than $1.0 \times 10^{-7} \text{ mol L}^{-1}$.
(c) a K_w value greater than 1.0×10^{-14} .
(d) a pH greater than 7.
13. 'Disproportionation' refers to a redox reaction, where atoms of a particular element within a single species are simultaneously oxidised and reduced. Which of the following would **not** be regarded as a disproportionation reaction?
- (a) $\text{Cl}_2(\text{g}) + 2 \text{OH}^-(\text{aq}) \rightarrow \text{ClO}^-(\text{aq}) + \text{Cl}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$
(b) $2 \text{H}_2\text{O}_2(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
(c) $\text{NH}_4\text{NO}_3(\text{s}) \rightarrow \text{N}_2\text{O}(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$
(d) $2 \text{CuCl}(\text{s}) \rightarrow \text{CuCl}_2(\text{s}) + \text{Cu}(\text{s})$

Questions 14 and 15 refer to the equilibria associated with calcification.

Ocean acidification is a complex process which changes the chemistry of seawater and affects various marine organisms. Calcifying species use the $\text{Ca}^{2+}(\text{aq})$ and $\text{CO}_3^{2-}(\text{aq})$ in seawater to produce $\text{CaCO}_3(\text{s})$, which then forms structures such as the shells or exoskeletons of marine organisms.

Two of the chemical equilibria associated with the process of calcification are shown below.



14. State the effect of an increased $\text{CO}_2(\text{g})$ concentration on the rate of each forward reaction.

	Equilibrium 1	Equilibrium 2
(a)	increased rate	decreased rate
(b)	increased rate	increased rate
(c)	decreased rate	increased rate
(d)	decreased rate	decreased rate

15. State the effect of an increased $\text{CO}_2(\text{g})$ concentration on the equilibrium position of each reaction.

	Equilibrium 1	Equilibrium 2
(a)	reverse favoured	forward favoured
(b)	reverse favoured	reverse favoured
(c)	forward favoured	reverse favoured
(d)	forward favoured	forward favoured

16. Consider the reaction between aqueous sodium hydrogencarbonate and hydrochloric acid solution. The sodium hydrogencarbonate was present in excess and the reaction was allowed to proceed to completion.

Which of the following would **not** be correct, once the reaction was complete?

- (a) $[\text{Na}^+(\text{aq})] > [\text{Cl}^-(\text{aq})]$
 (b) $[\text{HCO}_3^-(\text{aq})] > [\text{Na}^+(\text{aq})]$
 (c) $[\text{H}_3\text{O}^+(\text{aq})] > [\text{OH}^-(\text{aq})]$
 (d) $[\text{Cl}^-(\text{aq})] > [\text{H}_3\text{O}^+(\text{aq})]$

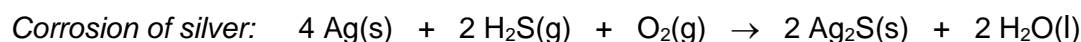
17. When zinc metal is placed into a solution of 1 mol L^{-1} nitric acid, nitrogen dioxide gas is formed and the zinc metal dissolves.

Which redox equation **best** represents the reaction occurring?

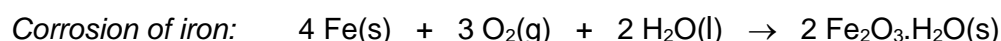
- (a) $\text{Zn(s)} + 2 \text{HNO}_3(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$
 (b) $\text{Zn(s)} + \text{NO}_3^-(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$
 (c) $\text{Zn(s)} + 2 \text{NO}_3^-(\text{aq}) + 4 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$
 (d) $\text{Zn(s)} + \text{HNO}_3(\text{aq}) + 3 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$

Questions 18 and 19 refer to metal corrosion.

Silver metal is particularly susceptible to a form of corrosion known as tarnishing. The chemical equation for this corrosion process is shown below.



The corrosion of iron is a particularly damaging and expensive problem, due to the extensive use of iron in modern life. The chemical equation for this corrosion process is shown below.



18. Select the option which correctly identifies the change in oxidation number of each element involved in the process of silver corrosion.

	Ag	H	S	O
(a)	(0) to (+1)	no change	no change	(0) to (-2)
(b)	no change	(0) to (+1)	no change	(0) to (-2)
(c)	(0) to (+2)	no change	(-2) to (-4)	no change
(d)	(0) to (+1)	no change	(-2) to (-4)	no change

19. Select the statement that is **not** common to both the corrosion of silver **and** the corrosion of iron.

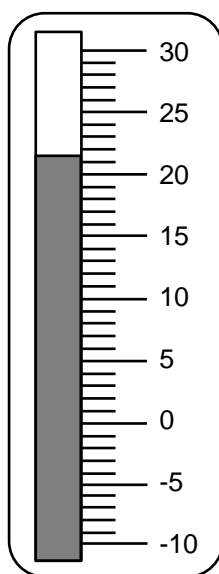
- (a) The metal is the anodic site.
 (b) Oxygen gas is the oxidising agent.
 (c) The metallic element forms a compound.
 (d) A thin layer of metallic oxide forms on the metals.

Questions 20, 21 and 22 relate to the experimental data collected below.

A group of chemistry students was measuring the temperature change associated with a particular chemical reaction. They used a thermometer to record the initial and final temperature of the reaction mixture, in order to investigate the change in enthalpy associated with the reaction.

The data they collected, along with a diagram of the thermometer used, is provided below.

	Trial 1	Trial 2
Initial temperature (°C)	22	23
Final temperature (°C)	21	24



20. The data collected was
- (a) primary and stated to the appropriate degree of accuracy.
 - (b) secondary and stated to the appropriate degree of accuracy.
 - (c) primary and not stated to the appropriate degree of accuracy.
 - (d) secondary and not stated to the appropriate degree of accuracy.
21. An appropriate conclusion the students could draw from this data was that the reaction being investigated
- (a) is exothermic.
 - (b) is endothermic.
 - (c) is neither exothermic nor endothermic.
 - (d) requires further investigation before making a statement regarding enthalpy change.
22. Select the **least** appropriate description of the data.
- (a) It has been collected in an unethical manner.
 - (b) It is unreliable at this point in time.
 - (c) It contains sources of uncertainty.
 - (d) It contains sources of random error.

23. Four beakers (A, B, C and D) were placed on a laboratory bench, each containing distilled water and several drops of universal indicator. A small sample of a different salt was then dissolved into each beaker, according to the table below.

Beaker A	Beaker B	Beaker C	Beaker D
+ $\text{NH}_4\text{NO}_3(\text{s})$	+ $\text{MgF}_2(\text{s})$	+ $\text{KCH}_3\text{COO}(\text{s})$	+ $\text{Na}_3\text{PO}_4(\text{s})$

The colour of the solution in beaker

- (a) A would change from green to blue.
- (b) B would change from green to yellow.
- (c) C would change from green to orange.
- (d) D would change from green to purple.

Questions 24 and 25 relate to the electrolysis of tin(II) chloride.

24. When **molten** tin(II) chloride is electrolysed, tin metal and chlorine gas are produced.

Select the **correct** statement regarding the electrolysis of molten tin(II) chloride.

- (a) Tin metal forms at the anode.
- (b) Tin(II) ions are oxidised.
- (c) Chloride ions migrate towards the positive electrode.
- (d) Electrons move from the negative to positive electrode.

25. When **aqueous** tin(II) chloride is electrolysed, tin metal is still formed, however oxygen gas is produced rather than chlorine gas.

This result suggests that the water present in the electrolyte is

- (a) reduced at the cathode.
- (b) oxidised at the cathode.
- (c) reduced at the anode.
- (d) oxidised at the anode.

End of Section One

See Next Page

Section Two: Short answer**35% (82 marks)**

This section has **8** 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.

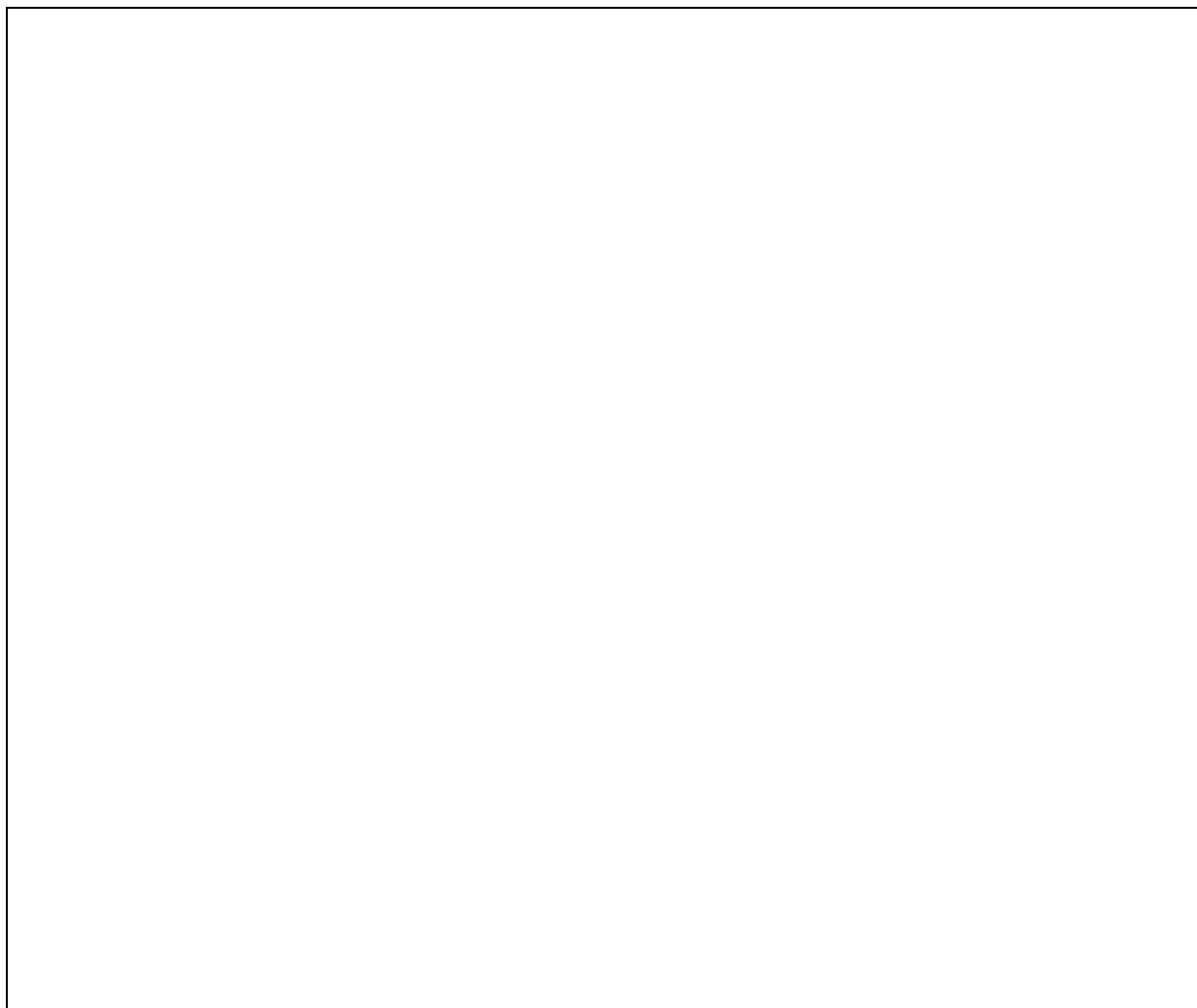
Suggested working time: 60 minutes.

Question 26**(8 marks)**

The Wohlwill process is used for the electrolytic refining of metallic gold (Au). This method involves a similar process to that of the electrorefining of copper metal.

Sketch a diagram showing how this process could be set up. Your diagram should include the following labels;

- the materials used for the electrodes and electrolyte
- the anode and cathode
- the polarity (sign) of each electrode
- the direction of cation flow



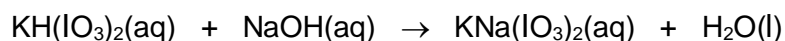
Question 27

(7 marks)

Potassium hydrogen iodate, $\text{KH}(\text{IO}_3)_2$, can be used as a primary standard in acid-base titrations, providing the percentage purity of the solid is known.

An 8.435 g sample of **impure** $\text{KH}(\text{IO}_3)_2(\text{s})$ was dissolved in distilled water, transferred to a volumetric flask and made up to 500.0 mL. Then 25.00 mL aliquots of this solution were titrated against standardised $0.05084 \text{ mol L}^{-1} \text{ NaOH}(\text{aq})$. An average titre of 20.70 mL was required to reach the equivalence point.

The chemical equation for the titration reaction that occurred is given below.



Calculate the percentage purity of the $\text{KH}(\text{IO}_3)_2(\text{s})$ that was used in this experiment.

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Question 28**(12 marks)**

Permanganic acid (HMnO_4) can be found as an unstable red-violet solution which decomposes at temperatures above 40°C .

It can be made by mixing a solution containing manganese(II) ions with powdered lead dioxide, PbO_2 , in the presence of sulfuric acid. This suspension is then stirred. The reaction produces permanganic acid and a precipitate of lead(II) sulfate.

- (a) Write oxidation and reduction half-equations and an overall redox equation for this reaction. You may assume the sulfuric acid is present entirely as $\text{H}^+(\text{aq})$ and $\text{SO}_4^{2-}(\text{aq})$. (6 marks)

Oxidation half-equation	
Reduction half-equation	
Overall redox equation	

The reaction to produce permanganic acid is performed at a low temperature, to prevent the spontaneous decomposition of $\text{HMnO}_4(\text{aq})$.

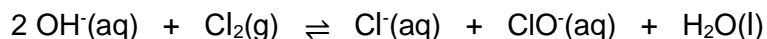
- (b) Explain, in terms of the collision theory, why a low temperature will inhibit this decomposition reaction. (4 marks)

Permanganic acid is known to be a strong acid.

- (c) Write the K_a expression for permanganic acid and give an indication of the expected K_a value. (2 marks)

Question 29**(10 marks)**

Consider the following reaction that has been allowed to establish equilibrium.



The following table considers the effects of imposing different changes upon this system.

- (a) Complete the following table by predicting which direction would be favoured, as well as the resulting effect on the concentration of $\text{ClO}^-(\text{aq})$ when compared with the original equilibrium. Consider each of the imposed changes in isolation. (8 marks)

Imposed change	Favoured direction (forward, reverse, no shift)	Effect on final concentration of $\text{ClO}^-(\text{aq})$ (increase, decrease, no change)
A small amount of $\text{NaClO}(\text{s})$ was added		
The volume of the canister was decreased		
Distilled water was added		
Several drops of $2 \text{ mol L}^{-1} \text{Mg}(\text{NO}_3)_2(\text{aq})$ was added		

A chemist decided to verify their predictions experimentally. They set up the equilibrium system described above, created the various imposed changes described in part (a) and examined the results.

- (b) Would the equilibrium system in this experiment be considered 'open' or 'closed' when the imposed changes were being made? Justify your answer. (2 marks)

Question 30

(10 marks)

A water tank contained 25.0 kL of contaminated water with a pH of 10.1. A chemist decided to add some solid acetylsalicylic acid crystals to the water tank, to lower the pH. Acetylsalicylic acid is a monoprotic acid with the formula $\text{C}_9\text{H}_8\text{O}_4$ ($M = 180.158 \text{ g mol}^{-1}$).

Calculate the mass of acetylsalicylic acid crystals that should be added to the tank and dissolved in the water, to lower the pH to 7.8.

[illegible]

Question 31**(11 marks)**

A chemistry class was given four (4) jars labelled A, B, C and D.

Each jar contained small pieces of a silver-coloured metal. The teacher informed the students that the metals were tin, cobalt, cadmium and nickel.

The students were asked to design an investigation that would determine the identity of the metal in each jar.

The students set up 4 test tubes, each containing 5 mL of 1.0 mol L⁻¹ lead(II) nitrate solution, Pb(NO₃)₂(aq). A piece of each different metal was then added to each test tube. The students' observations are recorded in the table below.

	Observations
Pb(NO ₃) ₂ (aq) + metal A	A silver metal dissolves in a colourless solution. A new grey solid and a green solution are produced.
Pb(NO ₃) ₂ (aq) + metal B	A silver metal dissolves in a colourless solution. A new grey solid is produced. Solution remains colourless.
Pb(NO ₃) ₂ (aq) + metal C	A silver metal dissolves in a colourless solution. A new grey solid is produced. Solution remains colourless.
Pb(NO ₃) ₂ (aq) + metal D	A silver metal dissolves in a colourless solution. A new grey solid and a pink solution are produced.

(a) Identify metals A and D.

(2 marks)

A	
D	

To distinguish between metals B and C, one student suggested adding a piece of each to separate solutions of aqueous nickel bromide, $\text{NiBr}_2(\text{aq})$.

- (b) Justify how this would allow metals B and C to be distinguished. Include observations for both samples and a relevant chemical equation in your answer. (5 marks)

- (c) Using the results of this investigation, how would the students be able to identify which of the metals (A, B, C or D) was the strongest reducing agent (reductant)? (2 marks)

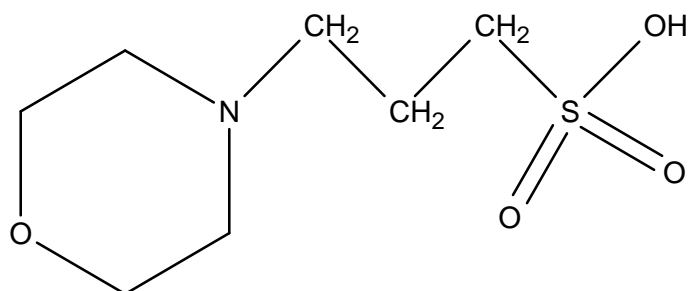
Another test tube containing $\text{NiBr}_2(\text{aq})$ was set up and some chlorine water was added to this solution. The test tube was stoppered and gently shaken.

- (d) Write oxidation and reduction half-equations for the reaction that would occur. (2 marks)

Oxidation half-equation	
Reduction half-equation	

Question 32**(12 marks)**

The name MOPS refers to the compound '3-morpholinopropane-1-sulfonic acid'. The chemical structure of MOPS is shown below.



The molecular formula of MOPS is $C_7H_{15}NO_4S$. MOPS is a weak, monoprotic acid.

- (a) Write a Bronsted-Lowry equation illustrating how MOPS dissolves in water. Use the molecular formula given. (2 marks)

MOPS is commonly used in buffer solutions. The simplest way to produce this buffer is using the sodium salt of MOPS.

- (b) Give the molecular formula of the sodium salt of MOPS. (1 mark)

A solution was made by dissolving 75 g of the sodium salt of MOPS into 200 mL of distilled water.

- (c) Justify, with the use of a relevant chemical equation, whether the pH of this solution would be acidic, basic or neutral. (3 marks)

An **equal mass** of solid MOPS was then added to the beaker containing the solution of the sodium salt. The mixture was stirred until all solid had dissolved.

A student tested the buffering capacity of the resulting solution. They were able to add 9 mL of 1 mol L⁻¹ NaOH(aq) before the pH of the buffer rose significantly. However, they were only able to add 6 mL of 1 mol L⁻¹ HCl(aq) before a similar fall in pH was noted.

- (d) Define 'buffering capacity'. (2 marks)

- (e) Explain why this buffer solution had a higher buffering capacity upon addition of excess base. (4 marks)

Question 33**(12 marks)**

On a table of standard reduction potentials, the 'hydrogen half-cell' or 'standard hydrogen electrode' is designated an EMF of 0 V. The standard hydrogen half-cell is set up using a platinum electrode, hydrogen gas (H_2) and a solution containing hydrogen ions (H^+).

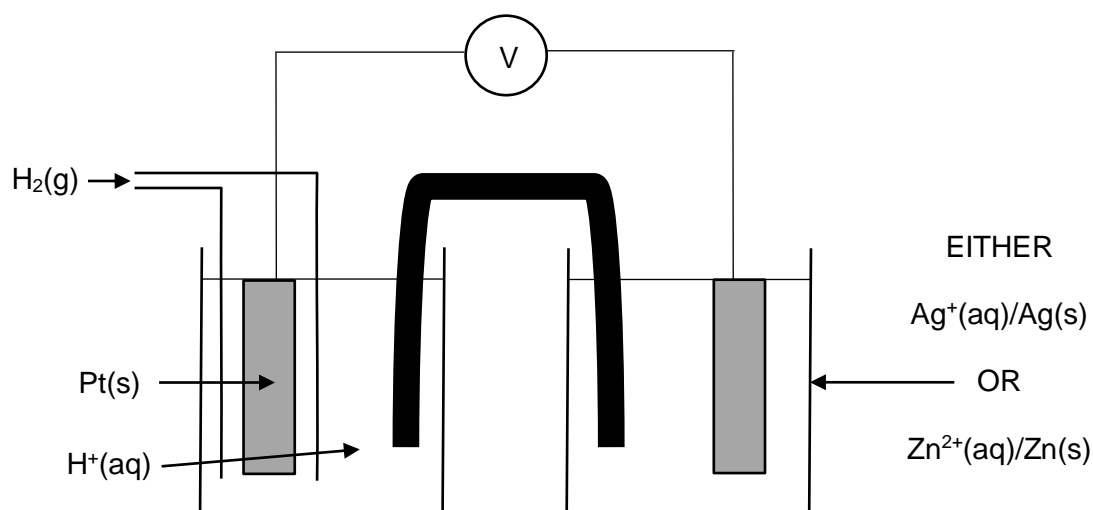
- (a) State the values that would be used when setting up the hydrogen half-cell under standard conditions. (2 marks)

Partial pressure of $\text{H}_2(\text{g})$	
Concentration of $\text{H}^+(\text{aq})$	

A standard hydrogen half-cell was joined by wires and a salt bridge to a second half-cell. Two different experiments were performed;

- In Experiment 1, the $\text{Ag}^+(\text{aq})/\text{Ag}(\text{s})$ half-cell was used.
- In Experiment 2, the $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ half-cell was used.

A diagram of the experimental set up is shown below. Assume all half-cells were set up under standard conditions.



- (b) In which experiment would the greater EMF have been produced? State the value of this EMF. (2 marks)

- (c) Discuss how the role of the hydrogen half-cell differs in Experiment 1 and 2. Include a relevant half-equation for the hydrogen half-cell in each case. (6 marks)

- (d) State the function of the salt bridge in this experiment. (2 marks)

End of Section Two

See Next Page

Section Three: Extended answer**40% (98 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.

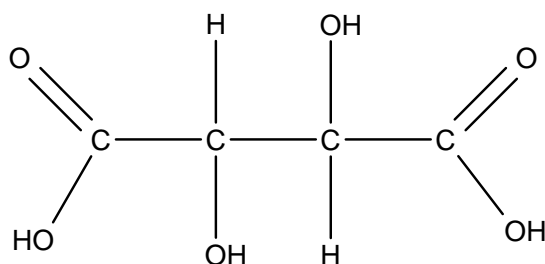
Suggested working time: 70 minutes.

Question 34**(24 marks)**

The pH of wine is usually between 2.9 - 3.9, depending on the type of wine and the type of grapes used to make the wine. The 'total acidity' of wine, is a measure of the total amount of all the various acids present in wine. This is also referred to as the '**total ionisable hydrogen**' present, i.e. all the hydrogen in the wine that has the ability to ionise and contribute to overall acidity.

The total acidity of wine is monitored carefully during the winemaking process. Too much acid can result in the wine being sour, whilst too little can cause the wine to taste flat and lack freshness. Total acidity is measured before the grapes are harvested, after the wine is produced, and then as the wine ages. There are many different weak acids that are found in wine, such as tartaric acid, malic acid, citric acid and succinic acid.

Generally, the most abundant acid found in wine is tartaric acid, $C_4H_6O_6$. Tartaric acid is a weak, diprotic acid found in grapes, as well as other fruits such as bananas, tamarinds and citrus fruits. Its chemical structure is shown below.



Grapes that are grown in a warmer climate usually contain lower concentrations of tartaric acid than those grown in cooler climates. The concentration of tartaric acid from grapes grown in warmer regions is generally in the range of 2-3 g L⁻¹, whilst for grapes grown in cooler areas the concentration is around 6 g L⁻¹.

To determine the total acidity of wine, a titration is performed. A sample of wine is titrated against a strong base, and the number of moles of OH⁻(aq) required to reach the equivalence point is said to be equal to the number of moles of '**total ionisable hydrogen**' present in the wine.

A 10.00 mL sample of wine was taken and made up to 100.0 mL with distilled water. Then 20.00 mL aliquots of the dilute wine were titrated against a standard solution of 0.01575 mol L⁻¹ KOH(aq). An average titre of 16.73 mL was required to reach equivalence.

- (a) Calculate the concentration of 'total ionisable hydrogen' in the 10.00 mL sample of wine. State your answer to the appropriate number of significant figures. (6 marks)

Using a digital pH meter, the pH of the wine was measured to be 3.2.

- (b) Calculate the concentration of hydronium (hydrogen) ions present in the wine. Justify why this concentration does not match the concentration of 'total ionisable hydrogen' calculated in part (a). (3 marks)

Since tartaric acid is **diprotic**, there are two possible salts that can be produced in a neutralisation reaction with potassium hydroxide solution; potassium bitartrate ($\text{KC}_4\text{H}_5\text{O}_6$) and potassium tartrate ($\text{K}_2\text{C}_4\text{H}_4\text{O}_6$). One of these salts is acidic and one is basic.

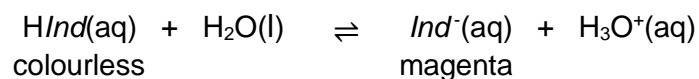
- (c) Complete the table below, by classifying each salt as acidic or basic. Give a relevant hydrolysis equation to support each of your choices. (3 marks)

Salt	Acidic / Basic	Equation
$\text{KC}_4\text{H}_5\text{O}_6$		
$\text{K}_2\text{C}_4\text{H}_4\text{O}_6$		

The pH at the equivalence point of this titration is known to be approximately 8.2.

- (d) Use this information to write a balanced equation for the reaction that takes place between potassium hydroxide and tartaric acid in this titration. (2 marks)

The acid-base indicator phenolphthalein is used in this titration. The general equation below can be used to represent phenolphthalein indicator.



- (e) State the colour change that would be observed in the conical flask during this titration. Justify how this colour change occurs, using the equation above and Le Chatelier's principle. (5 marks)

It is known that 62.4% of the 'total ionisable hydrogen' in this particular wine was contributed by tartaric acid ($\text{C}_4\text{H}_6\text{O}_6$).

- (f) Calculate the concentration of tartaric acid in the wine in grams per litre (g L^{-1}). State (by circling your choice below) whether the grapes used to make this wine are likely to have been grown in a warm or cool climate. (5 marks)

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Grapes were most likely grown in a;
(circle your choice)

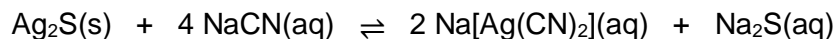
warm
climate

4

cool
climate

Question 35**(19 marks)**

Silver metal can be extracted from the ore 'argentite' which contains the compound $\text{Ag}_2\text{S}(\text{s})$. In the first step of this extraction process, the ore containing $\text{Ag}_2\text{S}(\text{s})$ is crushed, and then a solution of sodium cyanide, $\text{NaCN}(\text{aq})$, is added to leach the silver out of the ore. This forms the complex ion sodium argentocyanide, $\text{Na}[\text{Ag}(\text{CN})_2](\text{aq})$, as shown in the equation below.



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

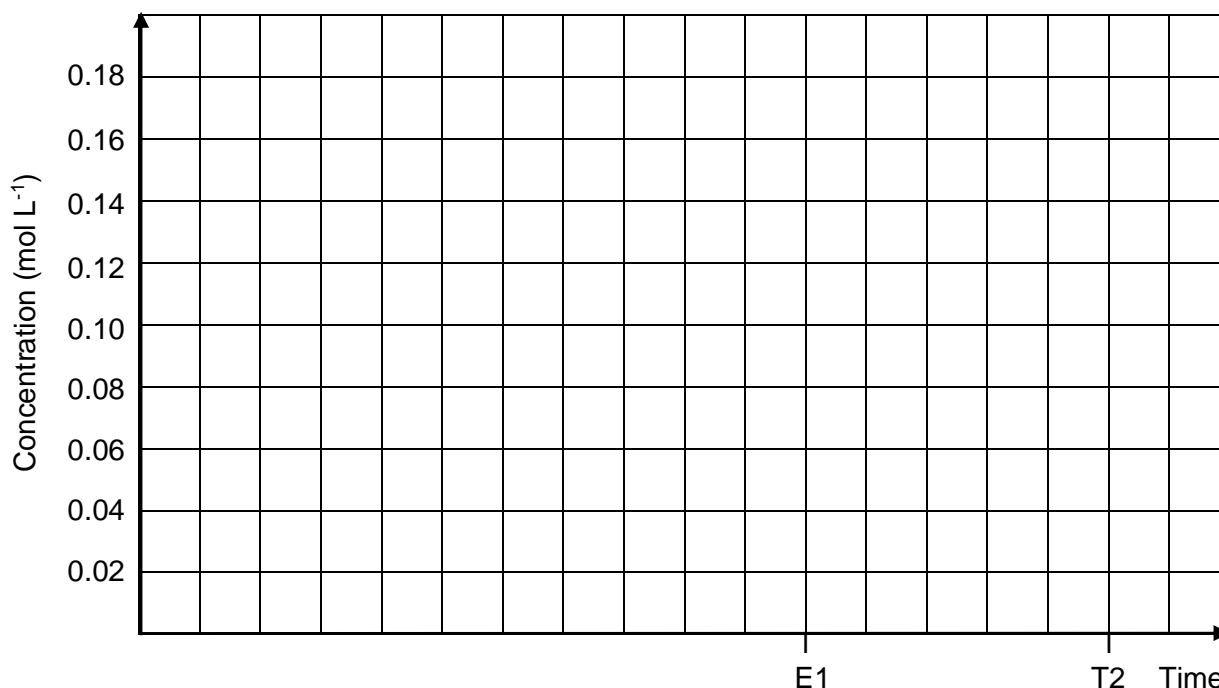
If 12.5 kL of $5.0 \text{ g L}^{-1} \text{NaCN}(\text{aq})$ was added to the leaching tank and poured over the crushed ore;

- (b) Calculate the maximum mass of $\text{Ag}_2\text{S}(\text{s})$ that could react. (4 marks)

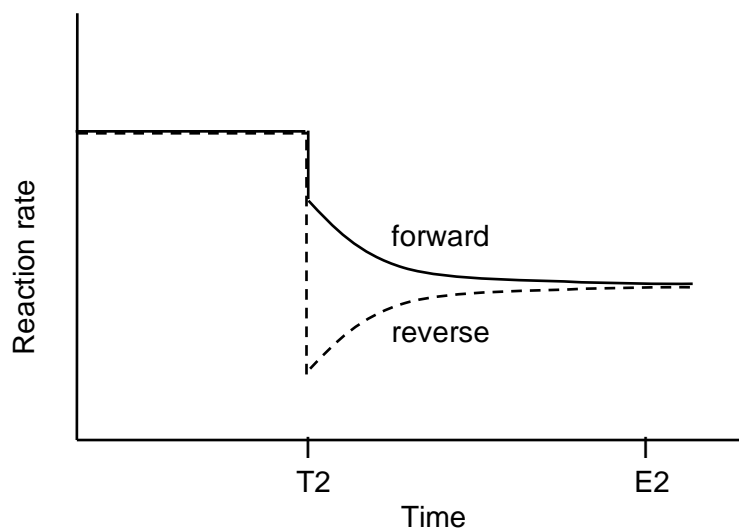
- (c) Explain, in terms of the collision theory, why the ore is crushed before mixing with the NaCN(aq) solution. (3 marks)

A particular leach tank contained an excess mass of crushed argentite ore containing $\text{Ag}_2\text{S}(\text{s})$. A 0.16 mol L^{-1} solution of NaCN(aq) was poured over the ore, and the reactants were mixed. At Time E1, equilibrium was established. The concentration of the NaCN(aq) was measured again and found to be 0.04 mol L^{-1} .

- (d) On the axes below, sketch curves showing the concentration of all relevant species, from Time 0 until the establishment of equilibrium at Time E1. Continue your curves from Time E1 to Time T2. Label each curve. (5 marks)



At Time T2, a temperature change is imposed on the system. The following rate graph was drawn to illustrate the effects of this imposed change.



- (e) State whether the temperature was increased or decreased at Time T2. (1 mark)

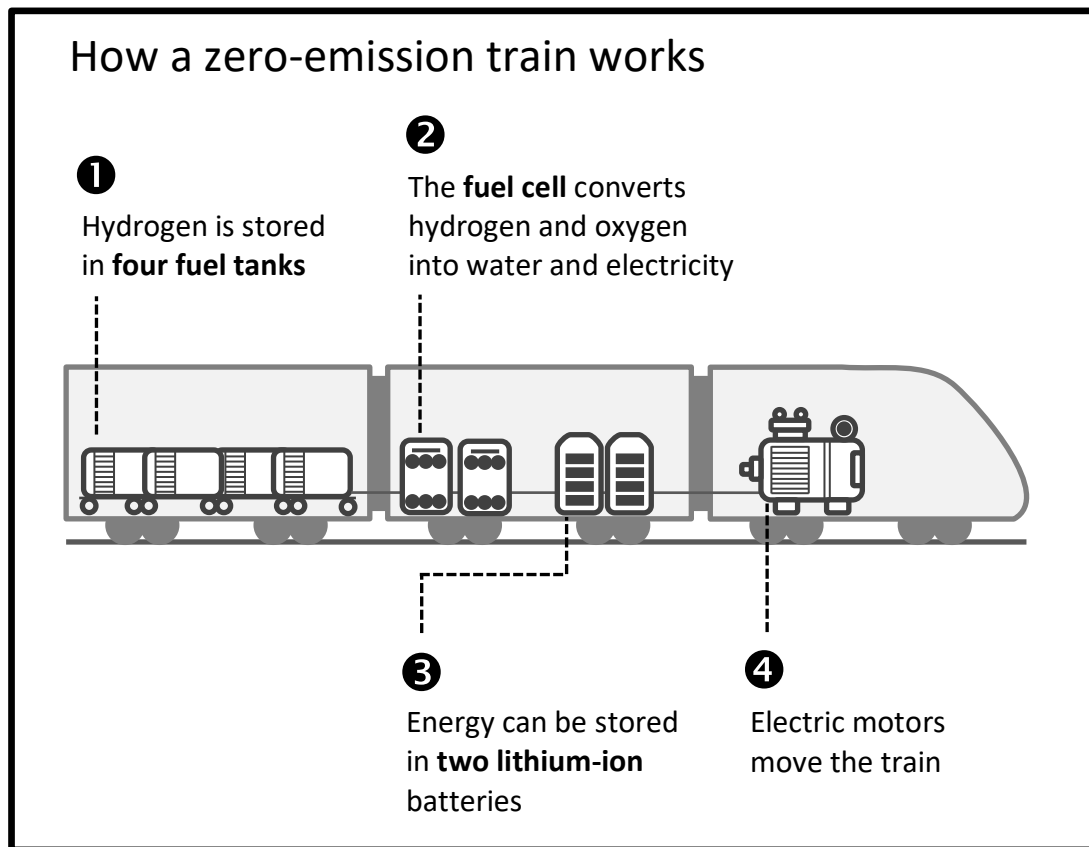
- (f) Justify, using the information provided in the rate graph above, whether the forward reaction is endothermic or exothermic. (4 marks)

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Question 36**(19 marks)**

The 'Hydroflex' train was launched in the United Kingdom last year, as Britain's first hydrogen-fuelled train. The technology is currently being trialled, but the government is hoping that hydrogen trains will be in common use by 2022, and that all diesel trains will be removed from use by 2040.

The diagram below provides some information about how the hydrogen train works.



The fuel cell used is more specifically described as a 'polymer electrolyte membrane' (or PEM) fuel cell stack. These cells function at a temperature of around 50-100 °C. The electrolyte is a water-based acidic polymer membrane.

- (a) Write oxidation and reduction half-equations and an overall equation to represent the reaction occurring in the PEM fuel cell. Calculate the EMF produced under standard conditions. (4 marks)

Reduction half-equation	
Oxidation half-equation	
Overall equation	
EMF under standard conditions	

The PEM is also often called a 'proton-exchange membrane' because one of its main functions is to conduct protons from one half-cell to another. The design of the PEM is instrumental in the function of the fuel cell. As well as conducting protons it has to;

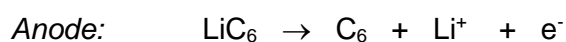
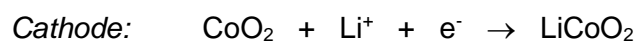
- separate the two half-reactions
- prevent hydrogen and oxygen gas crossover
- allow the conduction of protons but not the conduction of electrons
- resist degradation from the surrounding environment.

(b) At which electrode are protons produced? Justify your answer. (2 marks)

(c) Why must the PEM have the ability to conduct protons but **not** electrons? (2 marks)

As shown in the diagram on the previous page, the hydrogen train also contains lithium-ion batteries. These are similar in design to those used in electric vehicles, mobile phones and other portable devices.

The chemistry of lithium-ion cells is quite complex, but in general, relies on the transfer of lithium ions between electrodes. The relevant half-equations for a lithium-ion battery are given below.



(d) Justify why fuel cells and lithium-ion batteries can both be classified as 'galvanic' cells. (2 marks)

- (e) Classify the lithium-ion battery as a 'primary' or 'secondary' cell. Justify your choice using the information provided. (3 marks)

One of the main advantages of replacing current diesel-powered trains with hydrogen trains is to reduce carbon dioxide emissions. The increase in atmospheric $\text{CO}_2(\text{g})$ is a primary cause of global warming, but can also lead to other negative environmental consequences such as ocean acidification.

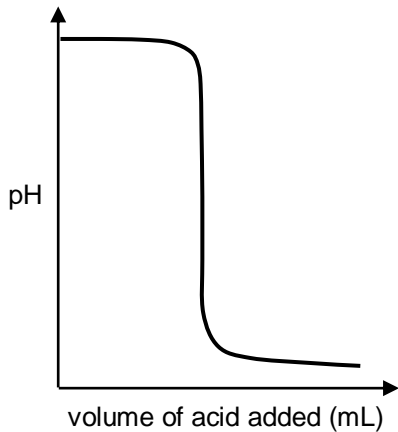
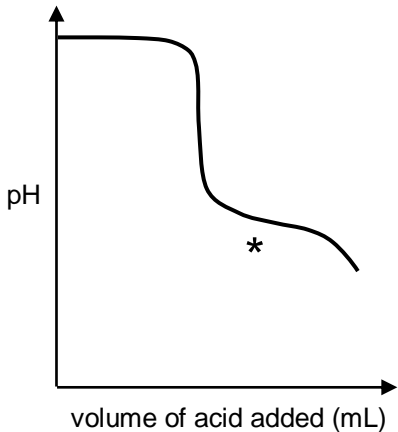
- (f) Describe, using relevant chemical equations, how an increase in atmospheric $\text{CO}_2(\text{g})$ has led to a decrease in the pH of our oceans. (6 marks)

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Question 37**(18 marks)**

A group of chemistry students were comparing and contrasting two different acid-base titrations. They set up 'Titration A' and 'Titration B' as follows;

	Titration A	Titration B
Substance in conical flask	20.00 mL of 0.10 mol L ⁻¹ NaOH(aq)	20.00 mL of 0.10 mol L ⁻¹ NaOH(aq)
Substance in burette	0.10 mol L ⁻¹ HCl(aq)	0.10 mol L ⁻¹ CH ₃ COOH(aq)
Sketch of titration curve		

- (a) In the table above, label the equivalence point on **both** titration curves. (2 marks)
- (b) State the pH at the equivalence point in Titration A. Justify your answer. (3 marks)

- (c) In Titration A, state the volume of HCl(aq) that would have been added from the burette to reach the equivalence point. (Note that a calculation is not required.) (1 mark)

- (d) Would the volume of $\text{CH}_3\text{COOH(aq)}$ required to reach the equivalence point in Titration B be higher, lower or equal to the volume of HCl(aq) required in Titration A? Circle your choice below, and briefly justify your answer. (2 marks)

higher

lower

equal

The students decided to investigate Titration A in more detail. Once they had successfully reached the equivalence point, they added 5 extra drops of HCl(aq) .

- (e) Calculate the pH of the resulting solution within the conical flask. Assume the volume of 1 drop is equal to 0.05 mL. (5 marks)

As can be seen in the curve for Titration B, if extra $\text{CH}_3\text{COOH}(\text{aq})$ is added after the equivalence point has been reached, the change in pH is much less pronounced. In fact, the addition of 5 extra drops of $\text{CH}_3\text{COOH}(\text{aq})$ lowers the pH by much less than 2 units.

- (f) Complete the table below, by listing the next two **compounds** with highest concentration (after water) that would be present in the conical flask for Titration B, when 5 drops of $\text{CH}_3\text{COOH}(\text{aq})$ has been added past the equivalence point. (2 marks)

Titration A	Titration B
1. $\text{H}_2\text{O}(\text{l})$	1. $\text{H}_2\text{O}(\text{l})$
2. $\text{NaCl}(\text{aq})$	2.
3. $\text{HCl}(\text{aq})$	3.

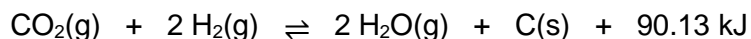
Further addition of $\text{CH}_3\text{COOH}(\text{aq})$ past the equivalence point (the region indicated by * on the titration curve) continues to cause a much smaller change in pH, compared to Titration A.

- (g) Justify why, upon addition of excess acid after equivalence, the change in pH in Titration B occurs to a much lesser degree than in Titration A. (3 marks)

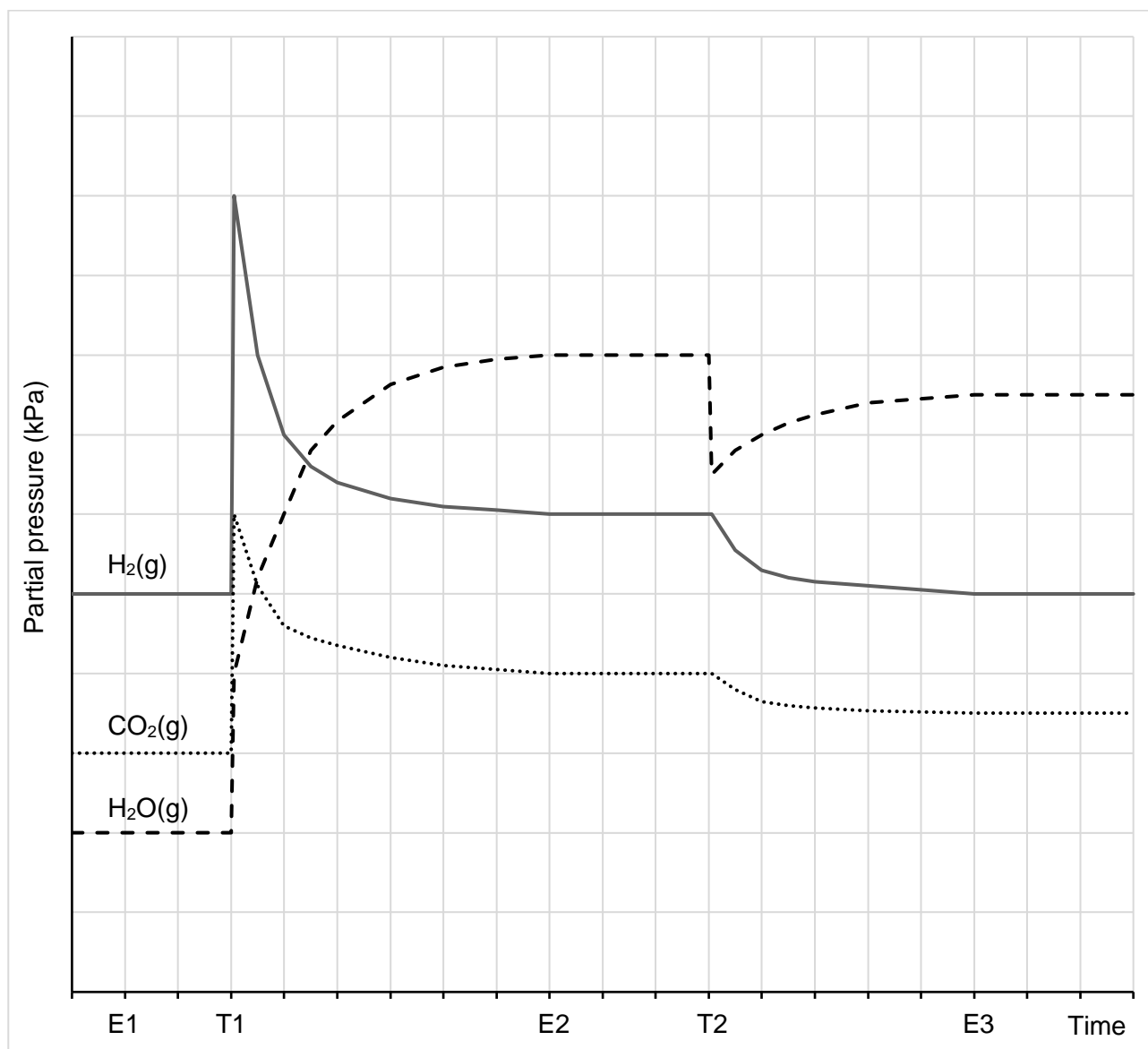
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Question 38**(18 marks)**

The Bosch reaction has applications in space travel and is utilised aboard space shuttles, since it is able to remove carbon dioxide from the air and generate clean water in the process. The reaction requires a metallic catalyst such as iron, cobalt or nickel. The equation for the Bosch reaction is given below.



Consider a reaction chamber, where the Bosch reaction has been allowed to establish equilibrium. The graph below shows the effect of imposing different changes on the system.



- (a) State the change imposed on the system at Time T1. (1 mark)

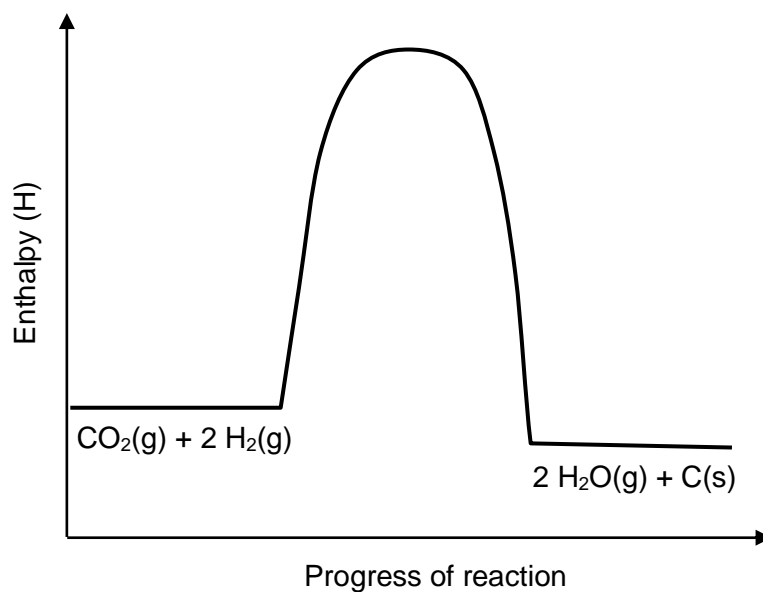
- (b) Explain, in terms of the collision theory, the effect of the imposed change at Time T1 on the position of equilibrium. (4 marks)

- (c) State the change imposed on the system at Time T2, as well as the effect this change has on the position of equilibrium. (2 marks)

- (d) Complete the table below, regarding the changes that would be observed in reaction rate in response to the change imposed at Time T2. In each box of the table, write either 'increased', 'decreased' or 'no change'. Your answers should be stated in comparison to the previous equilibrium that had been established at Time E2. (4 marks)

	Immediate change in rate (increase / decrease / no change)	Final / overall change in rate (increase / decrease / no change)
Forward reaction		
Reverse reaction		

The energy profile diagram for the Bosch reaction is shown below. The reaction has a very high activation energy and must be carried out at a temperature greater than 450 °C. It is only mildly exothermic.



- (e) Comment on the likely reversibility of this reaction. (2 marks)

- (f) Add to the energy profile diagram above, by indicating the effect of including metallic iron in the reaction system. (1 mark)

- (g) Explain, in terms of the collision theory, the role of the iron in this reaction. (4 marks)

End of questions

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