



Hale School
Year 12 Semester 1 Examination,
2018

Yr12 ATAR CHEMISTRY
UNIT 3

Write your name below:

Solutions

Circle your teacher's initials:

PRB

KF

AD

TIME ALLOWED FOR THIS PAPER

Reading time before commencing: Ten minutes
Working time for paper: Three hours

For Examiners only	
Section 1	
Section 2	
Section 3	
Total	

MATERIAL REQUIRED/RECOMMENDED FOR THIS PAPER

TO BE PROVIDED BY THE SUPERVISOR

This Question/Answer booklet for Sections 1 & 2.
A separate Question/Answer booklet for Section 3.
A separate Multiple Choice Answer sheet for Section 1.
A Chemistry Data Sheet.

TO BE PROVIDED BY THE CANDIDATE

Standard Items: Pens, pencils, eraser, ruler

Special Items: A calculator satisfying the conditions set by the Curriculum Council, and a '2B' pencil for the separate Multiple Choice Answer sheet.

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. Please check carefully, and if you have any unauthorised material with you, hand it to the supervisor **BEFORE** reading any further.

INSTRUCTIONS TO CANDIDATES

This paper consists of **THREE SECTIONS** as follows:

SECTION 1 contains **25 questions worth 2 marks each**. It is the multiple choice section.

Answer **ALL** questions in Section 1 on the Separate Multiple Choice Answer Sheet. Use a '**2B**' **PENCIL. DO NOT USE A BALL POINT OR INK PEN.** If you consider that two or more of the alternative answers are correct then select the BEST alternative. Marks will **NOT** be deducted for incorrect answers. This part is worth 50 marks and should take about 45 minutes.

Do not use pencil for Sections 2 & 3.

SECTION 2 contains **11 short answer questions**. You should answer **ALL** the questions. The answers are to be written in the spaces provided in this Examination booklet. This part is worth 72 marks and should take about 60 minutes.

SECTION 3 contains **6 extended response and calculation questions**. You should answer **ALL** the questions in detail in the **separate question/answer booklet provided**. This part is worth 90 marks and should take about 75 minutes.

At the end of the examination make sure that your **name** is on this Examination paper, the separate Question/Answer Booklet for Section 3 and your Multiple Choice Answer Sheet.

SPECIAL INSTRUCTIONS

Chemical Equations

For full marks, chemical equations should refer only to those species consumed in the reaction and any new species produced. These species may be **ions** [for example $\text{Ag}^+(\text{aq})$], **molecules** [for example $\text{NH}_3(\text{g})$, $\text{NH}_3(\text{aq})$, $\text{CH}_3\text{COOH}(\text{l})$, $\text{CH}_3\text{COOH}(\text{aq})$] or **solids** [for example $\text{BaSO}_4(\text{s})$, $\text{Cu}(\text{s})$, $\text{Na}_2\text{CO}_3(\text{s})$].

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Multiple-choice	25	25	45	50	24
Section Two: Short answer	11	11	60	72	34
Section Three: Extended answer	6	6	75	90	42
Total				212	100

Section One: Multiple-choice**24% (50 Marks)**

This section has **25** questions. Answer **all** questions on the separate Multiple-choice Answer Sheet Provided. For each question shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square, do not erase or use correction fluid, and shade your new answer. 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

1. Which of the following pairs of reagents could not be mixed to make a buffer solution?

- (a) NaOH(aq) and $\text{CH}_3\text{COOH(aq)}$
- (b) $\text{NaCH}_3\text{COO(s)}$ and $\text{CH}_3\text{COOH(aq)}$
- (c) NaOH(aq) and $\text{NaCH}_3\text{COO(s)}$**
- (d) $\text{NH}_4\text{Cl(s)}$ and $\text{NH}_3\text{(aq)}$

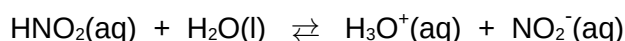
2. Which of the following processes is exothermic?

- (a) $2\text{Rb}^+(\text{g}) + \text{S}^{2-}(\text{g}) \rightarrow \text{Rb}_2\text{S(s)}$**
- (b) $\text{O}_3(\text{g}) \rightarrow 3\text{O}(\text{g})$
- (c) $\text{Mg}^+(\text{g}) \rightarrow \text{Mg}^{2+}(\text{g}) + \text{e}^-$
- (d) $\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$

3. When comparing 1.00 L of 0.100 mol L⁻¹ nitric acid with 1.00 L of 0.100 mol L⁻¹ ethanoic acid, which of the following statements is true?

- (a) Both acids react at the same rate with calcium carbonate solid.
- (b) The ethanoic acid would contain less hydroxide ions than the nitric acid
- (c) Both acids would require the same volume of 0.100 mol L⁻¹ NaOH solution for neutralisation**
- (d) The equilibrium constant for the hydrolysis of nitric acid is smaller than that for ethanoic acid


4. Nitrous acid ionises in water according to the following equation:



450 mL of water is added to 50 mL of nitrous acid solution at constant temperature. As a result of the dilution, at the new equilibrium, compared with the original solution, the

- (a) equilibrium constant for the reaction decreases
- (b) $[\text{H}_3\text{O}^+]$ in the solution is greater
- (c) pH of the solution is greater**
- (d) the amount in moles of H_3O^+ decreases

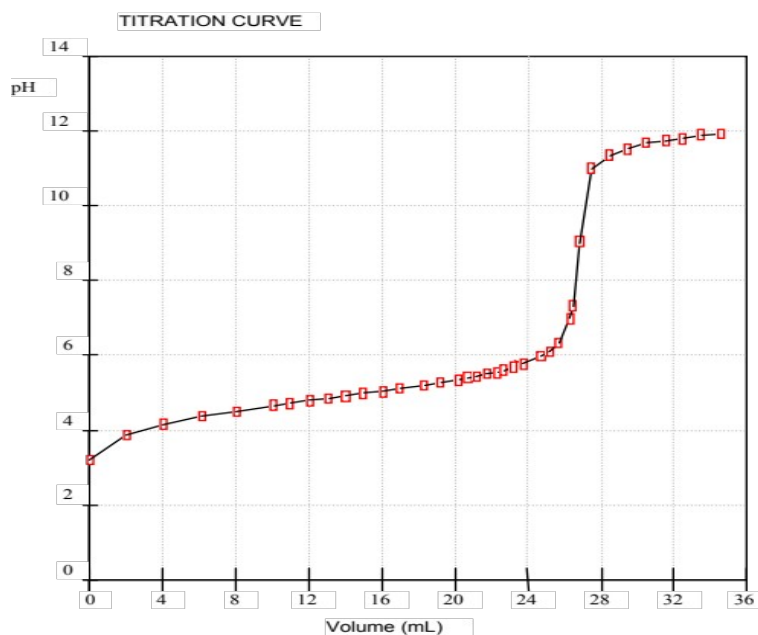
5. Consider the following indicators and their corresponding colour ranges in the table below:

Indicator name	
methyl orange	<div> <div>red</div> <div>→</div> <div>←</div> <div>yellow</div> </div>
bromothymol blue	<div> <div>yellow</div> <div>→</div> <div>←</div> <div>blue</div> </div>
azolitmin	<div> <div>red</div> <div>→</div> <div>←</div> <div>blue</div> </div>
cresol red	<div> <div>yellow</div> <div>→</div> <div>←</div> <div>red</div> </div>
Malachite green	<div> <div>→</div> <div>←</div> <div>yellow</div> <div>green</div> <div>→</div> </div>

Use the information in the table to decide which of the following are correct:

- Bromothymol blue and azolitmin will show the same colour in 0.001 KOH(aq)
 - Methyl orange is a good indicator for the titration of ammonia against hydrochloric acid solution
 - Azolitmin is able to distinguish between an aqueous solution of potassium carbonate and an aqueous solution of sodium cyanide.
 - Malachite green can distinguish a between a 1.0 mol L⁻¹ sulfuric acid solution and a 1.0 mol L⁻¹ carbonic acid solution
- (a) (ii) and (iv)
 (b) (ii), (iii) and (iv)
(c) (i), (ii) and (iv)
 (d) (i) and (ii) only
6. A saturated solution of calcium chromate consists of a yellow solution with a few yellow crystals of calcium chromate settled at the bottom of the solution.
- $$\text{CaCrO}_4(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CrO}_4^{2-}(\text{aq})$$
- What is observed when a few drops of concentrated calcium chloride solution is added to the mixture?
- (a) The yellow crystals dissolve and the solution becomes a darker yellow
(b) More yellow crystals form and the solution becomes a paler yellow
 (c) More yellow crystals form and the solution turns orange
 (d) The yellow crystals dissolve and the solution fades

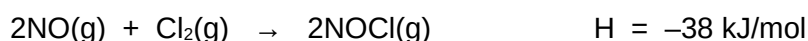
7. Consider the following titration curve:



Which of the following statements is **not correct** concerning this titration?

- (a) The titration is between a weak acid and a strong base
- (b) The equivalence point is basic due to the hydrolysis of the anion of the salt, producing hydroxide ions
- (c) The buffer region occurs when approximately 12.5 mL of base added from the burette
- (d) If phenolphthalein is used as the indicator the end point will not correspond with the equivalence point.

8. Nitrogen monoxide and chlorine react according to the equation:



The activation energy for the forward reaction is 62 kJ/mol. The activation energy for the reverse reaction is:

- (a) -62 kJ/mol
- (b) 24 kJ/mol
- (c) 38 kJ/mol
- (d) 100 kJ/mol

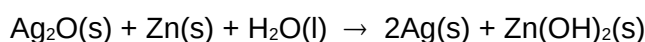
9. In which of the following reactions does the atom in **bold** show the greatest change in oxidation number?

- (a) **MnO₄⁻** to **Mn²⁺**
- (b) **MnO₂** to **Mn(OH)₃**
- (c) **PbO₂** to **PbSO₄**
- (d) **VO₂⁺** to **VO²⁺**

10. According to the Standard Reduction Potential Table, which of the following partially completed half reactions is able to oxidise Pb (s) to Pb²⁺ (aq), but is not able to oxidise aqueous iodide ions to solid iodine?

- (a) $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^-$
(b) $\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^-$
 (c) $\text{Br}_2(\text{l}) + 2\text{e}^-$
 (d) $2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$

11. The cell reaction occurring in some 'button' batteries, as current is drawn, is:



Which one of the following statements about the electrochemical cell is correct?

- (a) The anode is made of zinc and is oxidised.**
 (b) Silver forms the anode and is oxidised.
 (c) Zinc forms the cathode and is reduced.
 (d) Silver oxide forms the anode and is oxidised.
12. For a reversible reaction, catalysts alter
- (a) The heat of reaction for the forward reaction.
 (b) The size of the equilibrium constant.
(c) The time taken for an equilibrium to be established.
 (d) The yield achieved at equilibrium.
13. An indicator is red if the pH is less than 4.4 and yellow if the pH is greater than 6.2. The indicator is placed in 0.10 mol L⁻¹ solutions of KCN, H₂SO₄ and MgCl₂. The colours of the solutions are

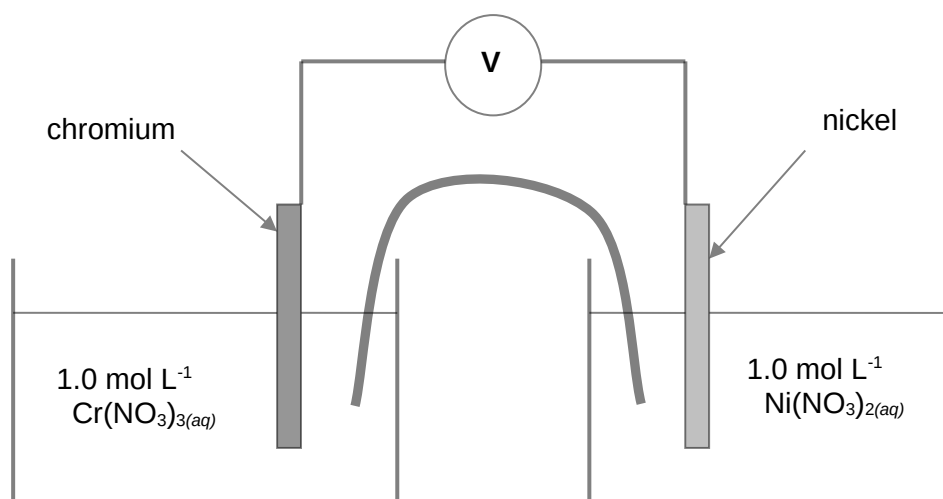
	KCN	H ₂ SO ₄	MgCl ₂
(a)	Red	Yellow	Yellow
(b)	Yellow	Red	Yellow
(c)	Red	Yellow	Red
(d)	Yellow	Red	Red

14. In which one of the following equations is the species in **bold** acting as a base?

- (a) $\text{H}_2\text{O} + \text{NH}_3 \rightleftharpoons \text{NH}_2^- + \text{H}_3\text{O}^+$**
 (b) $\text{HCO}_3^- + \text{NH}_3 \rightleftharpoons \text{CO}_3^{2-} + \text{NH}_4^+$
 (c) $\text{H}_2\text{PO}_4^- + \text{CH}_3\text{COOH} \rightleftharpoons \text{H}_3\text{PO}_4 + \text{CH}_3\text{COO}^-$
 (d) $\text{H}_2\text{CO}_3 + 2\text{Na} \rightleftharpoons 2\text{Na}^+ + \text{CO}_3^{2-} + \text{H}_2$

15. An acid-base titration is performed to determine the concentration of a sodium hydroxide solution. An aliquot of the sodium hydroxide solution is pipetted into a conical flask, while a standardised solution of propanoic acid is delivered from the burette. A student uses the indicator bromophenol blue, which changes colour at about pH 4. Which one of the following best explains why this is the incorrect choice of indicator?
- (a) Too much acid will be delivered and the calculated sodium hydroxide concentration will be too high.
 - (b) Too much acid will be delivered and the calculated sodium hydroxide concentration will be too low.
 - (c) Not enough acid will be delivered and the calculated sodium hydroxide concentration will be too high.
 - (d) Not enough acid will be delivered and the calculated sodium hydroxide concentration will be too low

Consider the following electrochemical cell to answer Questions 16 and 17



16. Which of the following statements is correct?
- (a) The nickel anode will increase in mass
 - (b) The electrode with a negative polarity will decrease in mass
 - (c) The concentration of Cr³⁺(aq) will decrease as the cell discharges
 - (d) Cations will move through the salt bridge towards the chromium half-cell
17. The main reason that an aqueous solution of potassium nitrate is suitable for use in a salt bridge is:
- (a) K⁺(aq) is a weak reductant
 - (b) NO₃⁻(aq) ions cannot be further oxidised
 - (c) Potassium and nitrate salts are always soluble in water
 - (d) It is available in pure form and does not react with the atmosphere

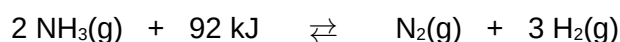
18. For which of the following conversions is an oxidising agent required?

- (a) $2\text{H}^+(\text{aq}) \rightarrow \text{H}_2(\text{g})$
 (b) $2\text{Br}^-(\text{aq}) \rightarrow \text{Br}_2(\text{aq})$
 (c) $\text{SO}_3(\text{g}) \rightarrow \text{SO}_4^{2-}(\text{aq})$
 (d) $\text{MnO}_2(\text{s}) \rightarrow \text{Mn}^{2+}(\text{aq})$

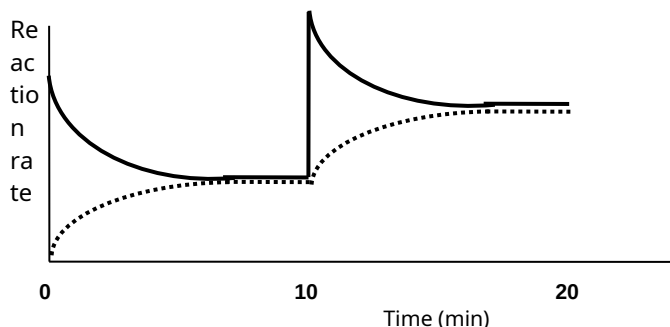
19. A titration was carried out to determine the vitamin C content of orange juice. 20.0 mL of diluted orange juice was pipetted into a conical flask. The burette was filled with standard sodium hydroxide solution. The correct choice for the final rinse of the glassware is

	Pipette	Burette	Conical Flask
(a)	distilled water	$\text{NaOH}(\text{aq})$	diluted orange juice
(b)	diluted orange juice	distilled water	distilled water
(c)	distilled water	distilled water	diluted orange juice
(d)	diluted orange juice	$\text{NaOH}(\text{aq})$	distilled water

20. Some ammonia gas is pumped into a sealed container whose volume can be increased or decreased. The reversible decomposition reaction begins immediately.



The forward and reverse reaction rates are measured and after 10 minutes a change is made to the gas system. The reaction rates are measured for a further 10 minutes. The graph at right shows how the rates of the forward and reverse reactions changed during the 20 minutes.

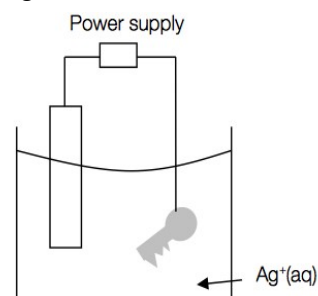


What change was made to the system after 10 minutes?

- (a) The volume of the gas mixture was decreased
 (b) More ammonia was pumped in
 (c) The mixture was heated
 (d) Some hydrogen was pumped in

21. A student decided to silver plate their locker key, as shown at right. Which of the following statements is correct ?

- (a) the key is the cathode
 (b) the cathode is silver metal
 (c) the key is the anode
 (d) electrons flow anticlockwise from the key



The following two questions **22** and **23** are about a step in the production of nickel at the Kwinana refinery. The reaction is represented by the following equation:



22. Which of the following conditions will increase the **yield** of nickel?

- (a) removing the nickel as soon as it forms
- (b) increasing the partial pressure of ammonia
- (c) **increasing the partial pressure of hydrogen**
- (d) increasing the total pressure of the system

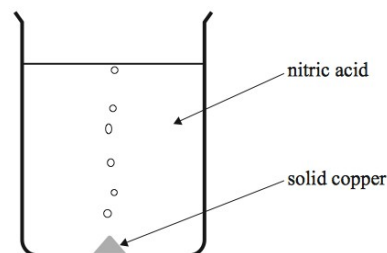
23. Which of the following will bring about the **fastest rate** of formation of nickel?

- (a) removing the nickel as soon as it forms
- (b) increasing the partial pressure of ammonia
- (c) **increasing the partial pressure of hydrogen**
- (d) decreasing the total pressure of the system

24. Copper reacts with concentrated nitric acid according to the following equation.



In the above reaction, the number of successful collisions per second is a small fraction of the total number of collisions. The **major** reason for this is that:



- (a) the nitric acid is only partially ionised
- (b) **not all the reactant particles have the minimum kinetic energy required for a successful collision**
- (c) copper is an unreactive metal
- (d) the reaction is endothermic

25. Using the standard reduction potential table predict which one of the following reactions could possibly occur spontaneously?

- (a) $\text{I}_2 + 2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{I}^-$
- (b) $\text{Cu}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Cu} + 2\text{H}^+ + \text{O}_2$
- (c) **$\text{H}_2\text{C}_2\text{O}_4 + \text{Br}_2 \rightarrow 2\text{Br}^- + 2\text{CO}_2 + 2\text{H}^+$**
- (d) $\text{Cr}_2\text{O}_7^{2-} + 11\text{H}^+ + 3\text{Cl}^- \rightarrow 2\text{Cr}^{3+} + 4\text{H}_2\text{O} + 3\text{HClO}$

End of Section One

Section Two: Short answer**34% (72 Marks)**

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

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**(4 marks)**

For each of the following reactions, give full observations. Include any colour changes, formation of a solid or evolution of a gas. If there is no reaction you need to state this.

- (a) A potassium permanganate solution is added, dropwise, into an acidified solution of hydrogen peroxide.

A purple solution is added to a colourless solution (✓), effervescence occurs, a colourless, odourless gas is produced & the purple solution turns pale pink (✓)

- (b) Cobalt carbonate is added to dilute hydrochloric acid solution.

A pink solid is added to a colourless solution (✓), effervescence occurs, a colourless, odourless gas is produced and the solution turns pink (✓)

No half marks! Important thing missing or incorrect equals minus 1

Question 27**(3 marks)**

A 0.00100 mol L⁻¹ solution of hydrochloric acid and a 0.0560 mol L⁻¹ solution of hydrofluoric acid both have a pH of 3.0. Explain fully why both solutions have the same pH.

HCl → H⁺ + Cl⁻ (100% ionisation) strong acid but dilute (✓)

HF ⇌ H⁺ + F⁻ (partial ionization) weak acid but more concentrated (✓)

Both have the same pH as they have the same [H⁺], since although HF is more concentrated, HF only partially ionises. (✓)

Question 28**(4 marks)**

Both sodium carbonate and sodium hydroxide react stoichiometrically with hydrochloric acid. Anhydrous sodium carbonate is a good primary standard often used in acid-base volumetric analysis to standardise hydrochloric acid solutions. Sodium hydroxide is not a primary standard substance.

- (a) Explain why sodium hydroxide is not used as a primary standard substance. (2 marks)

Sodium hydroxide cannot be obtained in its pure form (✓), as on exposure to air it will absorb moisture and also will react with carbon dioxide. (✓)

- (b) Distinguish between the terms 'equivalence point' and 'end point' of a titration. (2 marks)

Equivalence point

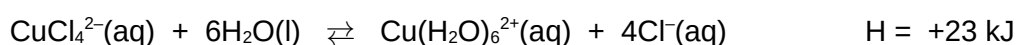
This is the point when the exact stoichiometric amounts of acid and base have been reacted (both have been fully consumed) (✓)

End point

This is the point in a titration when the indicator changes colour (✓)

Question 29**(8 marks)**

Consider 100 mL of a solution at 25°C and 100 kPa which contains the following equilibrium mixture.



Write 'increase', 'decrease' or 'no change' in the table to indicate the effect of the given change on the equilibrium yield and the rate of the forward reaction when equilibrium is re-established.

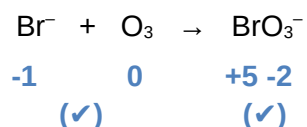
Imposed change	Effect on yield of $\text{Cu}(\text{H}_2\text{O})_6^{2+}$	Effect on rate of forward reaction
The temperature is decreased to 5°C	decrease	decrease
100 mL of distilled water is added	increase	decrease
The pressure is doubled	no change	no change
A few drops of concentrated lead nitrate solution are added	increase	decrease

Question 30

(8 marks)

Water is often purified by treatment with ozone. Any bromide ions present are converted to colourless bromate ions, BrO_3^- . Bromate ions are toxic, and so must be removed.

- (a) (i) Write the appropriate oxidation numbers on the lines under the equation. (2 marks)



- (ii) Identify the reducing agent and explain your choice using your answers to (i). (2 marks)

Reducing agent Br^- (\checkmark)

Explanation its oxidation number increases from -1 to +5 (\uparrow is oxidation) (\checkmark)

- (b) One way of removing the toxic bromate ions is to react the bromate ions with iodide ions. Bromide ions are reformed and the solution turns brown.

Deduce the oxidation and reduction half equations and give the balanced redox equation for this reaction. (4 marks)

Oxidation half equation



Reduction half equation



Balanced redox equation

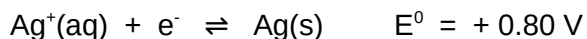
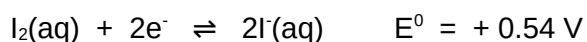


Question 31

(9 marks)

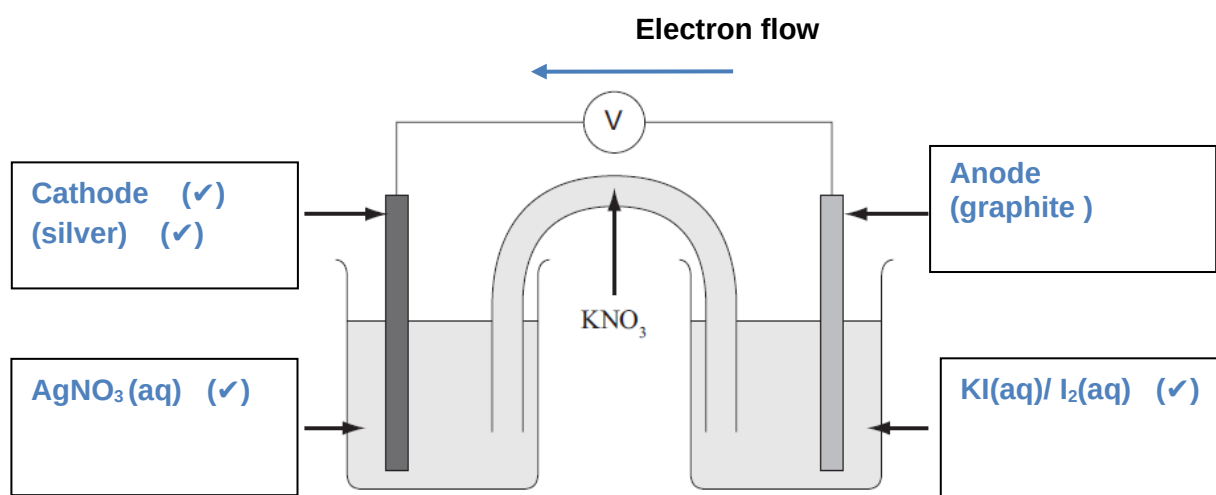
An electrochemical cell is set up under standard conditions of temperature, pressure and concentration, as sketched below.

The half-cells represented in the cell, and their respective reduction potentials, are:



(a) Complete the diagram below by

- Identifying the **solutions** and **electrode materials** (3 marks)
- Showing the **direction of electron flow** (1 mark)
- Labelling the **anode** and the **cathode** (1 mark)



(b) Describe the **observations** at each electrode:

(2 marks)

Anode: **A brown solution appears at the anode** (✓)

Cathode: **A silver-grey solid deposits on the cathode** (✓)

(c) What is the function of the salt bridge in an electrochemical cell?

(1 mark)

The salt bridge enables the flow of ions between the cells so as to complete the circuit within the electrochemical cell (✓)

(d) During the operation of an electrochemical cell, why is it important that the anode and cathode do not come into contact with each other?

(1 mark)

There is a charge separation so that the electrons can flow in the external circuit and create a current (electricity) (✓)

Question 32**(10 marks)**

- (a) Calculate the pH of the final solution when 100.0 mL of HNO_3 solution with a pH of 1.5 is mixed with 35.0 mL of $0.20 \text{ mol L}^{-1} \text{Ba(OH)}_2$ solution. (6 marks)

$$n(\text{H}^+) = cV = 10^{-1.5} \times 0.1 = 0.003162 \text{ mols} \quad (\checkmark)$$

$$n(\text{OH}^-) = 2 n(\text{Ba(OH)}_2) = 2 cV = 2 \times 0.2 \times 0.035 = 0.014 \text{ mols} \quad (\checkmark)$$

$$n(\text{OH}^-)_{\text{excess}} = 0.014 - 0.003162 = 0.010838 \text{ mols} \quad (\checkmark)$$

$$[\text{OH}^-] = n/V = 0.010838 / 0.135 = 0.08028 \text{ mol L}^{-1} \quad (\checkmark)$$

$$[\text{H}^+] = \frac{1 \times 10^{-14}}{0.08028} = 1.2456 \times 10^{-13} \text{ mol L}^{-1} \quad (\checkmark)$$

$$\text{pH} = -\log(\text{H}^+) = -\log(1.2456 \times 10^{-13}) = \underline{12.9} \quad (\checkmark)$$

- (b) 50.0 mL of distilled water is added to $10.0 \text{ mol L}^{-1} \text{HNO}_3$ solution to achieve a final concentration of 2.00 mol L^{-1} . What volume of the $10.0 \text{ mol L}^{-1} \text{HNO}_3$ is required and what is the final volume of the diluted acid? (4 marks)

Let V_1 = volume of conc HNO_3 , V_2 = volume of diluted acid

$$\text{hence } V_2 = 50 + V_1 \quad (\checkmark)$$

$$c_1 V_1 = c_2 V_2 \quad \rightarrow \quad (10 \text{ mol/L}) \times V_1 = (2 \text{ mol/L}) \times (50 + V_1) \quad (\checkmark)$$

$$10V_1 = 100 + 2V_1$$

$$8V_1 = 100$$

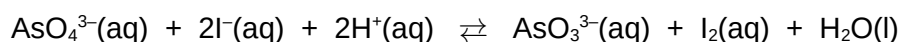
$$V_1 = \underline{12.5 \text{ mL}} \quad (\text{Volume of } \text{HNO}_3 \text{ required}) \quad (\checkmark)$$

$$V_2 = 50 + 12.5 = \underline{62.5 \text{ mL}} \quad (\text{Volume of diluted acid}) \quad (\checkmark)$$

Question 33

(6 marks)

Sodium arsenate solution can react with potassium iodide solution as represented by the following equation.

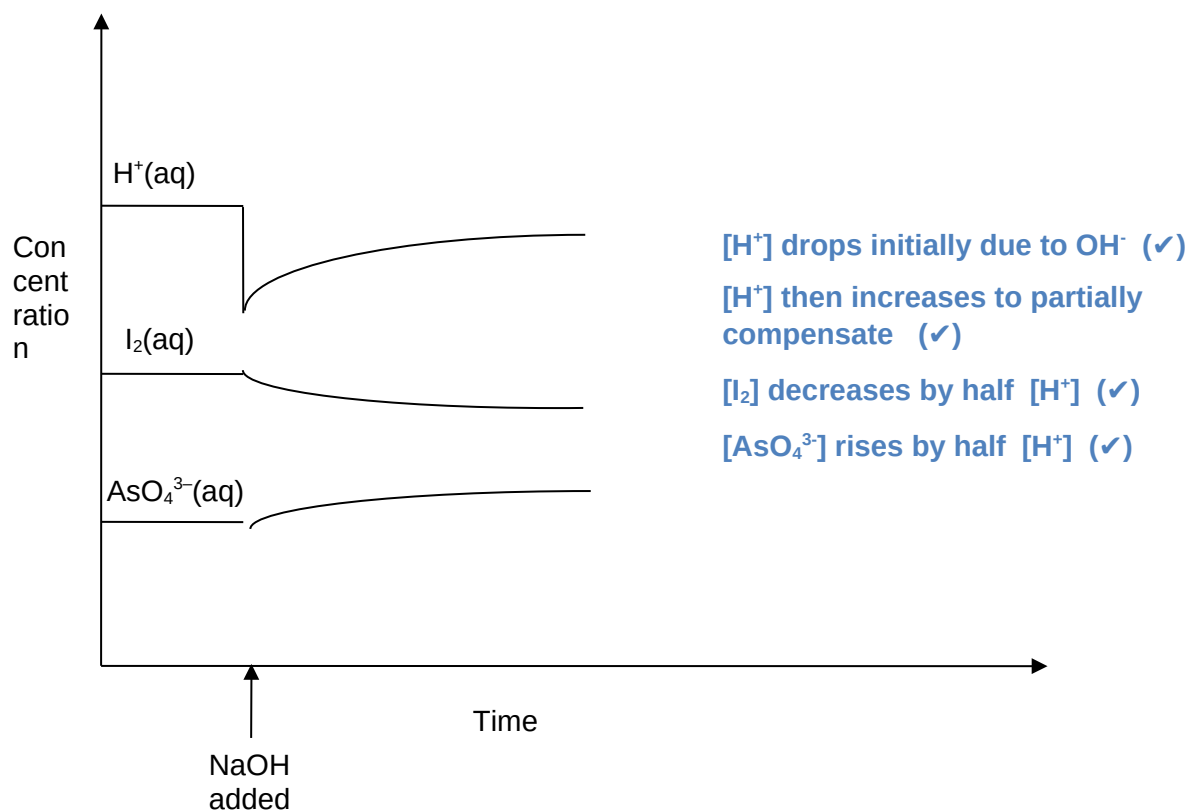


Iodine is brown in aqueous solution. None of the other species are coloured. The equilibrium mixture is brown.

- (a) Complete the table below by describing the expected observations as the system adjusts to the imposed changes. (2 marks)

Change imposed	Observations
Addition of a few drops of concentrated sodium iodide solution	the solution becomes darker brown (✓)
Doubling the volume by adding distilled water	the solution becomes lighter brown (✓)

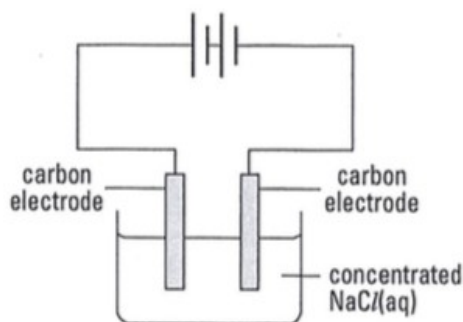
- (b) A few drops of concentrated sodium hydroxide solution are added to the equilibrium system. Complete the graph below, indicating qualitatively the concentration changes as the system re-establishes equilibrium. (4 marks)



Question 34

(8 marks)

The diagram below shows an electrolytic cell containing a 1.00 mol L⁻¹ NaCl solution with carbon electrodes. Standard conditions of temperature and pressure are assumed.



- (a) List all the species that migrate towards or come into contact with the following electrodes:

(i) Anode **water, chloride ions** (1 mark)

(ii) Cathode **water, sodium ions** (1 mark)

- (b) Write equations for the most favourable reactions that occur at the:

(i) Anode **$2\text{H}_2\text{O}(\text{aq}) \rightleftharpoons \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$** (1 mark)

(ii) Cathode **$2\text{H}_2\text{O}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$** (1 mark)

- (c) What minimum voltage needs to be applied to the sodium chloride cell to ensure that electrolysis occurs? (1 mark)

Using the table of standard reduction potentials provided (without values in neutral solution), we find

$$E^\circ = -1.23\text{V} + -0.83\text{V} \quad \rightarrow \quad V(\text{min}) = \underline{2.06\text{V}}$$

- (d) The carbon anode is replaced with a strip of copper. Describe the changes (or not) in the observations at this electrode. (2 marks)

The strip of copper will dissolve slowly over time (✓)

The solution in the cell will turn blue (✓)

- (e) State another way that the products of this electrolysis process can be altered. (1 mark)

Change the concentration of the sodium chloride solution (i.e. non standard conditions)

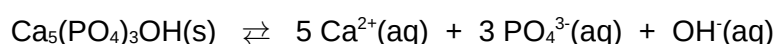
Question 35

(6 marks)

Imagine snacking on a dish of ice cream, washing it down with your favourite soft drink. Delicious! The bacteria in your mouth like it too. The bacteria consume sugar and produce acids. These acids slowly dissolve the hard enamel surface on your teeth, cause plaque and eventually tooth decay.

Tooth enamel is composed of an insoluble mineral called hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3\text{OH}(\text{s})$

When hydroxyapatite dissolves (**demineralisation**), it separates into calcium, phosphate and hydroxide ions. The dissolved ions can join back together to form the solid hydroxyapatite, this is called **re-mineralisation**. The process of demineralisation is represented as follows:



- (a) In adult teeth, these two processes (demineralisation and re-mineralisation) are in chemical equilibrium. Explain what is meant by chemical equilibrium. (2 marks)

Reactants and products of the processes are present in adult teeth at constant concentrations (✓)

Rate of demineralization = rate of re-mineralisation (✓)

- (b) Write the equilibrium constant expression for the demineralisation reaction. (1 mark)

$$K = [\text{Ca}^{2+}]^5 [\text{PO}_4^{3-}]^3 [\text{OH}^-]$$

- (c) In adults and children, if too much sugar is eaten, the concentration of **acid increases**. Explain the effect this will have on the equilibrium and consequently the tooth's condition. (2 marks)

H^+ combines with OH^- in the above equilibrium to form water



According to LCP, the forward reaction is favoured, so equilibrium shifts to the right and the tooth decays (✓)

- (d) The process of demineralisation occurs at pH below 5.5. What is the concentration of hydrogen ions at this pH? (1 mark)

$$[\text{H}_3\text{O}^+] = 10^{-5.5} = \underline{3.16 \times 10^{-6} \text{ mol L}^{-1}}$$

Question 36**(6 marks)**Consider 0.1 mol L⁻¹ solutions of:

- Sodium hydroxide
- Ammonium chloride
- Sulphuric acid
- Ethanoic (acetic) acid

- (a) Which solution would have the lowest electrical conductivity? Explain. (2 marks)

Ethanoic acid will have the lowest electrical conductivity as it is a weak acid and only partially ionises in solution, (✓)

so the concentration of ions that can act as charge carriers will be low. (✓)

- (b) Which solution would have the highest pH? Explain. (2 marks)

Sodium hydroxide is a strong base and 100% dissociates to produce a solution with [OH⁻] of 0.1 mol L⁻¹, hence the [H⁺] is 10⁻¹³ mol L⁻¹

The pH of sodium hydroxide will be 13 and the highest (✓)

Sulfuric acid and ethanoic acid will have low pH values, while ammonium chloride is an acidic salt due to the hydrolysis of the ammonium ion and so will also have a pH value below 7 (✓)

- (c) Which solution would have the highest concentration of ions? Explain. (2 marks)

Sulfuric acid will have the highest concentration of ions in solution as it is diprotic, and fully ionises in solution in its first ionisation and then partially ionises in its second ionization (✓)



Sodium hydroxide and ammonium chloride both dissociate 100% but will produce less ions in solution. (✓)

**End of Section Two**

Section Three: Extended answer**42% (90 Marks)**

This section contains six (6) questions. You must answer all questions. Write your answers in the spaces provided.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression.

Final answers to calculations should be expressed to **three (3)** significant figures and include appropriate units.

Suggested working time: 75 minutes

Question 37**(21 marks)**

Chemists and biochemists use the equilibrium constants (K_a) for different acid ionisations to compare their strengths. The K_a values of several naturally occurring, monoprotic, Bronsted-Lowry acids are shown in the table below.

Common name and source	IUPAC name	Structural formula	K_a (at 25°C)
benzoic acid (from bark resin)	benzoic acid	C_6H_5COOH	6.46×10^{-5}
pyruvic acid (metabolic product)	2-oxopropanoic acid	$CH_3COCOOH$	4.07×10^{-5}
lactic acid (from milk)	2-hydroxypropanoic acid	$CH_3CHOHCOOH$	1.38×10^{-4}

- (a) What is meant by the terms **monoprotic** and **Bronsted-Lowry acid**? (2 marks)

monoprotic **donates one acidic hydrogen per molecule**

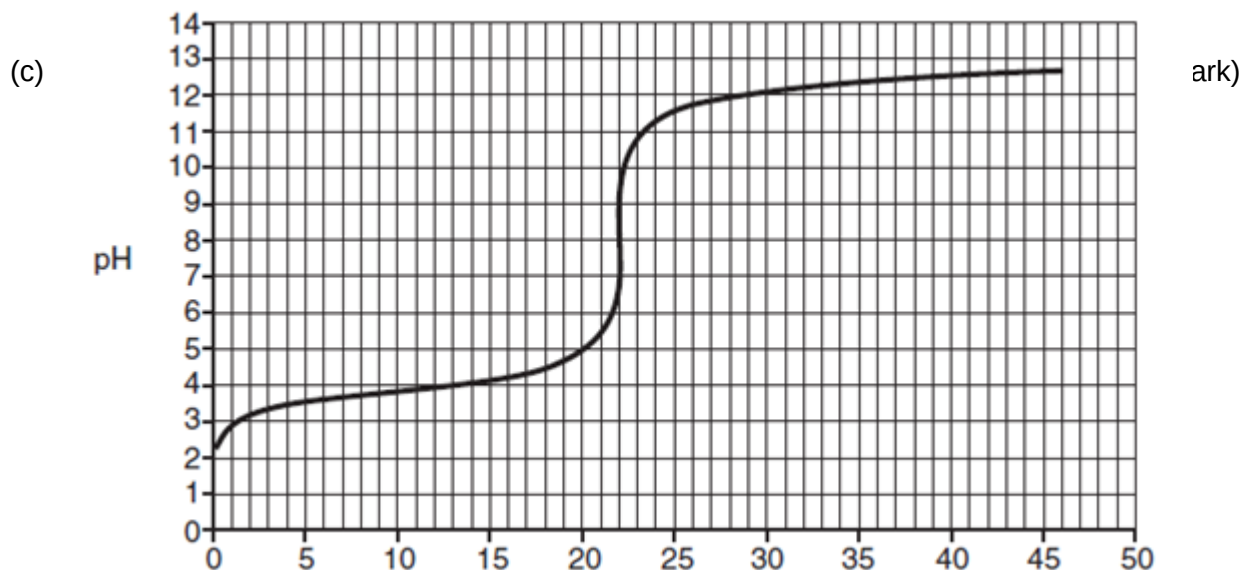
Bronsted-Lowry acid **is a proton donor**

- (b) 0.100 mol L⁻¹ solutions were prepared of each of the acids in the table above. Which of these solutions has the highest pH? (1 mark)

Pyruvic acid

(The acid with the lowest hydrogen ion concentration will have the highest pH. Since all are monoprotic acids of the same concentration, the lower the K_a value the lower the extent of ionisation and hence lower $[H^+]$)

Glycolic acid, HOCH_2COOH , is a weak, monoprotic acid. A student pipetted a 25.0 mL aliquot of 0.125 mol L^{-1} glycolic acid into a conical flask. The student added sodium hydroxide solution from a burette. A pH meter and data logger were used to measure continuously the pH of the contents of the conical flask. The pH curve that the student obtained is shown below.



- (d) Determine the concentration, in mol L^{-1} , of the NaOH (2 marks)

$$n(\text{OH}^-) = n(\text{glycolic}) = cV = 0.125 \times 0.0250 = 3.125 \times 10^{-3} \quad (\checkmark)$$

$$c(\text{NaOH}) = n/V = 3.125 \times 10^{-3} / 0.0220 = \underline{0.142 \text{ mol L}^{-1}} \quad (\checkmark)$$

- (e) List **all** the species (ions and molecules), present at the equivalence point of this titration. List them in order of **decreasing** concentration. (3 marks)



(-1 mark for each species missing /wrong place)

- (f) Give two pieces of evidence, from the graph, that demonstrate that glycolic acid is a weak acid. (2 marks)

Original pH is > 2 indicating a $[\text{H}^+]$ less than 0.01 mol L^{-1} . The 0.125 mol L^{-1} glycolic acid must only be partially ionised (\checkmark)

The equivalence point is basic, indicating weak acid vs strong base titration (\checkmark)

- (g) Had the student not had access to a pH meter, what would have been a suitable acid-base indicator to use from the following list? Explain your choice. (2 marks)

Indicator	pH range	Colour change
Alizarin yellow	10.0- 12.0	Yellow to purple
Thymol blue	8.0-9.6	Yellow to blue

Bromocresol purple	5.2-6.5	Yellow to purple
--------------------	---------	------------------

Thymol blue is the best indicator (✓)

The pH range of the indicator needs to match the pH of the equivalence point (around 8.5) and so this indicator is the best choice with a pH range of 8-9.6, it will change colour at the equivalence point (✓)

- (h) A buffer of glycolic acid and ammonium glycolate is used as a facial cleanser. Explain, using equations, (6 marks)

- How this buffer could be prepared from ammonia solution and glycolic acid.
- How a solution containing glycolic acid and glycolate ions can act as a buffer

Preparing Buffer

50% neutralise the glycolic acid by the addition of ammonia solution as this will form a solution that is equimolar for glycolic acid (weak acid) and the glycolate ion (its conjugate base). (✓)

This will be a good buffer since it has a reservoir of H^+ in the glycolic acid molecules and an ability to absorb added H^+ the glycolate ion. (✓)



Acting as Buffer

The following equilibrium system is established in the buffer solution. When changes are imposed it adjusts according to Le Chateliers Principle.



Addition of acid, reverse reaction is favoured as the glycolate ion (weak base) accepts added protons to resist pH change.

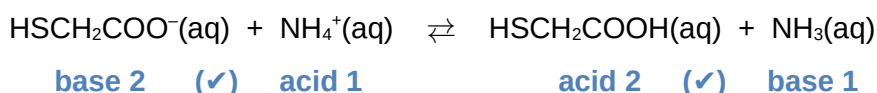


Addition of hydroxide ions neutralises some of the $H_3O^+(aq)$ and the forward reaction is favoured as the $HOCH_2COOH$ releases protons to resist pH change



- (i) Ammonium thioglycolate, $HSCH_2COONH_4$, is the ammonium salt of thioglycolic acid, $HSCH_2COOH$. When ammonium thioglycolate is dissolved in water, an acid-base equilibrium is set up. The equilibrium strongly favours the left-hand side.

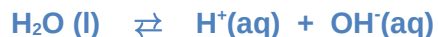
In the spaces below, label one conjugate acid-base pair as **Acid 1** and **Base 1** and the other as **Acid 2** and **Base 2** (2 marks)



Question 38 (17 marks)

The water corporation monitors the pH of drinking water very closely. They use pH meters that are calibrated to take the temperature of the water into account when measuring the $[H^+]$, rather than using indicators. Water self-ionises to a small degree.

- (a) Write an equation for the self-ionisation of water. (1 mark)



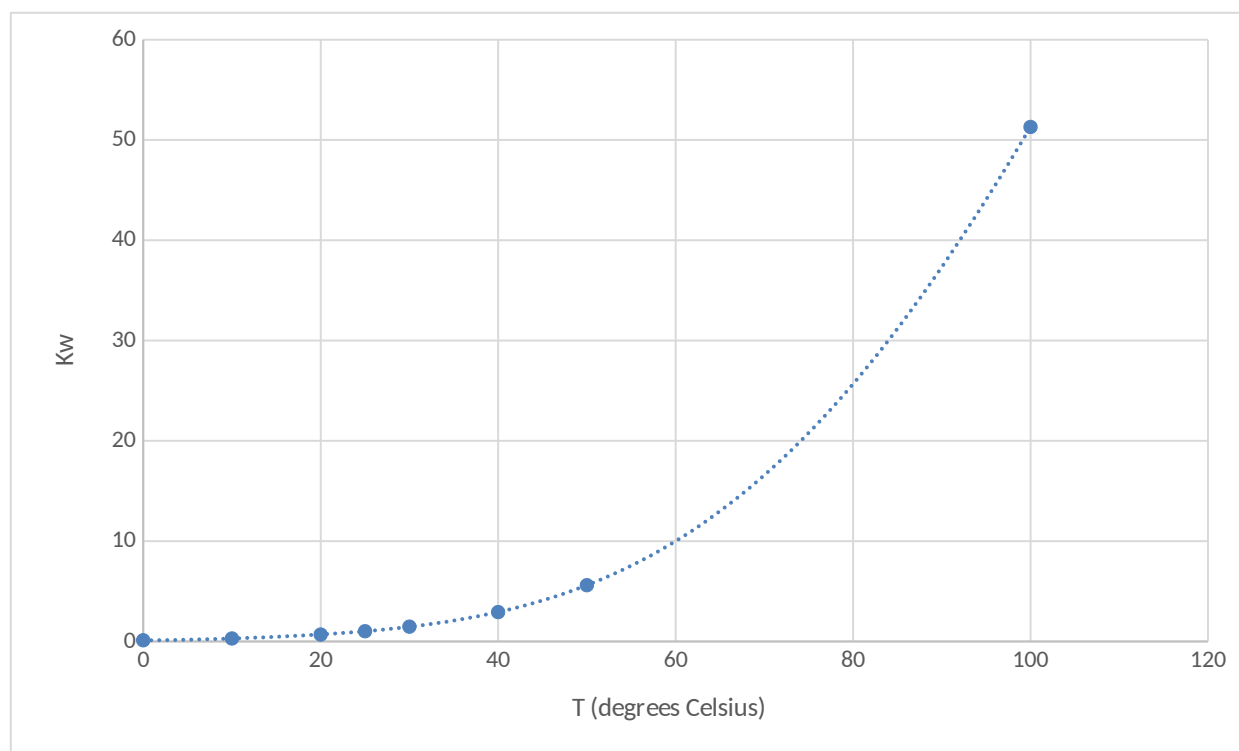
At a given temperature, the self-ionisation of water is at equilibrium. The equilibrium constant expression for this reaction is:

$$K_w = [H^+][OH^-]$$

The values for the equilibrium constant at a range of temperatures are given in the table below.

Temperature (°C)	0	10	20	25	30	40	50	100
$K_w (x 10^{-14})$	0.11	0.29	0.68	1.01	1.47	2.92	5.60	51.3
$[H^+] (x 10^{-8})$ mol L ⁻¹	3.3	5.3	8.2	10	12.1	17	24	71.6

- (b) Plot a graph of the K_w value versus temperature. (4 marks)



labelled axes (✓) , uniform scales (✓) , plotted points (✓) , curve drawn (✓)

- (c) Calculate the missing values for $[H^+]$ and complete the table above. (2 marks)

- (d) Calculate the pH of water at 10°C and 40°C. (2 marks)

10°C: $\text{pH} = -\log(5.3 \times 10^{-8}) = \underline{7.28} \quad (\checkmark)$

40°C: $\text{pH} = -\log(17 \times 10^{-8}) = \underline{6.77} \quad (\checkmark)$

- (e) Describe the relationship between K_w and temperature. (1 mark)

As temperature increases the K_w increases

- (f) From your graph, estimate the value of K_w at 45°C. (1 mark)

acceptable range: 4.0 – 4.5

- (g) What is the relationship between $[\text{H}^+]$ and temperature? (1 mark)

As temperature increases the $[\text{H}^+]$ will increase

- (h) Is water acidic, basic or neutral as temperature increases? Explain. (2 marks)

Water is neutral as temperature increases (\checkmark)

As one mole of water produces a 1:1 ratio of the hydrogen and hydroxide ions, so as temperature increases $[\text{H}^+] = [\text{OH}^-]$ always (\checkmark)

- (i) From this data, is the ionisation of water an endothermic or exothermic reaction? Justify your answer. (3 marks)

As temperature increases, K_w increases, so the forward reaction is favoured by a temperature increase (\checkmark)

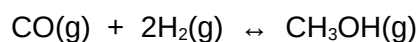
According to LCP, as temperature is increased (heat is added) for a system at equilibrium, the equilibrium will shift to lower the temperature (remove the heat) to partially counteract this change imposed (\checkmark)

Hence the pathway that will use the heat is the endothermic pathway and so the forward reaction is endothermic (\checkmark)

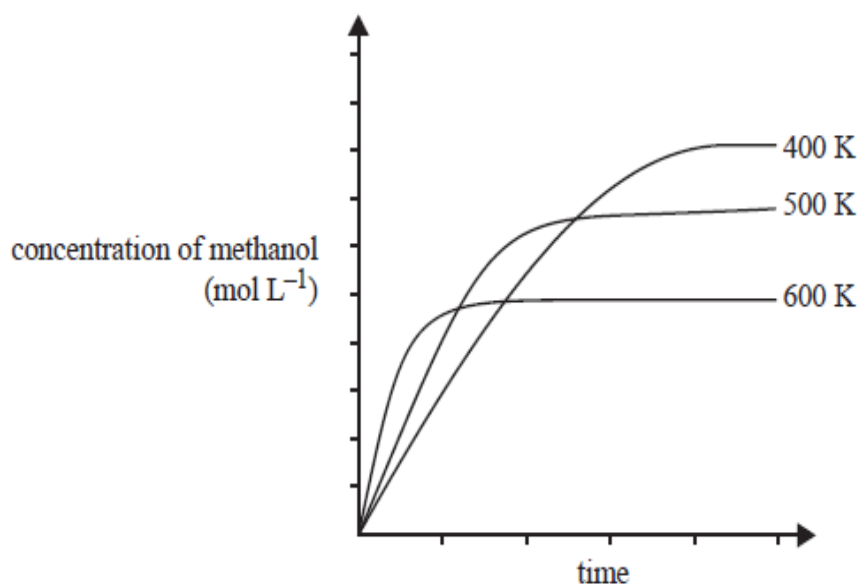
Question 39**(12 marks)**

Methanol is produced on an industrial scale by the catalytic conversion of a mixture of hydrogen and carbon monoxide at a temperature of 520 K and a pressure of 50 to 100 atmospheres. (1 atmosphere is equivalent to normal atmospheric pressure).

The reaction that occurs in the methanol converter is:



Carbon monoxide gas and hydrogen gas are mixed in a reaction vessel and equilibrium is established. The graph below shows how the concentration of methanol in this vessel changes with time at three different temperatures. The pressure is the same at each temperature.



- (a) Deduce whether the forward reaction is exothermic or endothermic, making reference to Le Chatelier's Principle. (2 marks)

Exothermic (✓)

Lower temp gives greater yield showing that forward reaction is favoured at lower temperature. This must be exothermic as it releases energy to oppose the lowering of the temp (according to LCP) (✓)

- (b) Explain why, in practice, a moderately high temperature of 520 K is used. (2 marks)

High temperature is favorable for a fast reaction rate but will give a low yield, and low temperature is favourable for a high yield but the reaction is too slow (✓)

A compromise temperature is used to maintain a good rate of reaction without compromising yield (a catalyst can also be used to keep the rate high) (✓)

- (c) Explain why at a given temperature, the use of high pressure results in a greater equilibrium **concentration** and **rate** of production of methanol. (3 marks)

Yield

The reaction involves converting 2 moles of gas into 1 mole of gas (✓)

A high pressure will cause both forward and reverse rates to increase but the forward reaction rate will increase more, due to a greater number of gaseous moles. More product is formed as a result and the yield increases (✓)

Rate

High pressure will increase the frequency of successful collisions between gas molecules and hence the rate of production of methanol will increase (✓)

- (d) A catalyst consisting of copper, zinc and aluminium is used to increase the rate of this reaction. Explain, using collision theory, how a catalyst increases the rate of this reaction. (3 marks)

A catalyst increases the reaction rate by providing an alternative reaction pathway with a lower activation energy (✓)

A greater proportion of particles will have energy greater than the activation energy (✓)

There will be a greater number of successful collisions and hence an increase in the reaction rate (✓)

The industrial process for the manufacture of methanol is not a closed system. The reactants are constantly fed into the reaction chamber and the products and unreacted reactants are passed into a cooling chamber. The methanol liquefies and is separated from the unreacted hydrogen and carbon monoxide and these gases are recycled into the reaction chamber.

- (e) Why do industrial chemists use an open system, rather than a closed system, for the manufacture of methanol? (2 marks)

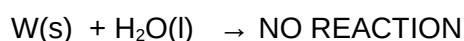
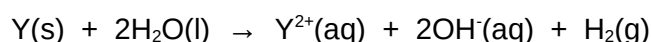
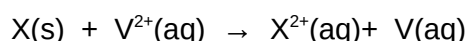
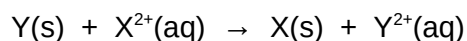
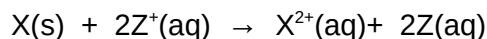
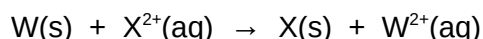
The products are able to leave the system and escape, thus lowering the concentration of the methanol (✓)

This will keep pushing the equilibrium in the forward direction maximising the production of methanol. (✓)

Question 40

(16 marks)

A student was investigating the reactivity of a series of unidentified metals, W, X, Y, Z and V, and their nitrate salts.. She carried out a series of experiments and recorded the following in her note book.



Metal V did not react with dilute hydrochloric acid all other metals did

- (a) From this information, list the metals in order of increasing ease of oxidation. (3 marks)

Least likely to be oxidised **V Z X W Y** Most likely to be oxidised
 (-1 mark for each mistake)

- (b) Identify the strongest oxidant in the reactions above. **V²⁺** (1 mark)

- (c) The alkali metals, in group 1, are all reducing agents. Explain why they are reducing agents and discuss the trend descending group 1, in terms of atomic structure and relevant atomic properties. (3 marks)

Metals in group one react by losing their valence electron (oxidation). Substances that undergo oxidation act as reductants and donate their electrons to the oxidant. (✓)

Descending group 1, the ability to act as a reductant increases. This is because atomic radius increases, the valence electron is further from the nucleus and the force of attraction on the outer electron is weaker. (✓)

(although the nuclear charge increases, the extra electron shells counteract this and the effective charge is constant)

Less energy is required to remove the valence electron and so it is lost more easily. (✓)

(the ionisation energy decreases, where ionization energy is the energy required to remove the furthestmost electron from 1 mole of a substance in its gaseous state)

Sulfuric acid can act as an **oxidising** agent (oxidant). Depending on the conditions it can react in one of three ways to produce:

- (i) sulfur dioxide
- (ii) hydrogen sulfide gas, H_2S
- (iii) elemental sulfur

(d) Write balanced half equations showing each of these possible reactions: (3 marks)

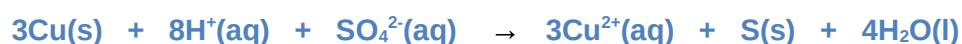


(e) Copper metal is able to dissolve in hot, concentrated sulfuric acid.

(i) Write the oxidation half equation for the dissolving of copper metal. (1 mark)



(ii) Write the overall redox reaction between copper and hot concentrated sulfuric acid to produce **elemental sulfur**. (1 mark)



(iii) Write full observations for this overall redox reaction. (2 marks)

Observations:

Salmon pink solid dissolves in colourless solution (✓)

Solution turns blue and yellow solid produced (✓)

(f) Can copper metal be oxidised by a 1.00 mol L^{-1} **dilute** solution of sulfuric acid? Explain your answer. (2 marks)

No (✓)

$\text{Cu}^{2+}(\text{aq})$ is a stronger oxidant than $\text{H}^+(\text{aq})$ at 1.00 mol L^{-1} , so dilute acid is not able to oxidise Cu metal (✓)

Question 41

(15 marks)

The sedimentary rock limestone consists almost entirely of two chemicals, calcium carbonate and silicon dioxide. Limestone sourced from the west end of Rottneest Island was analysed for its calcium carbonate content as follows:



- A 2.158 g sample of the limestone was pulverised and added to a beaker containing 200.0 mL of 0.294 mol L⁻¹ hydrochloric acid solution.
- The mixture was thoroughly stirred until no more effervescence was observed and only a small amount of insoluble residue was left at the bottom of the beaker.
- 20.0 mL aliquots of the resulting solution were titrated against a standardised NaOH(aq) solution in the burette of concentration 0.118 mol L⁻¹

The results of successive titrations are given in the table below.

Titration	1st	2nd	3rd	4th
Final reading (mL)	20.20	37.65	21.65	39.05
Initial reading (mL)	1.50	20.20	4.15	21.65
Titre volume (mL)	18.70	17.45	17.50	17.40

(✓)

- Write an ionic equation for the reaction occurring when the limestone is mixed with the hydrochloric acid solution. (2 marks)



balanced equation (✓)

ionic equation (✓)

- With the aid of a calculation, explain why 200.0 mL of 0.294 mol L⁻¹ hydrochloric acid solution was considered sufficient to dissolve all the calcium carbonate in the sample of limestone. (2 marks)

$$n(\text{H}^+) = (0.294 \text{ mol/L})(0.200 \text{ L}) = 0.0588 \text{ mol} \quad (✓)$$

If all of the 2.158 g sample was CaCO₃, then

$$n(\text{CaCO}_3) = m/M = 2.158\text{g}/100.09\text{g/mol} = 0.0216 \text{ mol} \quad (✓)$$

This is less than half $n(\text{H}^+)$, so $\text{H}^+(\text{aq})$ are in excess

- Many oxides, such as magnesium oxide or copper oxide, dissolve in acids. Explain why silicon dioxide does not react with or dissolve in acidic solutions. (2 marks)

The oxides that dissolve in acid are typically ionic substances.

Silicon dioxide is a covalent network substance (✓), with a very strong lattice holding the Si and O atoms in place (✓), and so it does not react with acids.

- (d) Enter the values for titre volume in the table above and calculate an appropriate value for the average titre volume. (2 marks)

Average titre volume = 17.45 mL (✓) (ignore 1st titration, average other three)

- (e) Calculate the percentage by mass of calcium carbonate in the limestone sample. (7 marks)



$$n(\text{OH}^-) = (0.118 \text{ mol/L})(0.01745 \text{ L}) = 2.06 \times 10^{-3} \text{ mol} \quad (\checkmark)$$

$$\text{Hence } n(\text{H}^+) \text{ in } 20\text{mL} = 2.06 \times 10^{-3} \text{ mol} \quad (\checkmark)$$

$$n(\text{H}^+) \text{ excess in } 200\text{mL} = (200\text{mL}/20\text{mL}) \times 2.06 \times 10^{-3} \text{ mol} = 0.0206 \text{ mol} \quad (\checkmark)$$

$$\begin{aligned} n(\text{H}^+) \text{ reacted with } \text{CaCO}_3 &= n(\text{H}^+) \text{ initial} - n(\text{H}^+) \text{ excess} \\ &= 0.0588 \text{ mol} - 0.0206 \text{ mol} = 0.0382 \text{ mol} \quad (\checkmark) \end{aligned}$$



$$n(\text{CaCO}_3) = 0.5 \times n(\text{H}^+) = 0.0191 \text{ mol} \quad (\checkmark)$$

$$\text{Hence } m(\text{CaCO}_3) = n M = 0.0191 \text{ mol} \times 100.09 \text{ g/mol} = 1.912 \text{ g} \quad (\checkmark)$$

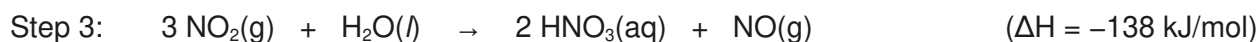
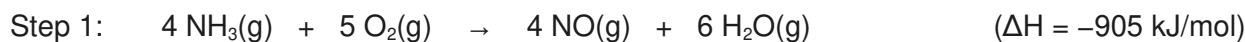
So %mass of CaCO_3 in limestone is

$$1.912\text{g}/2.158\text{g} \times 100\% = \underline{88.6\%} \quad (\checkmark)$$

Question 42

(9 marks)

Nitric acid can be produced from ammonia in a 3 step process, as shown below. The ammonia is first heated with oxygen, in the presence of a platinum/rhodium catalyst, to form nitric oxide and water. The nitric oxide is then oxidised further to nitrogen dioxide, which is then hydrated to form nitric acid.



- (a) Apart from nitric acid, what are the other two products of the overall process? (1 mark)

Water (H_2O) and nitrogen monoxide (NO) (✓)

- (b) If 300 moles of ammonia are reacted with an excess of other reagents, then state the number of moles of nitric acid produced. (3 marks)

$$\begin{aligned} n(\text{NO}) &= 4/4 \times n(\text{NH}_3) \\ &= 300 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{NO}_2) &= 2/2 \times n(\text{NO}) \\ &= 300 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{HNO}_3) &= 2/3 n(\text{NO}_2) \\ &= 200 \text{ mol} \end{aligned}$$

200 moles of HNO_3 (✓)

- (c) Briefly explain from where the energy needed to run a nitric acid plant may be sourced. (1 mark)

Each step of the reaction process is exothermic, so the energy released by each step can be used to run the plant. (✓)

- (d) If 2.50 tonnes of ammonia is reacted with excess oxygen, what mass of nitric acid will be produced, if step 3 of this process has a 90% yield? (Assume the other steps have 100% yield). (4 marks)

$$n(\text{NH}_3) = m/M = 2.5 \times 10^6 \text{ g} / 17.034 \text{ g/mol} = 1.47 \times 10^5 \text{ mol} \quad (\checkmark)$$

$$n(\text{HNO}_3) = 2/3 \times 1.47 \times 10^5 \text{ mol} = 9.78 \times 10^4 \text{ mol} \quad (\text{theoretically}) \quad (\checkmark)$$

$$\text{Actual yield} = 90\% \times 9.78 \times 10^4 \text{ mol} = 8.81 \times 10^4 \text{ mol} \quad (\checkmark)$$

$$\begin{aligned} \text{So } m(\text{HNO}_3) &= n \times M = 8.81 \times 10^4 \text{ mol} \times 63.018 \text{ g/mol} \\ &= 5.55 \times 10^6 \text{ g} = \underline{5.55 \text{ tonnes}} \quad (\checkmark) \end{aligned}$$