



**EDITH COWAN UNIVERSITY**

**2023 ATAR REVISION  
SEMINAR**

**ATAR CHEMISTRY**

**CURRICULUM DOT**

**POINTS EXAMINATION**

**AND STUDY TIPS**

**REVISION NOTES EXAMINATION  
QUESTIONS**

**EXAMINATION MARKER  
COMMENTS**

**Prepared and presented  
by**

**Dr Tejinder Kaur**

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# EXAMINATION TIPS:

## ADVICE FOR CANDIDATES FROM THE EXAMINATION REPORT:

- Examine syllabus points closely, ensuring that you can state, define, and explain chemistry terminology contained within them.
- Read questions carefully to determine what is required in your answer.
- Ensure that you use correct chemistry terminology, and your answers are concise and appropriate.
- Include units in your calculations where appropriate, even if it is not explicitly requested in the question.
- Convert masses to grams, if required, in calculations and check that you are transferring numbers correctly from the question and through each part of the calculation.
- Use the spare pages to plan longer written responses.
- Know how organic homologous series react with other molecules and ensure you can draw full structures with all bonds attached between the correct elements in the structure.
- When asked to construct a graph, ensure that scales are appropriate and sensible, axes have a title and units (where appropriate), the graph has a title describing both variables, points are plotted in the correct location and that the line/curve of best fit is smooth, not simply from the first point to the last.
- When discussing reasoning for acidic/basic solutions due to salts, ensure you discuss hydroxide/hydronium ion balances in your reasoning.
- Ensure you focus on the chemistry that is occurring in situations such as dissolving, discussing intermolecular forces that are predominantly participating. Do not use statements such as 'like dissolves like'.
- State the words in an acronym in full the first time you use it in a response.
- Use ionic equations where appropriate in solution chemistry.
- Check balancing of equations including charges.
- Ensure you can give explicit properties of primary standard.
- Fully define and give appropriate examples for systematic and random errors.

## ADVICE FROM ME:

- Familiarize yourself with Chemistry Data Booklet. Back-to-back.
- Familiarize yourself with the glossary words provided by SCASA.
- Read the instructions carefully on Exam Day.
- Ensure you use a pen – not gel or pencil.
- During reading time, read the short and extended questions and plan 'your response' on the paper.
- Remember that questions do not need to be answered in order.
- Do questions you are most comfortable with first.
- Use the number of lines and number of marks as an indication as to how much to write for short. and extended answer question – rule of thumb 1mark- 1point.
- Answer multi-choice by elimination – cross out the ones you know are wrong and then pick... the answer is in front of you.
- DO NOT leave any multi-choice questions blank – guess if you need to.
- Show ALL working in calculations and give clear 'signposts' so a marker can follow your working.
- Answers to the APPROPRIATE number of significant figures and with units.
- Extended answer – if running out of time use dot points to get chemistry information down.
- Include graphs/diagrams (and explain) in longer answers.
- Annotate (Label) the diagrams.

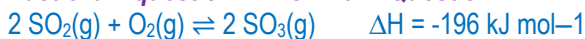
# TOPIC 1: EQUILIBRIUM

## Curriculum Dot point: Rate of Chemical reaction

- collision theory can be used to explain and predict the effects of concentration, temperature, pressure, the presence of catalysts and surface area of reactants on **the rates of chemical reactions**.

- Concentration
  - ✓ Increasing concentration, increases reaction rate
  - ✓ As the increasing concentration increases the Frequency of collisions between particles – more collisions = greater chance of successful collisions = faster rate of reaction.
- Pressure (for gas reactants)
  - ✓ Increasing the pressure, increases the reaction rate
  - ✓ As the pressure increases the frequency of collisions between the particles – again more collisions = faster reaction rate
- State of sub-division
  - ✓ The greater the sub-division of the reactants when they are in different phases the faster the rate of reaction
  - ✓ The particles can only collide on the surface that the 2 phases meet. So, if you increase the amount of the surface exposed then the frequency of collisions will increase and then the rate of reaction will increase.
- Temperature
  - ✓ Increasing the temperature, increases reaction rate – Does NOT matter if endothermic or exothermic!
  - ✓ As the temperature increases the number of particles with energy equal to or greater than the activation energy. Thus greater percentage of collision will be successful and the rate of reaction will increase.
  - ✓ Also increases the average speed of the particles which leads to particles colliding with greater frequency and more force.
- Catalyst
  - ✓ Adding a catalyst increases the reaction rate
  - ✓ The catalyst provides an alternative reaction pathway with a lower activation energy. Thus, a larger number of particles will have energy equal to or greater to the new activation energy and therefore a greater percentage of collision will be successful, and the rate of reaction will increase.

## Past exam question: WACE 2022 Question 7



Which of the following changes will initially decrease the rate at which  $\text{SO}_2(\text{g})$  is consumed?

- (a) decrease the volume of the reaction vessel
- (b) decrease the partial pressure of  $\text{O}_2(\text{g})$
- (c) heat the reaction vessel
- (d) add an appropriate catalyst

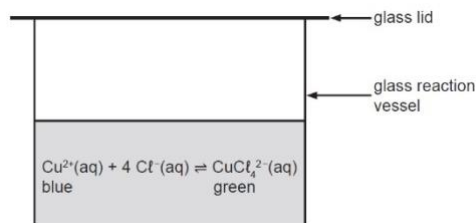
## Curriculum Dot points: Open and close systems

- chemical systems include physical changes and chemical reactions and may be open (which allow matter and energy to be exchanged with the surroundings) or closed (which allow energy, but not matter, to be exchanged with the surroundings).
- observable changes in chemical reactions and physical changes can be described and explained at an atomic and molecular level.
- the characteristics of a system in dynamic equilibrium can be described and explained in terms of reaction rates and macroscopic properties.

- Many chemical reactions are **reversible** and when they occur in a **closed system** where they reach a point where they are said to be in **equilibrium**
- Characteristics of a system in equilibrium:
  - ✓ The forward and reverse reactions are occurring at the **same rate**
  - ✓ There is no visible change in the reaction vessel – the colour, pressure and temperature remain **constant**. (the macroscopic properties)
  - ✓ The concentration of all species is **unchanged**. (NOT equal)
- The system is said to be **dynamic** as the reactions are still happening as opposed to **static** where the reactions have stopped.

### Past exam question: WACE 2020 Question 12

A group of chemistry students observed a demonstration in which solid sodium chloride was added to an aqueous solution of copper chloride in a glass reaction vessel. A tight-fitting lid was placed on the reaction vessel. The solid sodium chloride was allowed to dissolve and in the entire system was heated and then cooled. This resulted in colour changes. The reaction system is shown below.



The students were asked to decide if the system was opened or closed and if the demonstration involved chemical and/or physical processes. Their responses are shown in the following table.

Which student has the correct responses?

	Student	Type of system (open/closed)	Type of process (chemical/physical)
(a)	1	Closed	Physical
(b)	2	Closed	Chemical
(c)	3	Closed	Chemical and physical
(d)	4	Open	Chemical

### Examination report information:

Only 55% of candidates correctly answered this question.

### Curriculum Dot points: Dynamic Equilibrium

- over time, in a closed system, reversible physical and chemical changes may reach a state of dynamic equilibrium, with the relative concentrations of products and reactants defining the position of equilibrium.
- equilibrium law expressions can be written for homogeneous and heterogeneous systems; the equilibrium constant ( $K$ ), at any given temperature, indicates the relationship between product and reactant concentrations at equilibrium.
- the relative amounts of reactants and products (equilibrium position) can be predicted qualitatively using equilibrium constants ( $K_c$ ).

$K = \frac{[\text{products}]}{[\text{reactants}]}$  but only include the aqueous and gases not solid or liquids.

E.g., For the reaction:  $aA + bB \rightleftharpoons cC + dD$

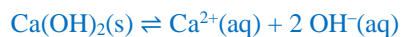
$$K_c = \frac{\frac{[\text{products}]}{[\text{reactants}]}}{\frac{[C]^c [D]^d}{[A]^a [B]^b}}$$

- Large  $K$  means there is a greater ratio of products to reactants at equilibrium, large proportion of products (name) or small proportion of reactants (name).
- Small  $K$  means and there is a greater ratio of reactants to products at equilibrium, small proportion of products (name) or large proportion of reactants (name).

**Past exam question: WACE 2022 Question 10**

Consider the equilibrium system below:

Which of the following is the correct equilibrium constant expression for the dissolution of calcium hydroxide, represented by the following equation?



(a)  $K = \frac{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}{[\text{Ca(OH)}_2]}$

(b)  $K = \frac{[\text{Ca(OH)}_2]}{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}$

(c)  $K = [\text{Ca}^{2+}] [\text{OH}^{-}]^2$

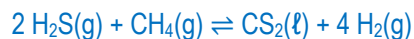
(d)  $K = \frac{1}{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}$

**Examination report information:**

Was answered well by most candidates.

**Past exam question: WACE 2020 Question 29(a)**

Some hydrogen sulfide and methane were sealed inside a reaction vessel and the following equilibrium was established:



Write the equilibrium constant expression (K) for this reaction system.

**Examination report information:**

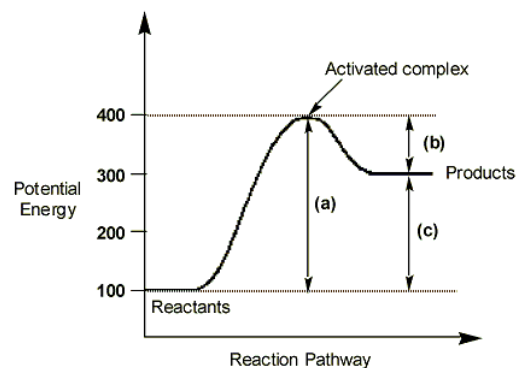
Was answered moderately well by candidates. It is very important to remember that in the equilibrium constant expression, solids and liquids are not included, as they have constant concentrations.

### Curriculum Dot points: Enthalpy Changes

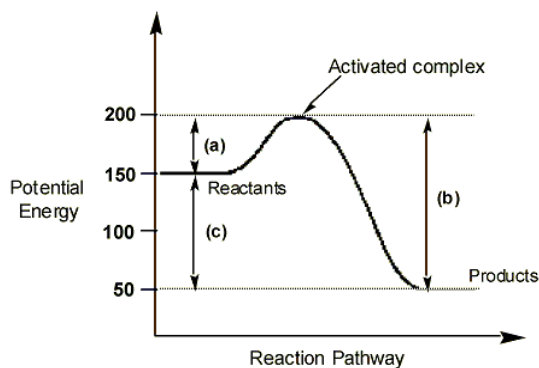
- the reversibility of chemical reactions can be explained in terms of the activation energies of the forward and reverse reactions.
- the effect of changes of temperature on chemical systems initially at equilibrium can be **predicted** by considering the enthalpy changes for the forward and reverse reactions; this can be represented on energy profile.

### Assumed knowledge

#### Endothermic reaction



#### Exothermic reaction



A reaction where the products have more energy than the reactants

- $\Delta H$  has a positive value
- Heat is taken into the reaction
- The temperature of the surroundings decreases
- (a) is  $E_a(\text{forward})$
- (b) is  $E_a(\text{reverse})$
- (c) is  $\Delta H$

A reaction where the products have less energy than the reactants

- $\Delta H$  has a negative value
- Heat is released from the reaction
- The temperature of the surroundings increases
- (a) is  $E_a(\text{forward})$
- (b) is  $E_a(\text{reverse})$
- (c) is  $\Delta H$

- Increasing the temperature increases the average kinetic energy of all particles, thus a greater proportion of particles have the required activation energy, leading to an increase in successful collisions.
- The rate of both the forward and reverse reactions increase.
- This affects the equation with the highest activation energy more (endothermic reaction)
  - For example a reaction with the forward being exothermic
    - In this case the reverse reaction.
    - The reverse reaction will thus be faster relative to the forward reaction.
    - Equilibrium is re-established at a higher rate than before with a net reverse reaction.

### Past exam questions: WACE 2017 Question 33(a) & (b)

Both dynamite and TNT are explosive substances that are sometimes confused with each other. The active ingredient in dynamite is a stabilised form of nitroglycerine  $C_3H_5N_3O_9$ , while TNT is the common name for the explosive compound 2,4,6-trinitrotoluene,  $C_6H_2(NO_2)_3CH_3$ .

- (a) An explosion is a 'very fast and very exothermic reaction'. Use a solid line (-) to draw, and then label, an energy profile diagram reflecting an explosive reaction. (3 mark)

Nitroglycerine is extremely shock-sensitive and readily becomes unstable. In dynamite the nitroglycerine is combined with inhibitors and stabilisers, making it safer to use. Typically, dynamite is between 25% to 50% nitroglycerine.

- (b) An inhibitor is a substance that decreases the rate of, or prevents, a chemical reaction. On the diagram in part (a) above, indicate by way of a dashed line (---) any change/s that would be evident if an inhibitor were to be used. (1 mark)

**Examination report information:**

Candidates need to be able to show clearly a diagram representing low  $E_a$  and highly exothermic. This was a very straightforward question if the question was read thoroughly.

**Curriculum Dot point: Explaining Changes in Equilibrium**

- the effects of changes in concentration of solutions and temperature on chemical system initially at equilibrium can be **predicted and explained** by applying collision theory to the forward and reverse reactions.

- When adding a substance double check – is the substance in the system will it react with something in the system – particularly important for aqueous systems. Remember that ionic substances will dissociate into their ions.
- Increasing the concentration of a reactant means an increase in particles per unit volume on the reactant side of the equation.
- This leads to a greater frequency of collisions between reactant particles, and an increase in the proportion of successful collisions.
- Thus the rate of the forward reaction will initially be greater than the reverse reaction.
- As the reaction progresses the concentration of the products will increase, and concentrations of the reactants decrease thus increasing the reverse reaction rate and decreasing the rate of the forward.
- A new equilibrium will be established at a higher rate than before
- There has been a net forward reaction and thus the concentration of products increases, the concentration of other reactants has decreased, and the concentration of the reactant added has increased.

**Past exam question: WACE 2022 Question 26**

Consider the following system at equilibrium:



colorless    deep red    pale brown

For each of the applied changes after equilibrium is re-established, predict the:

- shift in equilibrium position (left, right or no change)
- rate of the forward reaction compared to the original rate (increase, decrease or no change)
- colour of the reaction mixture.

Change	Shift in equilibrium position	Rate of the forward reaction compared to original rate.	Colour of reaction mixture
The reaction mixture is heated			
A few crystals of $\text{FeCl}_3$ are added			
$\text{H}_2\text{O}$ is added			
A few drops of concentrated $\text{Na}_3\text{PO}_4$			



**Examination report information:**

Was answered well by most candidates.

**Curriculum Dot point: Le Châtelier's Principle**

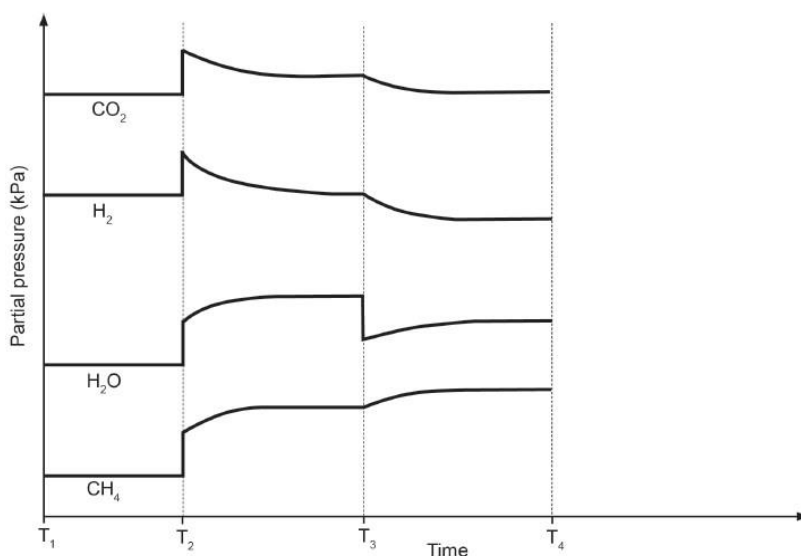
- the effects of changes in temperature, concentration of species in solution, partial pressures of gases, total volume, and the addition of a catalyst on equilibrium systems can be **predicted** using Le Châtelier's Principle.

**Le Châtelier's principle** states that: If a change is made to a system at equilibrium so that it is no longer at equilibrium, a net reaction will occur (if possible) in the direction that counteracts the change.

- ▶ **With an increase in concentration:** The system shifts in order to use up the added reactant, counteracting the change to return to equilibrium.
- ▶ **With an increase in pressure:** The system shifts to reduce the pressure again and partially counteract the change.
- ▶ **With the addition of a catalyst:** The system will not change.

**Past exam question: WACE 2018 Question 38c**

Graphs can be drawn to show the effects of imposed changes on equilibrium systems. The graph below shows the effects of some changes that might be made to the reacting system in a flexible vessel.



With reference to the above graph, answer the following questions.

- (c) (i) What happened at time  $T_1$ ? (1 mark)

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- (ii) Identify the change imposed at each time in the table below. (2 marks)

Time	Change imposed on the system
$T_2$	
$T_3$	

- (iii) The temperature of the reaction vessel was decreased at  $T_4$ . Sketch on the graph above to show how this affected the partial pressures of all species present. Include any changes to scale and continue until a new equilibrium is established. (3 marks)

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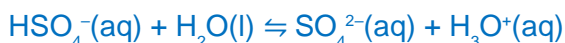
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**Examination report information:**

Part (i) was answered well. In part (ii) candidates did not identify the imposed change on a closed system could be in a flexible vessel. Many gave the simplistic answer of increasing the pressure (rather than reducing the vessel volume) or decreased partial pressure of water (rather than remove water). In part (iii) candidates did not draw the graphs as comparative scales and therefore did not show the varying partial pressures due to the stoichiometry of the reaction clearly.

**Past exam question: WACE 2017 Question 28(b)**

A hydrogen sulphate/sulphate system is represented by the following equation.



The reaction is endothermic in the forward direction as written. Predict what will happen to the pH when the temperature is increased. Justify this prediction. (4 marks)

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**Examination report information:**

There appeared to be an improvement in how candidates justified their response. Some candidate justified their prediction using reaction rates which was acceptable for this question.

**Curriculum Dot point: Climate change and Kyoto Protocol**

- Levels of carbon dioxide in the atmosphere are rising and have a significant impact on global systems, including surface temperatures. The increasing level of carbon dioxide in the atmosphere causes more carbon dioxide to dissolve in the ocean producing carbonic acid and leading to increased ocean acidity. This is predicted to have a range of negative consequences for marine ecosystems such as coral reefs. Calcification is the process which results in the formation of calcium carbonate structures in marine organisms. Acidification shifts the equilibrium of carbonate chemistry in seawater, decreasing the rate and amount of calcification among a wide range of marine organisms. The United Nations Kyoto Protocol and the Intergovernmental Panel on Climate Change aim to secure a global commitment to reducing greenhouse gas emissions over the next few decades.

**Past exam question: WACE 2021 Question 15**

Which of the following processes does **not** contribute to the building of weakest seashells through ocean acidification?

- (a)  $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
- (b)  $2\text{H}^+(\text{aq}) + \text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- (c)  $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$
- (d)  $\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

**Examination report information:**

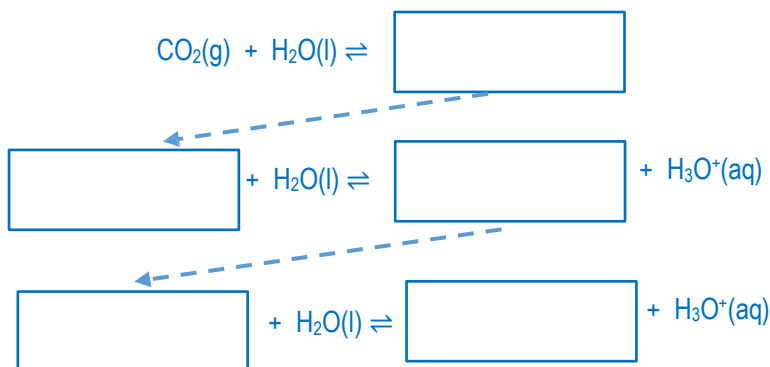
This question requires candidates to recognise that the equilibria involving carbonic acid formation, and associated hydrolysis, result in ocean acidification and can interfere with seashell building.

Only 53% of candidates were able to correctly answer this question.

**Past exam question: WACE 2020 Question 31**

The amount of carbon dioxide in the Earth's atmosphere is increasing, leading to more carbon dioxide dissolving in the oceans and hence ocean acidification.

(a) Complete the following sequence of equations to show what happens to carbon dioxide when it dissolves in water. (3 marks)



(b) Other than death, state **two** consequences of the above sequence of equations on marine organisms with shells. (2 marks)

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(c) Use Le Chatelier's Principle and the sequence in part (a) to predict what might happen, in relation to ocean acidification, if the United Nations Kyoto Protocol is discarded. Explain your reasoning. (4 marks)

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**Examination report information:**

Part (a) required candidates to have knowledge of the equilibrium that occur when  $\text{CO}_2$  is absorbed into the Earth's oceans and most demonstrated this. Part (b) saw many candidates write that seashells dissolve because of ocean acidification. These candidates were reflecting a common misconception about ocean acidification - seashells are carbonates and carbonates dissolve in an acid. Candidates need to understand that the name of the process (ocean acidification) is quite misleading - the Earth's oceans are not acidic because their pH is still above 7. Part (c) showed that many candidates do not know what the United Nations Kyoto Protocol was about and serves as a reminder that all parts of the syllabus are examinable.

# TOPIC 2: ACIDS & BASES

## Curriculum Dot points: strong and weak acid

- Acids are substances that can act as proton (hydrogen ion) donors and can be classified as monoprotic or polyprotic, depending on the number of protons available for donation.
  - The strength of acids is explained by the degree of ionization at equilibrium in aqueous solution which can be represented by chemical equations and acidity constants ( $K_a$ ).
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- o Monoprotic acid: the most common class of acids, they can donate only a single proton to a base, e.g: HCl,  $\text{CH}_3\text{COOH}$
  - o Polyprotic acid: Any acid capable of donating more than one proton to a base. This is done in sequential steps. e.g:  $\text{H}_2\text{SO}_4$
  - o In a weak acid, only some of the acid molecules ionise and an equilibrium forms.
  - o The equilibrium expression can be rearranged to give the acid dissociation equilibrium constant, which is a measure of the strength of acids.
  - o Strong acids ionise completely in water, so the  $K_a$  value is large, because there is a greater proportion of the products making the fraction larger.
  - o Weak acids only partially ionize, so the  $K_a$  value is small. The greater proportion of the reactants makes the overall fraction smaller.
  - o Remember the  $[\text{H}^+]$  and pH are inversely proportional, as  $[\text{H}^+]$  increases the pH decreases.
  - o **The higher the  $K_a$  value the stronger the acid.**

### Past exam question: WACE 2021 Question 3

Consider the acids listed in the following table.

Name	Formula	$K_a$ (25 °C)
bromoacetic acid	$\text{CH}_2\text{BrCOOH}$	$1.38 \times 10^{-3}$
dibromoacetic acid	$\text{CHBr}_2\text{COOH}$	$3.31 \times 10^{-2}$
tribromoacetic acid	$\text{CBr}_3\text{COOH}$	$1.91 \times 10^{-1}$

Which of the following identifies the strongest acid and classifies it correctly as monoprotic, diprotic or triprotic?

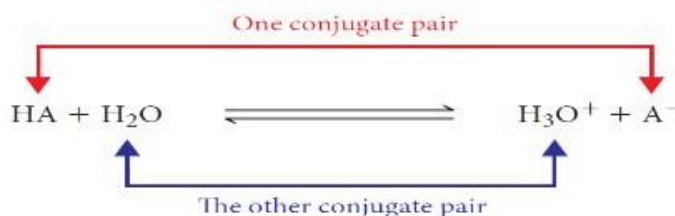
	Strongest acid	Classification
• A	bromoacetic acid	monoprotic
• B	dibromoacetic acid	diprotic
• C	tribromoacetic acid	monoprotic
• D	tribromoacetic acid	triprotic

### Curriculum Dot point: Bronsted Lowry model

- the relationship between acids and bases in equilibrium systems can be explained using the Brønsted-Lowry model and represented using chemical equations that illustrate the transfer of protons between conjugate acid-base pairs.

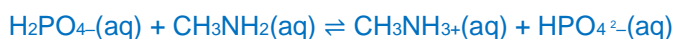
Using the Brønsted-Lowry definition, a general acid-base proton transfer reaction is developed.

- The acid (HA) donates a proton to form  $A^-$ .
- These two are a conjugate pair.
- Members of a conjugate acid-base pair differ from each other by the presence or absence of the transferable hydrogen ion ( $H^+$ ).
- There are 2 pairs formed in an acid-base reaction.



Past exam question: WACE 2021 Question 21

Identify a conjugate acid-base pair in the reaction represented by the following equation:



- (a)  $H_2PO_4^-(aq)$  and  $CH_3NH_2(aq)$
- (b)  $CH_3NH_3^+(aq)$  and  $HPO_4^{2-}(aq)$
- (c)  $H_2PO_4^-(aq)$  and  $HPO_4^{2-}(aq)$
- (d)  $H_2PO_4^-(aq)$  and  $CH_3NH_2(aq)$

### Curriculum Dot point: Nature of Salts

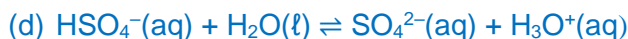
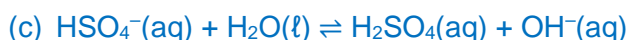
- the hydrolysis of salts of weak acids and weak bases can be represented using equations; the Brønsted-Lowry model can be applied to explain the acidic, basic, and neutral nature of salts derived from bases and monoprotic and polyprotic acids.

The acid-base nature of a salt is a combination of the nature of its parts that make it up. E.g. NaCl is made from  $Na^+$  and  $Cl^-$  ions and  $NaCH_3COO$  is made from  $Na^+$  and  $CH_3COO^-$  ions. You must consider the acid-base nature of the ions that make a salt to determine if it is acidic or basic.

- Acidic component and neutral component = acidic salt
- Basic component and neutral component = basic salt
- Neutral component and neutral component = neutral salt
- Acidic and basic component = dependent on the relative strengths of the components (usually neutral as both weak acid and bases cancel e.g.  $NH_4CH_3COO$ ) and therefore is a neutral salt.
- A component of a salt is acidic if it can react with water and produce a  $H_3O^+$  ion.  
E.g.  $H_2O + HS^- \rightleftharpoons H_3O^+ + S^-$
- A component of a salt is basic if it can react with water to produce a  $OH^-$  ion.  
E.g.  $HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$
- Multiprotic acids are confusing – you need to write equations for the reaction with water and decide.
- General rules that may be of assistance:
  - Salt components from strong acids are neutral ( $Cl^-$ ,  $NO_3^-$  etc)
  - Salt components from strong bases are neutral ( $Na^+$ ,  $Mg^{2+}$  etc)
  - Salt components from weak bases are acidic ( $NH_4^+$  etc)
  - Salt components from weak acids are basic ( $CH_3COO^-$ ,  $HCO_3^-$  etc)
  - Salts components of group 13 and transition metals are acidic – form a hydronium ion along with

**Past exam question: WACE 2021 Question 9**

The net ionic equation for the predominant hydrolysis reaction occurring in a 1.00 mol L<sup>-1</sup> potassium hydrogen sulfite solution is:



**Examination report information:**

This question required understanding of the acidity of different ions and hydrolysis. A process of elimination could have been used to narrow down the answer to either (c) or (d), as a neutrality and solubility of group one cations be easily recalled. Destructor (c) could also be easily eliminated as it should be commonly known that sulfuric acid is a strong acid.

**Curriculum Dot point: Buffer solutions**

- buffer solutions are conjugate in nature and resist changes in pH when small amounts of strong acid or base are added to the solution; buffering capacity can be explained qualitatively; Le Châtelier's Principle can be applied to predict how buffers respond to the addition of hydrogen ions and hydroxide ions.
- Buffers are solutions that can resist pH change when either acids or bases are added to them.
- They generally contain either a weak acid and its conjugate base or a weak base and its conjugate acid.
- They work because the weak acid and weak base can co-exist in solution without neutralising one another, yet still react to neutralise any strong acid or strong base added to the buffer.
- A buffer system is made of equal mole ethanoic acid and sodium ethanoate made up to say 1L.  
$$\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+$$
- The behaviour of this and any buffer system can be explained in terms of Collision theory (addition/removal of a reactant/product).
- Where adding a strong acid (e.g. HCl) increases the  $[\text{H}_3\text{O}^+]$  in the buffer as long as there is sufficient  $\text{CH}_3\text{COO}^-$  to react with the added  $[\text{H}_3\text{O}^+]$  and the concentration of  $\text{H}_3\text{O}^+$  is reduced close to before the addition of HCl and there is a minimal change in pH.
- And adding a strong base (e.g. NaOH) increases the  $[\text{OH}^-]$  in the system, which will react with the  $\text{H}_3\text{O}^+$  in the buffer, (producing water) if there is sufficient  $\text{CH}_3\text{COOH}$  to react with the added  $[\text{OH}^-]$  the concentration of  $\text{H}_3\text{O}^+$  is increased close to before the addition of NaOH and there is a minimal change in pH.
- Buffering capacity can be defined as the amount of acid or base the buffer can neutralize before the pH begins to change dramatically. Depends on 2 things:
  - The relative concentrations of the weak acid and its conjugate base – highest buffering capacity is achieved when equal.
  - The actual concentration of the weak acid and its conjugate base – buffering capacity increases with increasing concentration.

**Past exam question: WACE 2018 Question 29 a, d, e**

Wines and other alcoholic drinks can spoil when the alcohol (ethanol) they contain oxidises to acetic acid (ethanoic acid). An acidity regulator, monosodium citrate, is often added to drinks to prevent the formation of acetic acid. The monosodium citrate does this by acting as a buffer.

A citric acid/hydrogen citrate ion buffer can be prepared from citric acid  $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$  and monosodium citrate,  $\text{NaH}_2\text{C}_6\text{H}_5\text{O}_7$ .

- (a) Write an equation for the buffer system ( $\text{H}_3\text{C}_6\text{H}_5\text{O}_7/\text{H}_2\text{C}_6\text{H}_5\text{O}_7^-$ ) containing citric acid  $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$  and monosodium citrate,  $\text{NaH}_2\text{C}_6\text{H}_5\text{O}_7$ . (2 marks)

- (d) Explain why only a small change in pH is observed in this buffer solution when a small amount of sodium hydroxide solution is added, compared to adding a similar amount of sodium hydroxide solution to a system that is not a buffer solution. Your answer should refer to the buffer equilibrium in part (a). (4 marks)

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- (e) Increasing the concentration of this buffer solution will increase its buffering capacity. Explain this statement. (3 marks)

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**Examination report information:**

For part (a) many candidates could not write a buffer equation and failed to realise that it is a reversible reaction. Some chose to include all species rather than the pertinent ones. Part (d) was not well answered. Candidates attempted to use an alternative method rather than answering based on the citric acid buffering components. Candidates were unable to describe why a non-buffer system would have a large increase in pH. Part (e) asked candidates to answer with respect to 'this buffer solution', but many candidates gave a generalised statement about buffering capacity without referring to the components in 'this buffering system'

### Curriculum Dot point: Self ionization of water

- water is a weak electrolyte; the self-ionization of water is represented by  $K_w = [H^+][OH^-]$  where  $K_w = 1.0 \times 10^{-14}$  at 25 °C.

- $H_2O_{(l)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$
- At 25°C the  $K_w = 1 \times 10^{-14}$
- $[H^+] = [OH^-] = 1 \times 10^{-7} \text{ mol L}^{-1}$
- As  $K_w = [H^+][OH^-]$  ( $H_2O$  is ignored as it is in liquid state)
- $K_w = (1 \times 10^{-7})(1 \times 10^{-7}) = 1 \times 10^{-14}$
- Remember that the ionization constant is dependent on temperature and that it may change – giving different  $[H^+]$  and  $[OH^-]$  and therefore, a different pH but the water is still neutral as  
 $[H^+] = [OH^-]$ .  $[H^+] = [OH^-] = \sqrt{K_w}$
- $K_w$  can be used to calculate the  $[H^+]$  or the  $[OH^-]$  given the other one.

### Past exam question: WACE 2016 Question 31

Water is capable of self-ionisation.

- (a) Write an equation for the self-ionisation of water. (2 marks)

- (b) Write the equilibrium constant expression for the self-ionisation of water. (1 mark)

- (c) The equilibrium constant for the self-ionisation of water  $K_w$  is  $1.00 \times 10^{-14}$  at 25°C. What does this value indicate about the reaction? (1 mark)

The K values of the self-ionisation of water at 100 kPa are given here for a number of different temperatures.

Temperature (°C)	K Value
0	$0.114 \times 10^{-14}$
25	$1.00 \times 10^{-14}$
50	$5.48 \times 10^{-14}$
75	$19.9 \times 10^{-14}$
100	$51.3 \times 10^{-14}$

- (d) Calculate the pH of water at 50°C. (ANS: 6.63) (2 marks)

- (e) Is water acidic, basic or neutral at 50°C? State a reason for your answer. (2 marks)



### Examination report information:

Few candidates had difficulty with part (a). In part (b) a common error was the omission of 'K=...' in the response resulting in the loss of the mark; either candidates did not know how to write an equilibrium constant expression or have fallen into a lazy habit of neglecting it. Candidates often used the expression 'favours reactants' or 'reaction does not occur to a large extent' in part (c), demonstrating limited understanding of what the value of K means. While some candidates were unable to determine the correct  $H^+$  concentration for part (d), there were able to gain one mark for calculating a pH based on this incorrect concentration. For part (e) less than half of the candidates realised that water was neutral regardless of its temperature or could justify this statement by referring to the hydrogen ion concentration being identical to that of the hydroxide ion concentration and that pH reflects a neutral position only at 25°C.

#### Curriculum Dot points: pH scale

- $K_w$  can be used to calculate the concentration of hydrogen ions or hydroxide ions in solutions of strong acids or bases.
  - the pH scale is a logarithmic scale and the pH of a solution can be calculated from the concentration of hydrogen ions using the relationship  $pH = -\log_{10} [H^+]$ .
- 
- A strong acid can be calculated directly once  $[H^+]$  is known – look at the ionisation equation eg.  
 $HCl \rightarrow H^+ + Cl^-$  then  $[H^+] = [HCl]$  and  $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$  then  $[H^+] = 2 \times [H_2SO_4]$
  - For a strong base you need to find  $[OH^-]$  from the ionisation equation as per the acid, then find the  $[H^+]$  by using  $K_w$  and then the pH equation can be used.  
 $[OH^-] = K_w/[H^+]$
  - The pH of a solution is defined as the negative logarithm (to the base 10) of the hydronium ion concentration.
  - It essentially measures the concentration of hydrogen ions in solution and can be calculated using the formula:  $pH = -\log[H^+]$
  - This can then be rearranged to calculate concentration as follows:  $[H^+] = 10^{-pH}$
  - A change in pH of one unit corresponds to a ten-fold change in the hydronium ion concentration.

#### Past exam question: WACE 2019 Question 32

From a measuring cylinder, 34.0 mL of 0.114 mol L<sup>-1</sup> nitric acid, HNO<sub>3</sub> (aq), is added to a flask containing 44.5 mL of 0.0556 mol L<sup>-1</sup> solution of calcium hydroxide, Ca(OH)<sub>2</sub>(aq). Determine the pH of the final solution.

### Curriculum Dot points: Indicators

- acid-base indicators are weak acids, or weak bases, in which the acidic form is a different colour from the basic form.
- volumetric analysis methods involving acid-base reactions rely on the identification of an equivalence point by measuring the associated change in pH, using appropriate acid-base indicators or pH meters, to reveal an observable end point.
- data obtained from acid-base titrations can be used to calculate the masses of substances and concentrations and volumes of solutions involved.

The practical purpose of a titration is where solutions of unknown concentration are combined until equivalence is achieved.

- **Primary Standard:** A substance that can be used directly to prepare a standard solution – has a known formula, is obtained in pure form, has a relatively large molar mass and is stable over time. Sodium Carbonate and Oxalic acid are common primary standards.
- **End Point:** The point during a reaction where an indicator changes colour to show that the reaction is complete.
- **Equivalence Point:** The point during a reaction at which stoichiometric amounts of reactants have been reacted.
- Experimental procedure:
  - A standard solution is prepared by first weighting the mass accurately then made up to the required volume in a volumetric flask – bottom of meniscus on the line.
  - An aliquot is measured by a pipette which has been rinsed with the solution that goes in it, and is placed in a conical flask that has been pre-rinsed with distilled water. A few drops of a suitable indicator is added to the conical flask
  - The other solution is placed in a burette that has been pre-rinsed with the solution going in it.
  - The solution is released carefully from the burette into the conical flask until the end point is reached.
  - The initial and final burette readings are taken and the titre volume is calculated – final – initial volumes.
  - This is repeated until 3 concordant titre volumes are obtained
- Steps for minimizing errors:
  - Ensure bottom of meniscus is on the line for the volumetric flask and the pipette
  - Read the burette from the bottom of the meniscus – up to 2 dec pl.
  - Ensure that you are eye level with the equipment when reading volumes
  - Ensure that all glassware is rinsed correctly
    - Burette – distilled water and final rinse with solution going in it.
    - Pipette – distilled water and final rinse with solution going in it.
    - Conical flask – distilled water only
    - Volumetric flask – distilled water only
- Choice of indicators

Acid / base combination	Equivalence pH	Suitable indicator	Colour change (acid in flask – reverse for base in flask)
Strong acid / weak base	Acidic	Methyl Orange	Red to yellow
Strong acid/ strong base	Neutral	Phenolphthalein	Colourless to pink
Weak acid/ weak base	Neutral	Phenolphthalein	Colourless to pink
Weak acid/ strong base	Basic	Phenolphthalein	Colourless to pink

If you are given a indicator options, you MUST use those (look at the pH range of the indicator and the equivalence pH that would be achieved)

- Steps for calculations:
  - Calculate concentration of the standard solution first if required ( $n = m/M_r$  then  $C = n/V$ )
  - Calculate the average titre volume if required (use concordant titre values only)
  - Follow the general 4 steps for any calculation question: Write your BALANCED equation, calculate moles of known substance, calculate moles of unknown substance, calculate quantity (usually concentration in this case).
  - If it is a purity or other question type – ensure that you answer that question.
- If it is a complex procedure a flow chart or diagram may help you identify the procedure carried out and make it easier to do the calculation.

**Past exam question: WACE 2019 Question 39**

Herbicides are chemicals that kill plants, including weeds. The label of a commonly – available herbicide concentrate is shown below. (Important information only induced)

Ingredients: 155 g/L  $\pm$  5.00% sodium chloride  
 295 g/L  $\pm$  5.00% acetic (ethanoic) acid

A chemist was given the task of verifying the concentration of sodium chloride and acetic (ethanoic) acid stated for this herbicide. The sodium chloride content of the herbicide was analysed. It was found to be consistent within the tolerance of  $\pm$  5.00% of the stated concentration. The chemist then performed a series of titrations with sodium hydroxide to measure the acetic (ethanoic) acid concentration.

The herbicide solution used in the titrations was prepared by pipetting 5.00 mL of the concentrate into a 250.0 mL volumetric flask. The solution in the flask was then made up to the mark with distilled water.

A 20.00 mL sample of the diluted herbicide was pipetted into a conical flask and a few drops of a suitable indicator were added. This solution was then titrated with standardised 0.0947 mol L<sup>-1</sup> NaOH solution.

After an initial ‘rough titration’, a further four titrations were performed. The results are shown in the following table.

(a) Complete the table and determine the average titre. (2 marks)

Titration number	Burette readings (mL)		Titre
	Initial	Final	
1	1.28	20.75	
2	20.75	40.19	
3	1.48	21.82	
4	21.82	41.21	
Average titre			

(b) Identify with what solutions each of these pieces of glassware should be rinsed prior to their use in these titrations. (3 marks)

Glassware item	Rinse solution
5.00 mL pipette	
20.00 mL pipette	
250.0 mL volumetric flask	

(c) Demonstrate whether or not the experimentally determined value of the acetic (ethanoic) acid concentration matches the value given on the herbicide label, bearing in mind that a difference of  $\pm$  5.00% is considered acceptable. Show **all** workings and reasoning. (ANS: 280.25 – 309.75 g L<sup>-1</sup>) (8 marks)

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### Examination report information:

Generally, parts (a) and (b) were done well by most candidates. Part (c) challenged some candidates. Setting out was poorly done.

### Past exam question: WACE 2020 Question 37(d)

The following table provides some information about three different acid-base indicators.

Indicator	pH range	Acid colour	Base colour
methyl orange	3.2 – 4.4	red	yellow
bromothymol blue	6.0 – 7.6	yellow	blue
phenolphthalein	8.3 – 10.0	colourless	pink

Which of these indicators should the students use when titrating phosphoric acid with sodium hydroxide? Justify your choice with the aid of a relevant balanced chemical equation. (5 marks)

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### Examination report information:

Many candidates needed to provide better explanations for indicator selection, focusing on the pH of the solution at the equivalence point. It is not sufficient to say that the titration involved a weak acid and a strong base.

#### Curriculum Dot point. (SHE): Acid and base theories

- Models and theories are contested and refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory scope. Davy initially proposed that acids were substances that contained replaceable hydrogen (hydrogen that could be partly or totally replaced by metals) and bases were substances that reacted with acids to form salts and water. The Arrhenius model, which includes only soluble acids and bases, identified acids as substances which produce hydrogen ions in solution and bases as substances which produce hydroxide ions in solution. Subsequently, the Brønsted-Lowry model describes acid-base behaviour in terms of proton donors and proton acceptors. This approach includes a wider range of substances and can be more broadly applied.

### Past exam question: WACE 2021 Question 8

Which of the following equation/s demonstrate the Arrhenius model of acids and bases?

- (i)  $\text{HCl(aq)} \rightarrow \text{H}^{\text{+}}(\text{aq}) + \text{Cl}^{\text{-}}(\text{aq})$   
(ii)  $\text{CH}_3\text{COOH(aq)} + \text{H}_2\text{O(l)} \rightarrow \text{CH}_3\text{COO}^{\text{-}}(\text{aq}) + \text{H}_3\text{O}^{\text{+}}(\text{aq})$   
(iii)  $\text{KOH(aq)} \rightarrow \text{K}^{\text{+}}(\text{aq}) + \text{OH}^{\text{-}}(\text{aq})$   
(iv)  $\text{H}_2\text{PO}_3^{\text{-}}(\text{aq}) + \text{H}_3\text{O}^{\text{+}}(\text{aq}) \rightarrow \text{H}_2\text{O(l)} + \text{H}_3\text{PO}_4(\text{aq})$   
(iv)  $\text{H}_2\text{PO}_4(\text{aq}) + \text{H}_3\text{O}^{\text{+}}(\text{aq}) \rightarrow \text{H}_2\text{O(l)} + \text{H}_3\text{PO}_4(\text{aq})$
- (a) i, ii, iii  
(b) i only  
(c) ii and iii only  
(d) i and iii on

# TOPIC 3: REDOX

## Curriculum Dot points: redox reactions

- oxidation-reduction (redox) reactions involve the transfer of one or more electrons from one species to another.
  - oxidation involves the loss of electrons from a chemical species, and reduction involves the gain of electrons by a chemical species; these processes can be represented using half-equations and redox equations (acidic conditions only).
  - the species being oxidised and reduced in a redox reaction can be identified using oxidation numbers.
- Balancing half equations – Rules
    - Balance atoms other than oxygen or hydrogen – use numbers
    - Balance oxygen atoms – use water
    - Balance hydrogen atoms – use hydrogen ions
    - Balance charge – use electrons (add to the more positive side)
  - Adding half equations
    - Ensure the number electrons are equal (multiply if necessary)
    - Cancel out like terms on both side – or add up common terms
  - Join the two half equations ensuring that there are no electrons left on either side and collect and cancel like terms.

Know the rules for assigning oxidation numbers and how to use them:

- Elements in the elemental state the oxidation number is 0
- For monoatomic ions the oxidation number is the same as the charge on that ion
- Oxygen is  $-2$  except in Hydrogen peroxide where it is  $-1$
- Hydrogen is  $+1$  except in hydrides where it is  $-1$
- Group 1 is  $+1$  and group 2 is  $+2$
- For polyatomic ions the oxidation number of the elements add up to the charge on that ion.

## Past exam question: WACE 2019 Question 28

Calcium hypochlorite and hydrochloric acid react according to the equation shown below.



In this reaction, the chlorine in calcium hypochlorite and the chloride from the hydrochloric acid are both converted to chlorine gas.

(a) What is the oxidation number of the chlorine in:

- Calcium hypochlorite,  $\text{Ca(OCl)}_2$

- Hydrochloric acid,  $\text{HCl}$ ?

(2 marks)

Chlorine gas is produced by the oxidation of one of these substances and the reduction of the other.

(b) Write the **two** half – equations showing how chlorine gas is produced from both substances.

(5 marks)

## Examination report information:

Most candidates could work out the oxidation numbers in part (a), but many candidates struggled to omit spectator ions or use  $\text{Ca(OCl)}_2$  as a solid when writing the half-equations in part (b).

**Past exam question: WACE 2022 Question 37**

The copper cycle is a series of reactions involving copper. The first step involves adding copper to excess concentrated nitric acid to produce copper (II) nitrate, nitrogen dioxide and water. Write balanced half-equations for the oxidation and reduction reactions and a balanced overall redox reaction for this reaction.

(5 marks)

Oxidation:	
Reduction:	
Overall:	

**Examination report information:**

Most candidates answered this question well.

**Curriculum Dot point: Halogen displacement and combustion reaction**

- A range of reactions involve the oxidation of one species and reduction of another species, including metal an halogen displacement reactions, and combustion in both limited and excess oxygen environments.
- A more active metal (as an element) will displace a less active metal out of solution. The most active metal is potassium, and these will decrease in activity moving up the standard reduction potential tables on the data sheet from the bottom.
  - A more active halogen (as an element) will displace a less active halogen out of the solution. The most reactive halogen is fluorine, and they will decrease in activity moving down standard reduction potential table on the data sheet from the very top.
  - Combustion of organic compounds in excess oxygen will always produce carbon dioxide and water.
  - Combustion of organic compounds in limited oxygen environments will produce carbon monoxide and water.

**Past exam question: WACE 2020 Question 27**

Write balanced equation for any reactions occurring between the following substances and describe the observation(s). If there is no reaction, write 'no reaction' for the equation and if there is no change observed, write 'no visible reaction' for the observations, where applicable, use the colours stated in the chemistry data booklet. (8 marks)

Iron filings and dilute hydrochloric acid.

Equation:
Observation(s):

Chromium(III) nitrate solution and magnesium ribbon

Equation:
Observation(s):

Potassium chloride solution and bromine water

Equation:
Observation(s):

### Examination report information:

A common error was candidates for getting to balance equations, and not using the standard reduction potential tables to determine if a reaction was possible.

#### Curriculum Dot point: oxidizing and reducing agent

- the relative strength of oxidising and reducing agents can be determined by comparing standard electrode potentials, and can be used to predict reaction tendency.

The strongest oxidising agent is at the top of the data sheet (left to right direction)

- The strongest reducing agent is at the bottom of the data sheet (right to left direction)
- For a reaction to occur it must produce a positive EMF value

#### Past exam question: WACE 2021 Question 19

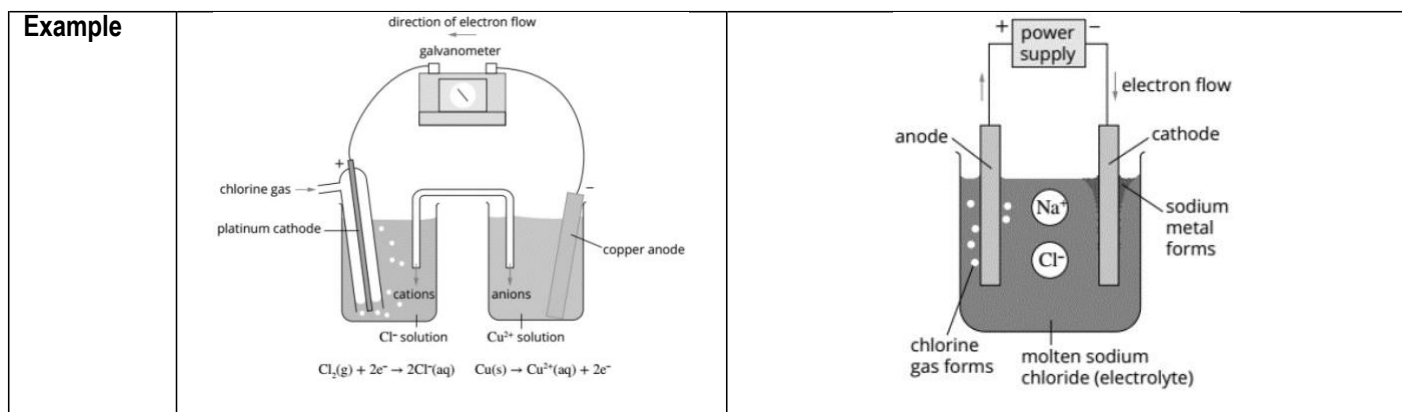
In which of the following reactions would there be no visible reaction at 25°C?

- A solid iron strip is placed in a solution of 1.00 mol L<sup>-1</sup> copper(II) sulphate.
- Bromine water and 2,3-dimethylbut-2-ene are shaken together
- Chlorine gas is bubbled through a solution of 1.00 mol L<sup>-1</sup> potassium iodide.
- 1.00 mol L<sup>-1</sup> potassium dichromate and 1.00 mol L<sup>-1</sup> acidic acid are mixed together.

#### Curriculum Dot points: electrochemical cells

- electrochemical cells, including galvanic and electrolytic cells, consist of oxidation and reduction half-reactions connected via an external circuit through which electrons move from the anode (oxidation reaction) to the cathode (reduction reaction)
- galvanic cells produce an electric current from a spontaneous redox reaction.
- electrochemical cells can be described in terms of the reactions occurring at the anode and cathode, the role of the electrolyte, salt bridge (galvanic cell), ion migration, and electron flow in the external circuit.
- the electric potential difference of a cell under standard conditions can be calculated from standard electrode potentials; these values can be used to compare the voltages generated by cells constructed from different materials.
- cell diagrams can be used to represent electrochemical cells.

	Galvanic cells	Electrolytic cells
Similarities	Reduction occurs at the cathode. Oxidation occurs at the anode Electrons flow from the anode to the cathode Cations move towards the cathode. Anions move towards the anode	
Charge on electrodes	Anode is negative. Cathode is positive	Anode is positive. Cathode is negative
Rest of circuit	Voltmeter reads the voltage produced. Salt bridge required	Battery produces the voltage required. No salt bridge
Voltage	Produced EMF is positive	Required EMF is negative
Energy conversion	From chemical energy to electrical energy	From electrical energy to chemical energy
Electrolyte	2 separate cells – 3 types of electrolytes Metal (metal electrode in salt of that metal) Solution (inert electrode in solution that contain the ions that react) Gaseous (gas passing over an inert electrode)	1 cell Molten or aqueous



- In a galvanic cell the salt bridge contains ions that are free to move and balance the charges formed in the compartments, it also completes the circuit so electrons can flow.
- To determine the voltage produced (galvanic cells), the potential difference, use the data sheet to find the half-cell voltages and: Cell potential difference =  $E^{\circ}_{\text{reduction}} - E^{\circ}_{\text{oxidation}}$
- The values of the data sheet are measured at standard conditions: 100 kPa, 1 mol L<sup>-1</sup> solutions, 25°C

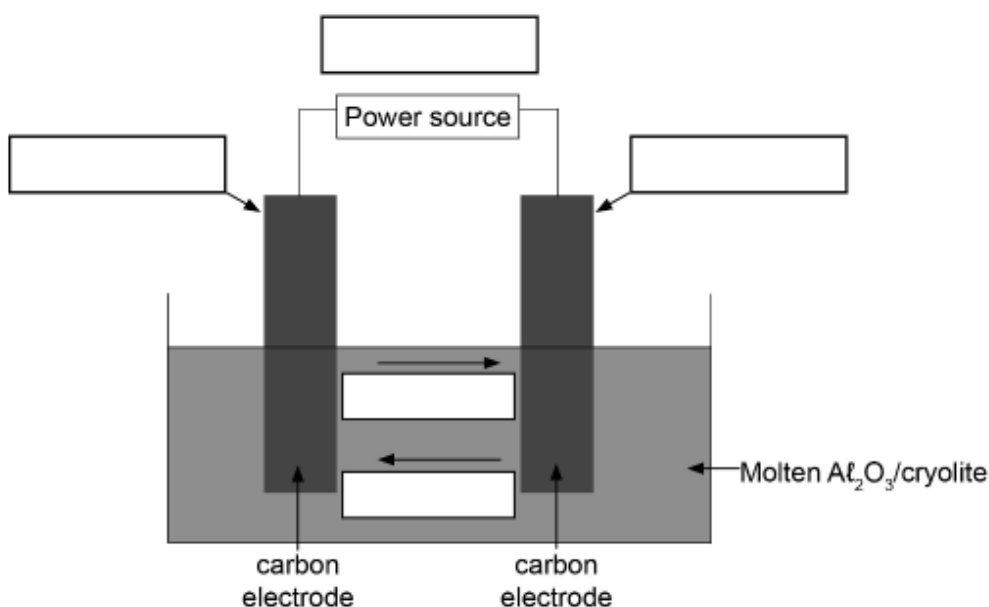
**Past exam question: WACE 2022 Question 35**

Aluminium can be refined through electrolysis. Molten aluminium oxide, which is mixed with a substance called cryolite to reduce the melting point, is electrolysed to produce aluminium and carbon dioxide, which is represented by the following equation:



On the diagram below, correctly place the following in the boxes:

- anode
- cathode
- direction of cation flow and direction of anion flow
- direction of electron flow. (3 marks)



**A good tip to answer questions like this:**

Only some candidates were able to answer this question. Many candidates struggled to label the anode or the cathode correctly. A good tip is to write the oxidation and reduction numbers on the equation. This will help you in labelling the anode and cathode correctly. Once both electrodes have been correctly labeled, the anion, cation and electron flow can be swiftly found.



**Curriculum Dot point:**

- Corrosion of iron is an electrochemical process that can be prevented by a range of techniques, including by exclusion of oxygen and/or water and through cathodic protection and sacrificial anodes.

Reactions involved in the corrosion of iron.

- Oxidation of iron:  $\text{Fe(s)} \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$
- Reduction of oxygen:  $\text{O}_2(\text{g}) + 2\text{H}_2\text{O(l)} + 4\text{e}^- \rightarrow 4\text{OH}^-(\text{aq})$
- Precipitation of iron hydroxide:  $\text{Fe}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Fe(OH)}_2(\text{s})$
- Further oxidation:  $4\text{Fe(OH)}_2(\text{s}) + \text{O}_2(\text{g}) + 2\text{H}_2\text{O(l)} \rightarrow 4\text{Fe(OH)}_3(\text{s})$
- Dehydration forming rust:  $2\text{Fe(OH)}_3(\text{s}) \rightarrow \text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O(s)} + 2\text{H}_2\text{O(l)}$

□ Prevention of corrosion

- Inert non-metallic coating: Coating with grease, paint, plastic or porcelain can prevent corrosion by excluding water and oxygen from iron. Once scratched, corrosion will commence.
- Inert metallic coating: Coating with less reactive metal excludes water and oxygen. If barrier is damaged corrosion will occur faster than before
- Galvanizing (cathodic protection): Coating with the more reactive metal, zinc, excluding oxygen and water. The zinc also corrodes in preference to the iron, so it protects the iron even if scratched.
- Cathodic protection using DC current: Applying an electric current to the iron, making it negative and thus will not oxidize. The anode is attached to a piece of scrap iron which becomes oxidised over time
- Sacrificial anode: A more active metal is bolted to the iron needing protection and must be in salt bridge contact with the iron. Works in damp or wet environment. The more reactive metal of the sacrificial anode is oxidised in preference to iron. Makes the iron the cathode and thus will not oxidise.

**Past exam question: WACE 2021 Question 31(a), (c) – (d)**

The corrosion of iron is an electrochemical process that results in the formation of a reddish brown solid commonly known as rust,  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O(s)}$ . Iron objects exposed to rainwater corrode relatively quickly.

Iron corrosion occurs in two stages. During the first stage, an electrochemical cell is established on the iron surface, with electron transfer and  $\text{Fe}^{2+}$  ion formation occurring. In the second step, oxygen and water gain electrons to produce a hydroxide ion.

- (a) Write half-equations and the overall balanced equation for the reaction occurring in the electrochemical cell. State symbols are **not** required. (4 marks)

Oxidation half-equation	
Reduction half-equation	
Redox equation	

A corrosion chemist inspected an outdoor playground and found that most of the equipment containing iron showed signs of corrosion. The chemist suggested several different methods for protecting the playground equipment from further corrosion, including the use of sacrificial anodes.

- (c) State what is a sacrificial anode (1 mark)

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- (d) State the name of a metal that could be used as a sacrificial anode to protect the equipment from further corrosion. Use standard reduction potentials to justify your choice. (2 marks)

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### Examination report information:

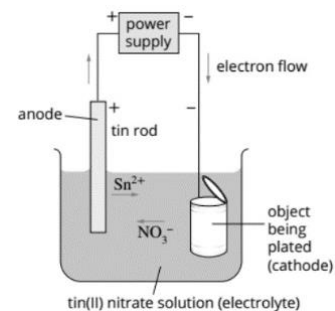
All parts of this questions were well answered. Part (a) provided clear scaffolding so that candidates were able to develop oxidation and reduction half equations. Understanding of sacrificial anodes was also well demonstrated.

### Curriculum Dot point: Electrolysis

- electrolytic cells use an external electrical potential difference to provide the energy to allow a non-spontaneous redox reaction to occur.
- describe the use of electrolysis in electrolytic refining, including for purification of copper, and metal electroplating, including for silver.

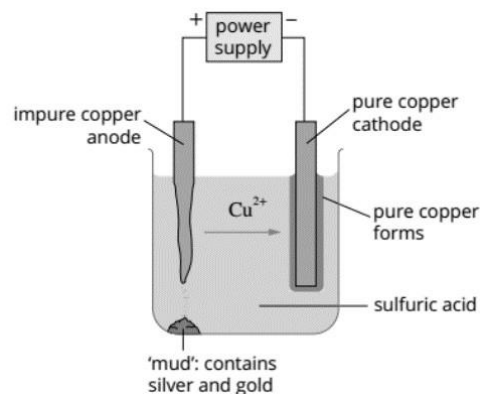
### Metal plating

- The object to be plated is at the cathode (negative)
- An electrode of the metal is at the anode (positive)



### Purification of copper

- Pure copper is at the cathode (negative)
- The impure copper is at the anode (positive)
- At the anode, copper and impurities that are more reactive than copper (such as nickel and zinc), are oxidised and enter the solution as ions. Impurities less reactive than copper (such as silver, gold, and platinum) are not oxidised and fall from the anode to the bottom of the tank.
- At the cathode, copper is reduced and forms 99.99% pure copper.

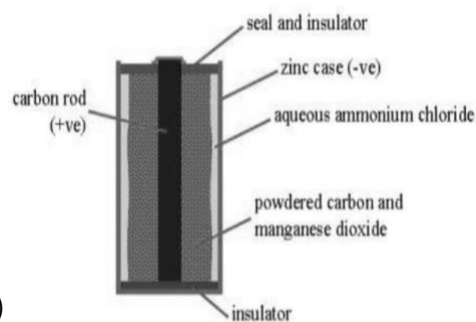
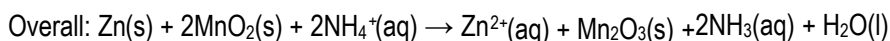
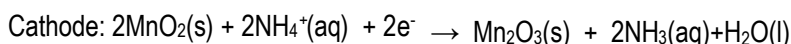
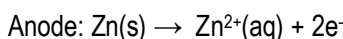


### Curriculum Dot point. Electrochemical cell real life application

- Spontaneous redox reactions can be used as a source of electrical energy, including primary cells (for example, the Leclanché cell), secondary cells (for example, the lead-acid accumulator) and fuel cells (for example, the hydrogen fuel cell). Fuel cells are a potential lower-emission alternative to the internal combustion engine and are already being used to power various modes of transport. Organisations, including the International Partnership for Hydrogen and Fuel Cells in the Economy, have been created to foster global cooperation on research and development, common codes and standards, and information sharing on infrastructure development.

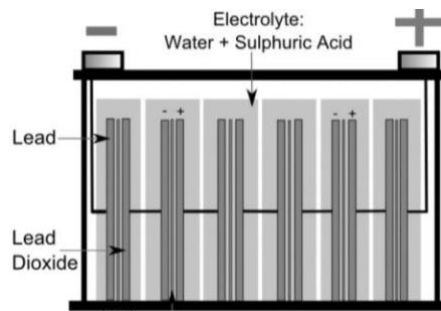
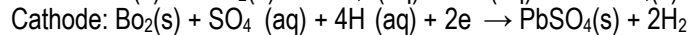
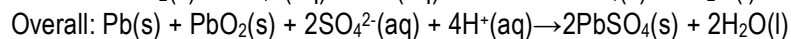
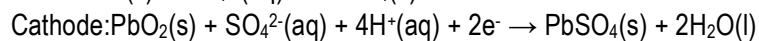
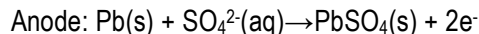
### Primary cells

- Non rechargeable cells.
- Example of galvanic (electrochemical) cells
- For example, the Leclanche cell



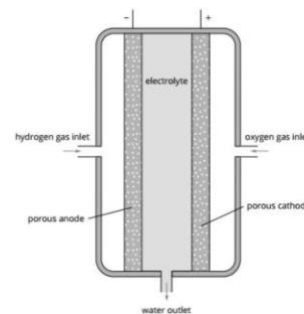
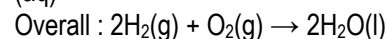
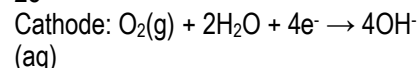
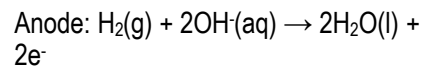
## Secondary cells

- Rechargeable cells
- On discharging act as a galvanic cell and on recharging act as an electrolytic cell
- For example, the lead-acid accumulator



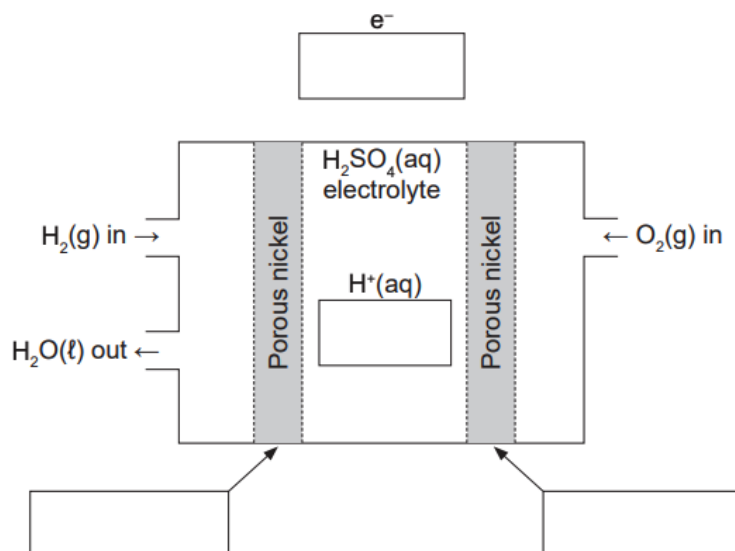
## Fuel cells

- Do not store the oxidising or reducing agents or the products.
- Contain electrodes that all reactants diffuse through then react with ions in the electrolyte.
- The electrolyte allows the movement of ions, maintains electrical neutrality and completes the circuit.
- Advantages include
  - constant flow of reactants means it can operate as long as fuel is available
  - efficiency doesn't reduce over time
  - the electrodes do not get depleted during the process of generating electricity
  - higher efficiency
  - produce energy at the same rate over a long period of time
  - produce constant voltage.
- For example, the hydrogen fuel cell.



## Past exam question: WACE 2021 Question 30

Fuel cells, such as the one shown in the diagram below, use gaseous hydrogen and oxygen to produce electricity.



In this particular fuel cell, which uses sulfuric acid as the electrolyte, the hydrogen and oxygen are circulated at very high pressure over porous nickel-platinum electrodes. Operating temperatures range from 25 to 90 °C.

(a) Complete the above diagram by adding labels/arrows to show the:

- anode
- cathode
- direction of electron flow
- direction of hydrogen ion flow.

(4 marks)

- (b) Write balanced half-equations for the oxidation and reduction reactions and the equation for the overall reaction occurring in this fuel cell. (4 marks)

Oxidation half-equation	
reduction half-equation	
Redox equation	

- (c) This fuel cell typically produces 0.7 V, which is significantly less than the predicted value of 1.23 V. State two specific conditions of this cell that would account for this observation (2 marks)
- 
- 
- 

**Examination report information:**

All parts of this question were done well by able candidates. Some candidates struggled to do part a and b. Many students wrote vague answer for part c.

## TOPIC 4: ORGANIC CHEMISTRY

**Curriculum Dot point: IUPAC Nomenclature**

- IUPAC nomenclature is used to name organic species, including those with a parent chain of up to 8 carbon atoms with simple branching and one of the following functional groups: alkenes, alcohols, aldehydes, ketones, carboxylic acids, esters, amines, and amides.
- structural formulae (condensed or showing bonds) can be used to show the arrangement of atoms and bonding in organic molecules that contain the following functional groups: alkenes, alcohols, aldehydes, ketones, carboxylic acids, esters, amines, and amides

**Table 1: the number of carbons and their prefix.**

Number of carbons	Prefix
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-

**Table 2: the type of bond and their suffix**

Type	Suffix
Single	-ane
Double	-ene

**Table 3: the name for branches**

Number of carbons	Name
1	Methyl-
2	Ethyl-
3	Propyl-
4	Butyl-

**Table 4: the names for multiple branches or functional groups**

Number branches	Name (prefix)
1	mono-
2	di-
3	tri-
4	tetra-

**Table 5: names of functional groups**

What	Group	General formula	Name	Example
Alkanes	N/A	$C_nH_{2n+2}$	-ane	Ethane
Alkenes	$\begin{array}{c}   \quad   \\ -C = C - \end{array}$	$C_nH_{2n}$	-ene	But-1-ene
Alcohols	-O-H	$C_nH_{2n+1}OH$ OR $C_nH_{2n+2}O$	-ol or hydroxyl -	Methanol
Aldehydes	$\begin{array}{c} O \\    \\ -C-H \end{array}$	$C_nH_{2n+1}CHO$ OR $C_nH_{2n+2}O$	-al	Ethanal
Ketones	$\begin{array}{c} O \\    \\ -C- \end{array}$	$C_nH_{2n}O$	-one	Propanone
Carboxylic acids	$\begin{array}{c} O \\    \\ -C-OH \end{array}$	$C_nH_{2n+1}COOH$ OR $C_nH_{2n}O_2$	-oic acid	Hexanoic acid
Esters	$\begin{array}{c} O \\    \\ -C-O- \end{array}$	$C_nH_{2n}O_2$	-oate	methylethanoate
Primary amines	$\begin{array}{c} H \\   \\ -N \\   \\ H \end{array}$	$C_nH_{2n+1}NH_2$	-amine or amino -	Propanamine
Amides	$\begin{array}{c} O \quad H \\    \quad   \\ -C - N - \end{array}$	$C_nH_{2n+1}ON$	-amide	N-methylethanamide

**Past exam question: WACE 2020 Question 26**

Complete this table by giving the IUPAC name or full structural formula of the indicated organic compounds. All hydrogen atoms must be shown. (4 marks)

Full structural formula	IUPAC name
$\begin{array}{ccccccc} H & H & H & H & & H & \\   &   &   &   & &   & \\ H-C & -C & -C & -C & -C & -N & \\   &   &   &   &    & & \\ H & H & H & H & O & & H \end{array}$	
$\begin{array}{c} H_3C \quad CH_3 \\ \diagdown \quad / \\ C = C \\ / \quad \diagdown \\ H_3C \quad CH_3 \end{array}$	
	heptan-2-amine
	hexan-3-one

**Examination report information:**

This question was answered well by most candidates. The main issues encountered with naming compounds were shortening the name of pentanamide to pentamide and not recognising the amide functional group, instead thinking it was a ketone and an amine. A common error with the drawing of structural formula was bonds not drawn carefully enough, resulting in them not going between the correct atoms.

### Curriculum Dot point: Reactions of Organic Compounds

- organic molecules have a hydrocarbon skeleton and can contain functional groups, including alkenes, alcohols, aldehydes, ketones, carboxylic acids, esters, amines and amides; functional groups are groups of atoms or bonds within molecules which are responsible for the molecule's characteristic chemical properties
- functional groups within organic compounds display characteristic chemical properties and undergo specific reactions; these reactions include addition reactions of alkenes, redox reactions of alcohols, and acid-base reactions of carboxylic acids; these reactions can be used to identify the functional group present within the organic compound.
- all alcohols can undergo complete combustion; with oxidising agents, including acidified  $\text{MnO}_4^-$  or  $\text{Cr}_2\text{O}_7^{2-}$  - oxidation of primary alcohols produce aldehydes and carboxylic acids, while the oxidation of secondary alcohols produce ketones; these reactions have characteristic observations and can be represented with equations.
- alcohols can react with carboxylic acids in a condensation reaction to produce esters and can be represented with equations.

#### Types of reactions:

##### 1. Combustion Reactions

All organic compounds that contain only Carbon, Hydrogen and Oxygen will burn in Oxygen gas and Carbon dioxide and water is produced.

##### 2. Substitution Reactions

Alkanes/cycloalkanes and Benzene.

UV light required.

Slow reaction.

A hydrogen is replaced by a halogen producing a substituted alkane and a hydrogen halide.

##### 3. Addition Reactions

Alkenes/cycloalkenes only.

Fast reaction.

The added substance 'adds' across the double bond.

4 substances can be added:

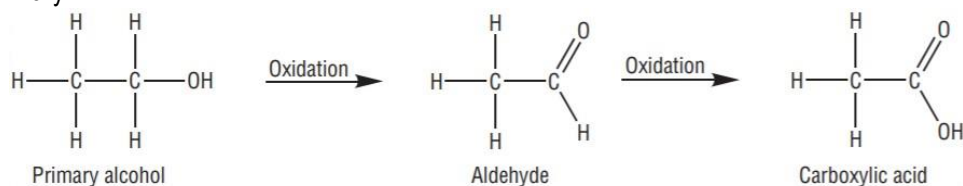
- Halogen, forming a dihalide alkane
- Hydrogen, forming an alkane.
- Hydrogen halide, forming a single halide alkane
- Water, forming an alcohol.

##### 4. Oxidation Reactions

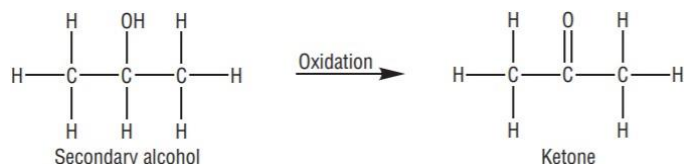
Reaction with acidified dichromate solution or acidified permanganate, which change colour to indicated that a reaction has occurred. Orange to green or purple to pale pink.

(a) Alcohols react differently with oxidation agents depending on the type of alcohol.

###### a. Primary



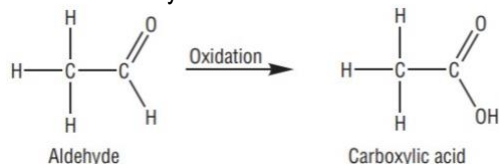
###### b. Secondary



###### c. Tertiary

Do not react

(b) Aldehydes react with oxidation agents to form carboxylic acids.



### 5. Reaction with Sodium

Alcohols will react with sodium and form an -oate ion.

Primary, secondary, and tertiary alcohols all react with sodium but with decreasing speed.

### 6. Acid Reactions

Carboxylic acids are weak acids and thus react as such, but often slower.

- acid + base  $\rightarrow$  salt + water
- acid + carbonate  $\rightarrow$  salt + water + carbon dioxide
- acid + metal  $\rightarrow$  salt + hydrogen

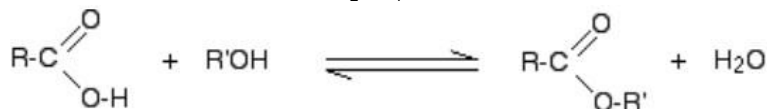
### 7. Condensation Reactions

Reactions that release water in the process.

Result in either esters or amides depending on the reactants.

(a) Making esters (esterification)

- Alcohol + carboxylic acid  $\rightarrow$  ester + water
- Presence of Concentrated  $\text{H}_2\text{SO}_4$  and Heat



(b) Making amides

- Amine + carboxylic acid  $\rightarrow$  amide + water

**Past exam questions: WACE 2017 Question 26(b) & WACE 2018 Question 33(c)**

26. Excess propene was bubbled through an aqueous bromine solution

(b) (i) Identify, by name or formula, any new substance formed

(1 mark)

(ii) Write descriptions of the substances **before** and **after** mixing

(2 marks)

33. Butanoic acid,  $\text{C}_4\text{H}_8\text{O}_2$ , is an organic compound that contains four carbon atoms in each molecule and, like butan-1-ol it is a colourless liquid.

(c) Complete the table below to describe a chemical test that could be used to distinguish between butan-1-ol and butanoic acid by stating the reagent/s used and the distinguishing observations. (3 marks)

Reagent/s used		
Substance being tested	Butan-1-ol	Butanoic acid
Observations		

### Examination report information:

26. In part (b)(ii) candidates cited a range of colours, including red, for bromine water. If the colour of a substance is listed in the Data booklet, this is the colour that should be used by a candidate. The colour of bromine water from the Data booklet is described as orange (though reddish-brown is commonly accepted) but bromine liquid is shown as red; presumably, candidates misread the Data booklet or did not know the difference between liquid bromine and aqueous bromine. Being a standard distinguishing test between saturated and unsaturated hydrocarbons, candidates would be expected to be familiar with observations made with this reaction. Candidates may have failed to recognise that the propene was in excess and so that after mixing, there would be no bromine present and hence solution would be colourless.

33. In part (c) candidates failed to demonstrate knowledge that reagents should be in solution form or acidified or simply wrote the ions. Several candidates did not understand the intent of the chemical test and chose a different reagent for each substance being tested.

#### Curriculum Dot point: Isomers

- isomers are compounds with the same molecular formulae but different structures; different types of isomerism include chain and position structural isomerism and cis-trans isomerism.
- Isomers have same molecular formula but different structural formula (remember that cyclo compounds can be included in isomers. Many organic chemicals can exhibit isomerism – alcohols, aldehydes/ketones, carboxylic acids/esters, amines, amides.
- Geometric isomerism – for alkenes – the cis version is when the hydrogens are on the same side and the trans version is when the hydrogens are on different sides

#### Past exam question: WACE 2017 Question 14

14. Which of the following are isomers of  $C_5H_8O_2$ ?

- $CH_3CH_2COCH_2CHO$
  - $CH_3CH_2CH_2CH_2COOH$
  - $CH_3COCH(CH_3)CHO$
  - $CH_2CHCH_2CH_2COOH$
- i and ii only
  - i, ii and iv only
  - i, iii and iv only
  - ii, iii and iv only

#### Curriculum Dot point: Intermolecular forces in Organic Compounds

- Organic compounds display characteristic physical properties, including boiling point and solubility in water and organic solvents; these properties can be explained in terms of intermolecular forces (dispersion forces, dipole-dipole interactions, and hydrogen bonds) which are influenced by the nature of the functional groups.

### The boiling point

Functional group	Intermolecular force(s)
Alkane	Dispersion forces,
Alkene	Dispersion forces,
Alcohol	Dispersion forces, dipole-dipole forces, hydrogen bonding
Aldehyde	Dispersion forces, dipole-dipole forces
Ketone	Dispersion forces, dipole-dipole forces
Carboxylic acid	Dispersion forces, dipole-dipole forces, hydrogen bonding *dimers formed
Ester	Dispersion forces, dipole-dipole forces
Amine	Dispersion forces, dipole-dipole forces, hydrogen bonding
Amide	Dispersion forces, dipole-dipole forces, hydrogen bonding

- For compounds with similar molar mass the type of intermolecular force formed will impact the boiling point – the stronger the force the higher the boiling point – dispersion forces only, followed by dispersion forces & dipole-dipole, finally by all three forces. \*carboxylic acids are higher as they form dimers effectively doubling their molar mass.



- For compounds with the same functional group and different length of carbon chain the increasing molar mass increases the **strength** of the dispersion forces and thus the boiling point.
- Tips for answering questions on boiling point
  - Identify what is causing the boiling point to change (different functional groups or length of carbon chain)
  - Which intermolecular forces could be formed between the molecules
  - The predominant intermolecular force between molecules
  - To explain you must describe the difference in boiling point in terms of the combination of forces that form between the molecules not just the predominant force.
  - Relate the boiling point back to the amount of energy required to disrupt the intermolecular forces, and the stronger the combination of intermolecular forces the more energy is required and thus the higher boiling point.
- Remember: there is a chance that the dispersion forces that could form between molecules is stronger than the combination of dispersion forces, dipole-dipole interactions, and hydrogen bonds between a smaller molecule. This depends on the size or mass of the molecule.

**Past exam question: WACE 2018 Question 33 (a)**

Consider the compounds and their properties listed in the table below:

Compound	Boiling point (°C)	Solubility in water (g L <sup>-1</sup> )
Butane (C <sub>4</sub> H <sub>10</sub> )	-0.5	0.061
Butan-1-ol (C <sub>4</sub> H <sub>10</sub> O)	117	73.0
Butanone (C <sub>4</sub> H <sub>8</sub> O)	79.6	27.5

Account for the difference in boiling points of the three compounds.

(5 marks)

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**Examination report information:**

This was a question which provided the top candidates an opportunity to demonstrate their ability. Many candidates explained the difference in boiling point simply in terms of hydrogen bonding (pentanoic acid) being stronger than dipole-dipole forces (pentanal) being stronger than dispersion forces (pentane) without referring to the sum of the intermolecular forces. The candidates needed to emphasise that dispersion forces can effectively be the strongest intermolecular forces for a molecule and it is the additional dipole-dipole forces and hydrogen bonding that explains the difference. Few candidates identified that dispersion forces existed in all compounds but those that did, failed to mention that the strength of these dispersion forces would be similar in each compound.

**Solubility**

- If the compound is able to form hydrogen bonds with water, it has a chance of being soluble in water, note that even though aldehydes, ketones and esters cannot form hydrogen bonds with other molecules of the same type, they can form hydrogen bonds with water, meaning small molecules can be soluble in water.
- As the length of the chain increase the dispersion forces start to predominate over the hydrogen bonds between the molecule and water and thus decreasing the solubility.
- Tips for answering questions on solubility
  - Identify the intermolecular forces that could form between solute molecules, between solvent molecules and the new forces that would form between the solute and solvent molecules.
  - Identify the predominant intermolecular force that would form between solute molecules, between solvent molecules, and the new forces that would form between the solute and solvent molecules.

- If soluble the strength of the new intermolecular forces that between the solute and solvent are sufficient to overcome the solute-solute and solvent-solvent forces.
- if insoluble the strength of the new intermolecular forces between the solute and the solvent are insufficient to overcome the solute-solute and solvent-solvent forces.

**Past exam question: WACE 2018 Question 33 (b)**

Consider the compounds and their properties listed in the table below:

Compound	Boiling point (°C)	Solubility in water (g L <sup>-1</sup> )
Butane (C <sub>4</sub> H <sub>10</sub> )	-0.5	0.061
Butan-1-ol (C <sub>4</sub> H <sub>10</sub> O)	117	73.0
Butanone (C <sub>4</sub> H <sub>8</sub> O)	79.6	27.5

- (b) Explain why these organic compounds have very different solubilities in water. (6 marks)

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**Examination report information:**

Responses to Part (b) were very disappointing. Candidates were able to identify the intermolecular forces for butane, butanone and butan-1-ol, but failed to mention the potential intermolecular forces for water. Candidates battled to understand that due to increased H-bonding in butan-1-ol there was greater solubility. Far too many gave the 'like dissolves like' response. Many candidates discussed the predominate intermolecular forces rather than the sum of intermolecular forces.

**Curriculum Dot point: Empirical Formula calculation**

- empirical and molecular formulae can be determined by calculation and the structure of an organic compound established from the chemical reactions they undergo, and other analytical data

- Moles of carbon in compound is same as moles of carbon dioxide produced
- Moles of hydrogen in compound is twice the moles of water produced
- Moles of nitrogen in compound is twice the moles of nitrogen gas produced
- Mass of all components in the compound must equal the mass of the sample.
- If there are more than one sample find the percentage of each element in the sample – the total will equal 100%. The mass of the element in each sample maybe different but the percentage will be the same.
- Think out the different equations and reactions given, draw a flow chart if you need to, you will be able to find the moles and mass of every element in the compound some way or another, use any or all of the moles equations.

**Past exam question: WACE 2018 Question 35**

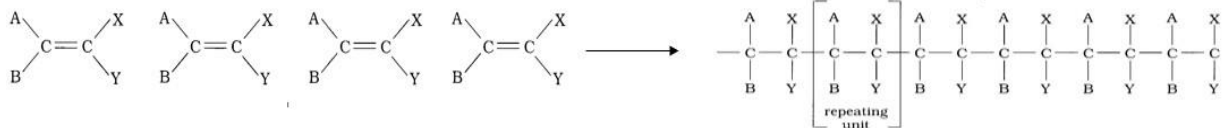
Fluconazole is an antifungal medication that contains carbon, hydrogen, fluorine, nitrogen, and oxygen.

A 3.42 g sample of fluconazole was combusted and produced 6.39 g of carbon dioxide and 1.21 g of water.

All of the nitrogen in a second 0.422 g sample of fluconazole was converted into nitric acid, which was neutralized by 16.5 mL of a 0.500 mol L<sup>-1</sup> solution of sodium hydroxide.

The second sample was also found to contain 0.0525 g of fluorine.

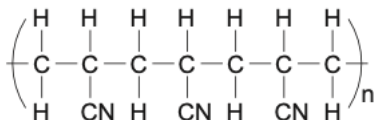




	Monomer	Polymer (segment)
Polyethene	$\text{CH}_2=\text{CH}_2$	$-\text{CH}_2-\text{CH}_2-\text{CH}_2-$
Polytetrafluoroethene	$\text{CF}_2=\text{CF}_2$	$-\text{CF}_2-\text{CF}_2-\text{CF}_2-$

**Past exam question: WACE 2020 Question 21**

Polyacrylonitrile fibres can be used to make blankets and carpets. The structural formula of a segment of this polymer is shown below.



Draw the structural formula of the monomer used to make polyacrylonitrile:

(2 marks)

**Examination report information:**

Was done well generally although a common mistake was drawing the repeating unit not the alkene.

**Curriculum Dot point: Condensation polymers**

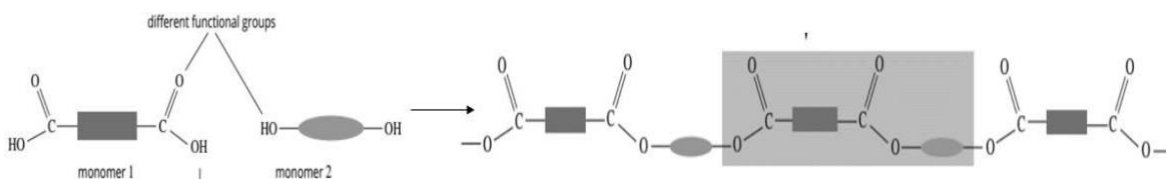
- condensation reactions can be used to produce polymers, including polyamides and polyesters
- the structure of a condensation polymer can be predicted and drawn from its monomer(s) and the structure of a condensation polymer can be used to predict the monomer(s) from which it was derived

**Condensation polymerisation**

- An application of condensation reactions to make esters or amides
- A small molecule is released for each 'link' made – usually water
- 2 types

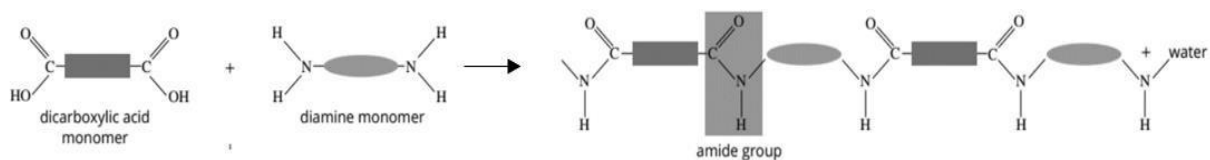
**1. Polyester**

- Involves a  $-\text{OH}$  group and a  $-\text{COOH}$  group, may be on the same molecule (a hydroxyl carboxylic acid) or as 2 separate molecules (a diol and dioic acid)



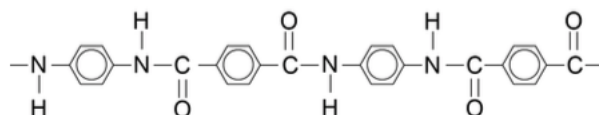
**2. Polyamides**

- Involves a  $-\text{NH}_2$  group and a  $-\text{COOH}$  group, may be on the same molecule (an amino carboxylic acid) or as 2 separate molecules (a diamine and dioic acid)



**Past exam question: WACE 2022 Question 31 (c)**

Kevlar is a polymer that is formed through a condensation reaction that releases water during the polymerisation of its monomers. A section of the Kevlar polymer is shown below.



(a) Draw the structural formula for the **two** monomers that react to form this polymer.

(2 marks)

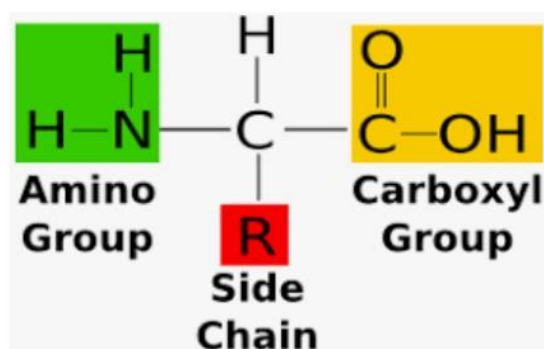
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**Examination report information:**

In part (a) most candidates were able to correctly draw the structural formula of the two monomers.

**Curriculum Dot point:  $\alpha$ -amino acids**

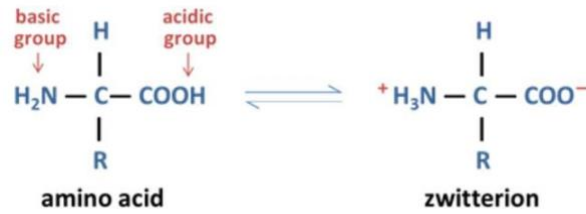
- $\alpha$ -amino acids can be represented using a generalised structure.



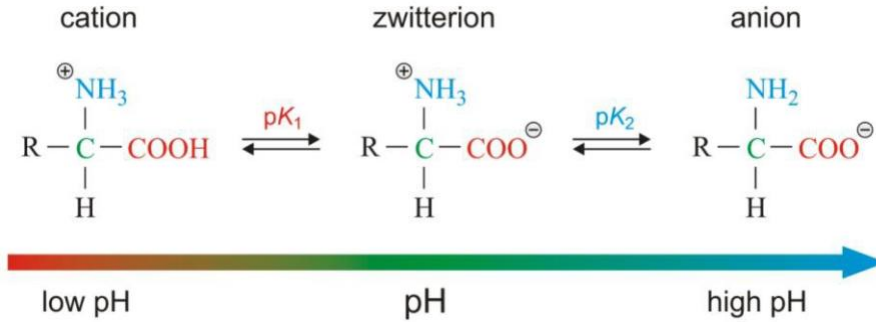
**Curriculum Dot point: Zwitter ions.**

- the characteristic properties of  $\alpha$ -amino acids include the formation of zwitterions and the ability to react to form amide (peptide) bonds through condensation reactions.

Self-ionisation: A proton is donated from the carboxylic acid end to the amine end, forms a Zwitterion.



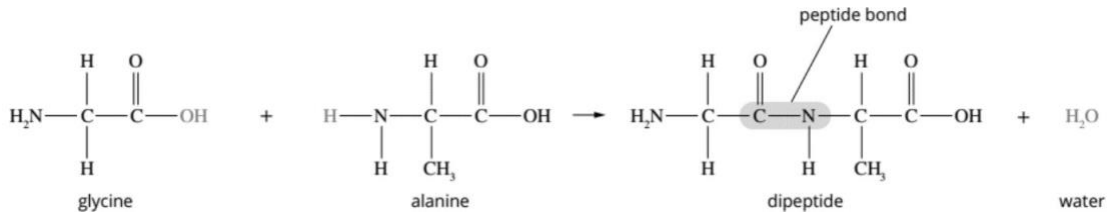
In an acid, the amino acid will act as a base and accept a proton (onto the amine end) and in a base, it will act as an acid and donate a proton (from the carboxylic acid end).



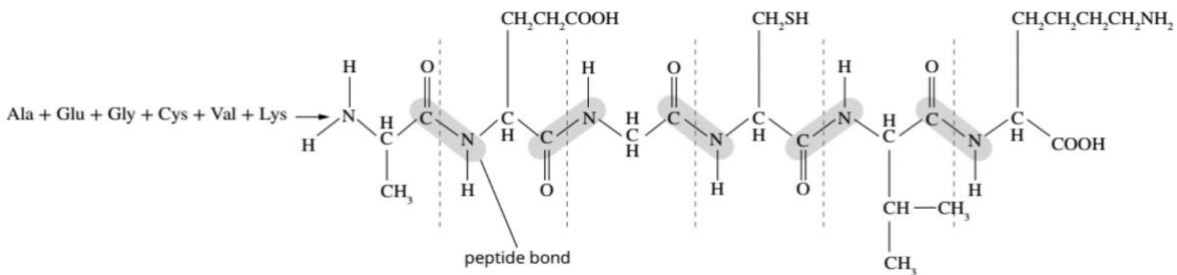
**Curriculum Dot point: Peptide bonds**

- $\alpha$ -amino acids undergo condensation reactions to form polypeptides (proteins) in which the  $\alpha$ -amino acid monomers are joined by peptide bonds.

- Special case of condensation polymerisation – 2 amino acids join via the  $\text{-NH}_2$  group on one amino acid and the  $\text{-COOH}$  group on another amino acid – make a peptide link.
- Water is released for each pair of amino acid that join.
- Making a dipeptide (joining of 2 amino acids)



- Making a small segment of protein



**Curriculum Dot points: Structure of Protein**

- The sequence of  $\alpha$ -amino acids in a protein is called its primary structure.
- Secondary structures of proteins, ( $\alpha$ -helix and  $\beta$ -pleated sheets) result from hydrogen bonding between amide and carbonyl functional groups; hydrogen bonding between amide and carbonyl functional groups within a peptide chain leads to  $\alpha$ -helix structures while hydrogen bonding between adjacent polypeptide chains leads to  $\beta$ -pleated sheets.
- The tertiary structure of a protein (the overall three-dimensional shape) is a result of folding due to interactions between the side chains of the  $\alpha$ -amino acid in the polypeptide, including disulphide bridges, hydrogen bonding, dipole-dipole interactions, dispersion forces and ionic interactions.

The function of a protein is a consequence of its shape, which in turn is determined by the order in which amino acids are joined together, the primary structure. If the primary structure is altered, the shape is altered and thus the function.

### Primary structure:

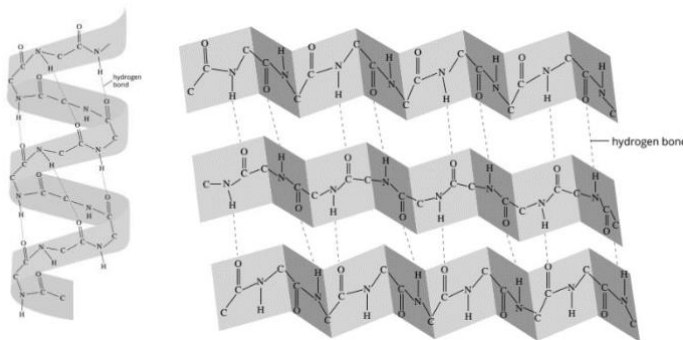
- The number, type and sequence of amino acids in the protein.
- Maybe represented by the three-letter abbreviations for the amino acids or by a structural formula of the protein.

### Secondary structure:

Hydrogen bonds form between the polar  $-NH$  group in one peptide link and the polar  $-C=O$  group in another peptide link at regular intervals.

**$\alpha$ -helix** structures form when the molecules coil into a spiral shape. The hydrogen bonds form every 4 amino acid molecules.

**$\beta$ -pleated sheet** form when the sections line up parallel to each other. This occurs with small amino acids with small side chains.

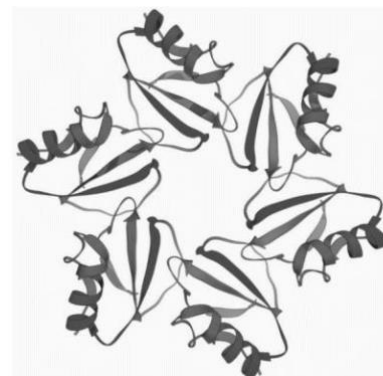


### Tertiary Structure:

The overall three-dimensional shape adopted by a protein molecule. Is produced by the three-dimensional folding of its secondary structures. The protein can twist back over itself to create a unique shape, which is responsible for the protein's function.

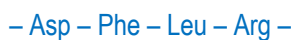
Caused by the interaction between the side chains – 5 different bonds and forces are responsible:

1. Hydrogen bonds – between side chains containing  $-O-H$ ,  $-N-H$  or  $-C=O$  groups
2. Dipole-dipole interactions – between side chains containing any polar group like  $-S-H$ ,  $-O-H$  or  $-N-H$
3. Ionic interactions – between a side chain containing  $-NH_3^+$  and another group that contains  $-COO^-$
4. Covalent cross-links – cysteine side groups react to form a disulphide bridge ( $-S-S-$ )
5. Dispersion forces – between non-polar side chains.



### Past exam question: WACE 2021 Question 34 (a, b, c, d, e, f)

Keratin 86 is a protein found in human fingernails. A small section of the amino acid sequence of Keratin 86 is shown below:



(a) Draw the full structural formula of this small section of Keratin 86.

(3 marks)

(b) The amino acid chains in Keratin 86 form  $\alpha$ -helices, with two  $\alpha$ -helices twisting around each other to form what is called a 'coiled coil' that is held together by disulfide bridges. What protein structural level is represented by an  $\alpha$ -helix.

(1 marks)

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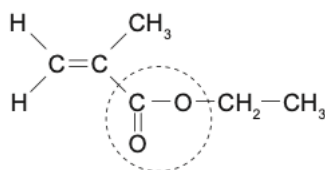
(c) What does the presence of disulfide bridges indicate about the primary structure of Keratin 86?

(1 marks)

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Synthetic fingernails are a popular fashion accessory. They are made in industrial laboratories from polymers. A monomer that can be used to make a polymer suitable for synthetic fingernails is shown below.

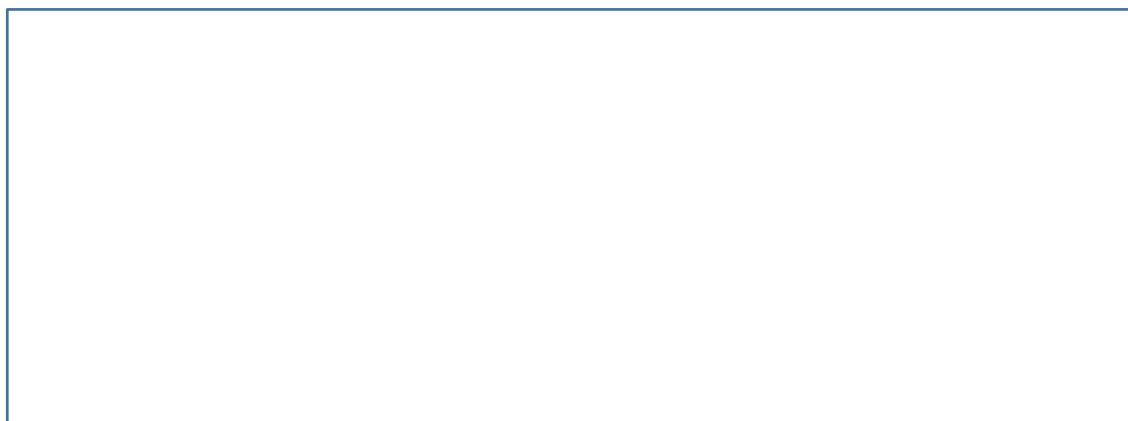


(d) Name the circled functional group in this monomer.

(e) Give the IUPAC name of the alcohol needed to make this monomer

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(f) Draw three repeating units of the polymer made from this monomer.



**Examination report information:**

In part (a) candidates needed to take care when accurately selecting and redrawing the structures given in the Data Booklet. The most common mistakes made were in:

- Failing to accurately draw the peptide link
- Terminating the polypeptide

The better candidates performed well in part (b) and (c) by correctly identifying that alpha helices are secondary structures as well as identifying that the amino acid cysteine is present in the primary structure. Most candidates accurately identified the carboxylate group in part (d) as well as identified the alcohol in the monomer.



**Curriculum Dot point: The Protein Data Bank**

- The Protein Data Bank (PDB) houses an international repository of structural data of proteins. The information is accessed and contributed to by scientists worldwide. The function of a protein is closely linked to its structure.

**Past exam question: WACE 2020 Question 14**

The protein data bank contains information relating to the structure of proteins. The structure of a protein is important because it is closely related to its

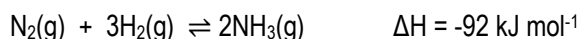
- equilibrium constant.
- bonding capacity.
- nutritional value.
- function.

## TOPIC 5: CHEMICAL SYNTHESIS

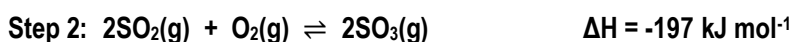
**Curriculum Dot point: Industrial application of chemical reactions.**

- chemical synthesis to form products with specific properties may require the construction of reaction sequences with more than one chemical reaction and involves the selection of particular reagents and reaction conditions in order to optimize.
- the rate and yield of the product reagents and reaction conditions are chosen to optimise yield and rate for chemical synthesis processes, including in the production of ammonia (Haber process), sulfuric acid (Contact process) and biodiesel (base-catalysed and lipase-catalysed methods).

- For the maximum yield of a product of a multi-step process, each step must be maximised.

**Ammonia**

	Rate	Yield	Actual
Temperature	High	Low	Moderate
Pressure	High	High	High but not extreme
Catalyst	Present	No effect	Present

**Sulphuric Acid**

STEP 2	Rate	Yield	Actual
Temperature	High	Low	Low
Pressure	High	High	Atmospheric
Catalyst	Present	No effect	Present

Sulfuric acid is manufactured by the Contact process, the steps of which are outlined below.

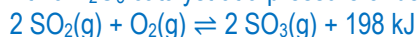
**Past exam question: WACE 2021 Question 38**

Sulfuric acid is manufactured by the Contact process, the steps of which are outlined below

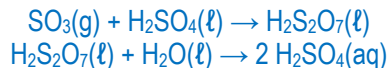
Step One: Molten sulfur is burned in air at approximately 1000 °C:



Step Two: The resulting sulfur dioxide is converted to sulfur trioxide as shown in the following equilibrium reaction. It is conducted at a temperature of about 450°C with a V<sub>2</sub>O<sub>5</sub> catalyst at a pressure of between 100 and 200 kPa:



Step Three: The resulting sulfur trioxide is absorbed into sulfuric acid, producing oleum (H<sub>2</sub>S<sub>2</sub>O<sub>7</sub>). Water is added to the oleum, producing 18 mol L<sup>-1</sup> sulfuric acid:



- (a) Use your understanding of collision theory and chemical equilibrium to discuss the reaction conditions for Steps 1 and 2 of the Contact process, given that the aim is to produce the greatest yield in the shortest time. In your discussion, also address economic concerns where appropriate.

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**Examination report information:**

Many candidates answered part (a) well. Some candidates either gave the opposite effects on yield for raising pressure or temperature or gave the mechanisms in which the reactions were affected rather than the effect. Not many candidates realised that as part of the lowered temperature and pressure compromise, the catalyst was used for economic benefit. There are many aspects of chemistry that can be asked using such industrial contexts. Some candidates misunderstood the question and attempted to explain the mechanisms of how temperature, pressure and catalysts work rather than why the conditions were considered optimal. This resulted in some candidates spending considerable time proving good chemistry which was superfluous to the question.

**Curriculum Dot point: limiting reagent calculation**

- quantities of products in a chemical synthesis reaction can be calculated by comparing stoichiometric quantities with actual quantities and by determining the limiting reagent.

- There are many different ways to determine the limiting reagent, all of which are acceptable as long as a statement is included.
- Remember to always use the limiting reagent for any further calculations.



### Curriculum Dot point.

the percentage yield of a chemical synthesis reaction can be calculated by comparing theoretical versus actual product quantities % Yield = actual yield (usually given in question)/theoretical yield (usually calculated) x 100. This is usually asked as part of a multi-step calculation, especially in industry style question. % Purity = impure mass/pure mass x 100

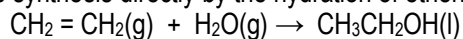
- Often forms part of a question in titrations. Finding the percentage of acetic acid in vinegar for example.

### Curriculum Dot points: enzymes

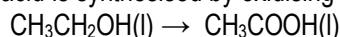
- enzymes are protein molecules which are biological catalysts and can be used on an industrial scale to produce chemicals that would otherwise require high pressure or temperature conditions to achieve an economically viable rate, including fermentation to produce ethanol versus hydration of ethene
- chemical synthesis processes may involve the construction of reaction sequences with more than one chemical reaction, including the hydration of ethene to form ethanol and the subsequent reaction of ethanol with acetic (ethanoic) acid to produce ethyl ethanoate

An example of a sequential reaction is the production of ethyl ethanoate.

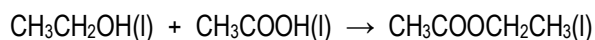
Step 1: Ethanol is synthesis directly by the hydration of ethene in the presence of a catalyst.



Step 2: Ethanoic acid is synthesised by oxidising some of the ethanol produced in step 1



Step 3: Ethyl ethanoate is produced by the condensation reaction between ethanoic acid and ethanol in the presence of a sulfuric acid catalyst.



### Production of ethanol

Hydration	Fermentation
<b>Raw material:</b> Crude Oil	<b>Raw material:</b> Plant material
<b>Equation:</b> $\text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{OH}$	<b>Equation:</b> $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{CH}_3\text{CH}_2\text{OH} + 2\text{CO}_2$
<b>Catalyst:</b> Acid	<b>Catalyst:</b> Yeast
<b>Conditions:</b> High temperature and high pressure	<b>Conditions:</b> Low temperature and low pressure

### Past exam question: WACE 2018 Question 20

Ethanol can be produced by reacting ethane with steam. The equation for this reaction, which is known as hydration, is shown below.



Which statement about this reaction is incorrect?

- (a) The hydration reaction requires higher pressures than fermentation to achieve an economically viable rate.
- (b) The hydration of ethene is an addition reaction.
- (c) Enzymes decrease the activation energies of both the hydration and fermentation reactions.
- (d) The hydration reaction requires higher temperatures than fermentation to achieve an economically viable rate.

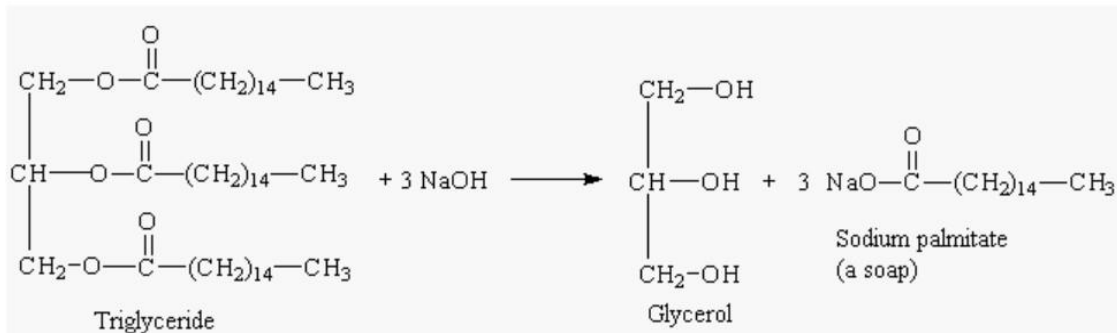
### Examination report information:

Option (d) was the most frequently selected incorrect answer, followed by option (a) and then option (b). Less than 50% of candidates got this question correct

### Curriculum Dot point.

- the base hydrolysis (saponification) of fats (triglycerides) produces glycerol and the salt of a long chain fatty acid (soap)

- Soaps are produced by the alkaline hydrolysis of fats and oils



- Animal fats and/or vegetable oils are boiled with concentrated sodium hydroxide, hydrolysing it to glycerol (propan-1,2,3-triol) and the carboxylate ions. All soluble in water.
- Solid soap, a mix of sodium carbonates is precipitated from this aqueous mixture by addition of a concentration sodium chlorine solution.

### Curriculum Dot point: Soap and detergent

- the structure of soaps contains a non-polar hydrocarbon chain and a carboxylate group; the structure of the anionic detergents derived from dodecylbenzene contains a non-polar hydrocarbon chain and a sulfonate group

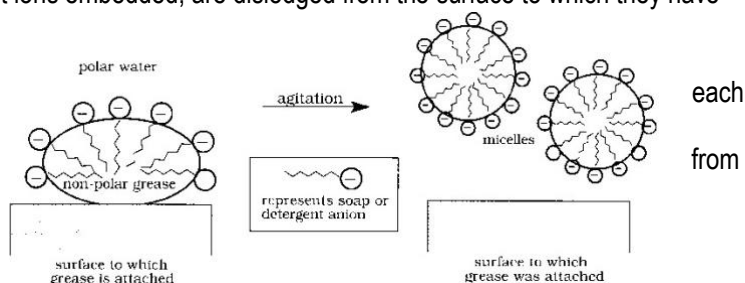
Soap	Detergent
<p>non-polar hydrocarbon chain <i>hydrophobic</i></p> <p>ionic head <i>hydrophilic</i></p>	

### Curriculum Dot point: Cleaning action of soap and detergent

- the cleaning action of soaps and detergents can be explained in terms of their non-polar hydrocarbon chain and charged group; the properties of soaps and detergents in hard water can be explained in terms of the solubilities of their calcium salts.

Both soaps and detergents work in the same fashion:

- The non-polar chains dissolve into the grease via dispersion forces, with the ionic heads sitting on the surface of the grease still in contact with the polar water via ion-dipole forces.
- With agitation, the grease globules, with soap/detergent ions embedded, are dislodged from the surface to which they have been attached.
- They are released into the water as spherical structures called micelles. These micelles repel other because they have negatively charged surfaces and thereby prevent the small globules joining together to form larger lumps of insoluble grease.
- The suspended micelles can then be washed away leaving behind a clean surface.



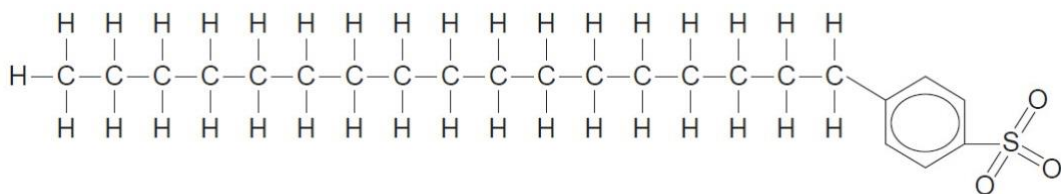
### In hard water

- In hard water (water with elevated concentration of calcium and magnesium ions) a soap 'scum' is formed from the reaction of soap anions with the  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  ions.
- $\text{M}^{2+}_{(\text{aq})} + 2\text{RCOO}^{-}_{(\text{aq})} \rightarrow \text{M}(\text{RCOO})_{2(\text{s})}$

- These insoluble salts are not effective as cleaning agents and their formation removes soap anions – rendering them unavailable to remove grease or form a micelle.
- Also the scum is unsightly. If there is an excess of soap after the scum has formed, cleaning may still occur.
- Synthetic detergents do not form scum in hard water as calcium and magnesium sulfonates are soluble in water.

**Past exam question: WACE 2019 Question 37**

Detergents and soaps are both used as cleaning agents. The general structure of a detergent is given below:



- (a) Explain how detergents are able to remove grease from a surface by referring to the intermolecular forces present. Include a labelled diagram to illustrate your answer. (7 marks)

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Detergents are considered to be more versatile cleaners than soap.

- (b) Explain why soaps are generally less effective than detergents as cleaning agents in hard water. Include a relevant equation in your answer. (4 marks)

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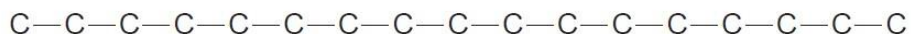
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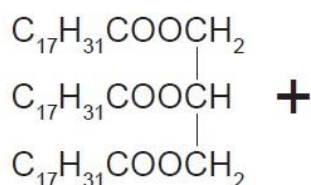
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Alkenes can also form soaps.

(c) Draw a structural diagram for the soap ion,  $C_{17}H_{31}CO_2^-$  using the incomplete structure below. Show **all** atoms and bonds. (2 marks)



(d) Write an equation showing the formation of this soap from the fat (triglyceride) shown below. (3 marks)



**Examination report information:**

In part (a), few candidates refer to the species having similar strength to overcome the dispersion forces that exist between the oil molecules and so will dissolve. Many also did not state that the charged head of the detergent ion exhibits stronger ion-dipole forces on attraction (and hydrogen bonds) with water molecules and so overcoming the hydrogen bonding between the water molecules dissolving preferentially in water. There were few diagrams that attracted full marks. In Part (b) candidates were unable to balance the ionic equation and/or did not know how to write the formula for a soap ion. They knew that precipitations occurred in hard water but could not explain that cleaning power was reduced. Candidates also struggled in part (c) to draw and work out the basic molecular construction by not counting the number of carbons, adding the COO head, determining the number of bonds and/or adding the appropriate number of H atoms.

**Curriculum Dot point: Polymers properties and uses**

- industry produces a vast range of plastics, including addition polymers (polyethene, polytetrafluoroethene) and condensation polymers (nylon and polyethylene terephthalate [PET]) which have different properties and uses.

- You must know the equations for the formation of those four plastic mentioned, if you can remember the reactants you can get the formation of the polymer.
- Ensure that you can relate the property of the plastic to its use.
- Addition polymers involve addition reaction where the monomers are alkenes;

	Monomer	Polymer (segment)
Polyethene	$CH_2=CH_2$	$-CH_2-CH_2-CH_2-$
Polytetrafluoroethene (teflon)	$CF_2=CF_2$	$-CF_2-CF_2-CF_2-$

Polymer	Property	Use
Polyethene (low density)	Soft and flexible Low melting point Non-conductor	Plastic bags Flexible containers Waterproof layers in cartons
Polyethene (high density)	Hard and crystalline High melting point Non-conductor	Plastic bottles Food storages containers
Teflon	High melting and boiling point Conductive Chemical resistance Low friction coefficient Heat and flame resistance Non-stick	Non-stick coatings on frying pans etc
PVC	Hard and rigid	Down pipes

- Condensation polymers involve condensation reactions.

	Monomer 1	Monomer 2
Nylon	Hexane-1,6-dioic acid	1,6-diaminohexane
Polyethylene terephthalate (PET)	1,4-benzenedicarboxylic acid	Ethane-1,2-diol
Polymer	Property	Use
Nylon	Strong Elastic Chemical resistance UV and heat resistance	Clothing Parachutes Rope Life vests
PET	Chemical resistance High strength to weight ratio Shatter proof Transparent	Bottles 3D printing

**Past exam question: WACE 2019 Question 38(a)**

Polymethyl methacrylate and polycarbonate are two polymers that are used as alternatives to glass. Polymethyl methacrylate is more commonly known as Perspex or plexiglass and is an addition polymer, while polycarbonate is a type of condensation polymer.

Both polymers are transparent to visible light and have other properties as listed below:

Polymethyl methacrylate	Polycarbonate
lightweight	moderate chemical resistance
moderate UV resistance	high heat resistance
low impact strength	high impact strength
low chemical resistance	low scratch resistance
low heat resistance	low UV resistance

- (a) For the following uses as an alternative to glass, identify which polymer would be the more appropriate. Justify your choice of polymer by comparing the effect **two** relevant properties as listed for both polymers. (4 marks)

Use	Choice of polymer	Justification
Skylight		
Safety glasses		

**Examination report information:**

Some candidates struggled to clearly articulate the relationship, property and use of the compound. They failed to justify their choice and simply gave a list of properties.

**Curriculum Dot point: Intermolecular forces and polymers**

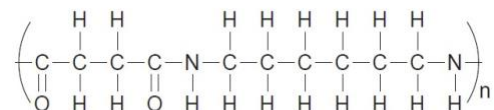
- the varied structures of different plastics due to characteristics, including cross-linking, chain length, and intermolecular forces leads to a range of distinct properties and consequent uses (for example, the different structures, properties and related uses for polyethene, polytetrafluoroethene, nylon and polyethylene terephthalate [PET])
- The forces between the individual polymer chains affect the properties and uses of different plastics.
  - As a chain gets longer the dispersion forces between the chains increase in strength thereby increasing the strength of the plastic.
  - Crosslinking is a process by which ionic or covalent bonds are introduced between the chain with the use of an initiator or additives to give increasing strength.
  - A particular example of this is vulcanization, which is a chemical process in which the rubber is heated with sulphur, accelerator, and activator at 140–160°C. The process involves the formation of cross-links between long rubber molecules to achieve improved elasticity, resilience, tensile strength, viscosity, hardness, and weather resistance.



**Past exam question: WACE 2021 Question 4 and 5**

4. Which of the following characteristics influence how a particular polymer might be used?
- The amount of crosslinking between the hydrogen atoms in the polymer.
  - The length of the carbon chains in the polymer.
  - The functional groups present in the monomer used to synthesise the polymer.
  - The melting point of the polymer.
- (a) ii, iii and iv only  
(b) i and ii only  
(c) ii and iii only  
(d) i, ii and iv only

5. Nylon 46 is a polymer that can withstand very large forces without breaking. Its structural formula is shown below.



The intermolecular forces contributing the most to the strength of nylon 46 is/are

- covalent network bonding.
- dispersion forces.
- hydrogen bonding.
- dipole-dipole forces.

**Examination report information:**

Question 4 was considered a challenging question. Question 4 emphasised the need for candidates to know more about different polymer characteristics and to identify inconsistencies in answer choices. For example, even if a candidate did not know what crosslinking was, they should have been able to buy juice that because hydrogen atoms can only form 1 bond they will not be able to link with other chains.

**Curriculum Dot point. Synthesis and Green chemistry**

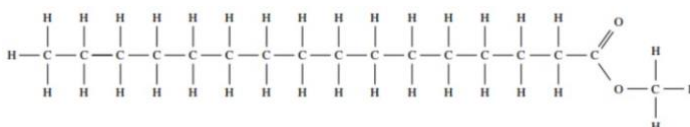
- Scientific knowledge can be used to design alternative chemical synthesis pathways, taking into account sustainability, local resources, economics and environmental impacts (green chemistry), including the production of ethanol and biodiesel.

**Principles of green chemistry** (you need to be able to relate these to specific situations or industrial processes)

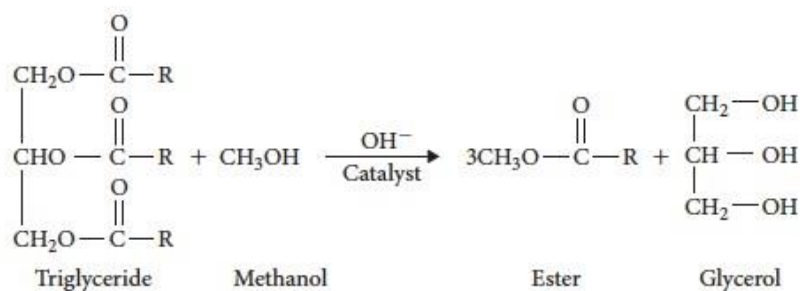
- Prevent waste
- Maximise atom economy
- Design less hazardous chemical synthesis
- Design safer chemicals and products
- Use safer solvents and reaction conditions
- Increase energy efficiency
- Use renewable raw materials
- Avoid chemical derivatives
- Use catalysts, not excess reactants
- Design chemicals and products that are biodegradable
- Analyse in real time to prevent pollution
- Minimise the potential for accidents

**Biodiesel**

- A typical biodiesel molecule is a methyl ester with 8 - 21 carbon atoms (17 is the most common).



- Formation of biodiesel starts with a triglyceride, the equation is the same, only the catalyst changes.



Method	Temperature (°C)	Pressure (kPa)	Time (min) in reactor	Catalyst use	Yield (%)
Base-catalysed	60 – 70	140 – 400	30 – 60	Only able to be used for one cycle of the production process	96 - 98
Lipase-catalysed	20 – 37	101.3	At least 150	Can be used many times	Typically 80 (can be up to 92)

**Past exam question: WACE 2017 Question 11**

The purpose of 'green chemistry' is to

- Utilise renewable energy sources (such as wind, solar or wave) at all times, even if they are more costly
- Design chemical products and processes that maximise profits and, if economical to do so, reduce harm to the environment
- Design chemical products and processes that work most efficiently.
- Design safer chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

## SCIENCE INQUIRY SKILLS

**Curriculum Dot points: Investigating Scientifically**

- identify, research, construct and refine questions for investigation; propose hypotheses; and predict possible outcomes.
- design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics.
- conduct investigations safely, competently and methodically for the collection of valid and reliable data, including: acid-base properties, using acid-base volumetric analysis techniques, effects of changes to equilibrium systems, and constructing electrochemical cells.
- represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships; identify and distinguish between random and systematic errors, and estimate their effect on measured results; discuss how the nature of the procedure and the sample size may influence uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions.
- interpret a range of scientific texts, and evaluate processes, claims and conclusions by considering the quality of available evidence, including confidence intervals in secondary data; and use reasoning to construct scientific arguments.
- communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats, including scientific reports.

**Past exam question: WACE 2022 Question 39 – a, b, c, e**

A student wanted to investigate how changing temperature would influence how rapidly oxalic acid solution would decolourise an acidified potassium permanganate solution.

The student was provided with the following chemicals and equipment:

- 0.1 mol L<sup>-1</sup> acidified potassium permanganate solution
- 0.1 mol L<sup>-1</sup> oxalic acid solution
- 250 mL conical flasks
- Bunsen burner
- tripod and gauze mat
- thermometer
- stop watches
- 5.00 mL, 10.00 mL, 20.00 mL and 25.00 mL pipettes
- distilled water
- 25.0 mL measuring cylinders.

(a) State a hypothesis for this investigation. (2 marks)

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(b) Identify the independent and dependent variables. (2 marks)

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(c) Identify two control variables. (1 mark)

i.

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ii. (1 mark)

(e) Outline the difference between systematic and random errors. Use an example of each from this investigation to support your answer. (4 marks)

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**Examination report information:**

Many candidates did not know what random and systemic errors were as well as their differences.

Congratulations! You have now completed your revision booklet!

Edith Cowan University would like to wish all students the best of luck with their future exams!

