
Student Number

2015
HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black or blue pen
- Draw diagrams using pencil
- Board-approved calculators may be used
- Use the Data Sheet and Periodic Table provided
- Use the Multiple-Choice Answer Sheet provided
- Write your Student Number at the top of this page and on the Multiple-Choice Answer Sheet

Total marks – 100

Section I Pages 2-26

75 marks
This section has two parts, Part A and Part B

Part A – 20 marks
- Attempt Questions 1-20
- Allow about 35 minutes for this part

Part B – 55 marks
- Attempt Questions 21-31
- Allow about 1 hour and 40 minutes for this part

Section II Pages 29-37

25 marks
- Attempt ONE question from Questions 32-34
- Allow about 45 minutes for this section

2015 HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION

Chemistry

Section I
Part A – 20 marks
Attempt Questions 1-20
Allow about 35 minutes for this part

Use the Multiple-Choice Answer Sheet provided for Questions 1-20

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

Sample 2 + 4 = (A) 2 (B) 6 (C) 8 (D) 9

A ○ B ● C ○ D ○

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

A ● B ⊗ C ○ D ○

If you have changed your mind and have crossed out what you consider to be the correct answer, then indicate this by writing the word *correct* and drawing an arrow as follows:

correct ←

A ⊗ B ⊗ C ○ D ○

1 Which reagent would be most suitable to use when testing for the presence of lead ions in a sample?

(A) $AgNO_3$

(B) $Ba(NO_3)_2$

(C) HCl

(D) HNO_3

2 The function of the catalyst in an equilibrium reaction is to increase the reaction rate by

(A) increasing the enthalpy change of both the forward and reverse reactions.

(B) decreasing the activation energy of both the forward and reverse reactions.

(C) increasing the kinetic energy of the collisions that are occurring.

(D) disturbing the equilibrium and favouring the forward reaction.

3 A hydrocarbon, placed in a spirit burner, burnt with a yellow flame and grey smoke was observed. The products of combustion are most likely to include

(A) carbon, carbon monoxide and hydrogen.

(B) carbon, carbon monoxide and water.

(C) carbon monoxide, carbon dioxide and hydrogen.

(D) methane, carbon monoxide and water.

4 Which of the following compounds is the most volatile?

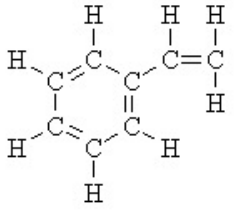
(A) Propane

(B) Propan-1-ol

(C) Propanoic acid

(D) Methyl propanoate

5. Identify the systematic name of the following molecule.



(A) Ethenylbenzene

(B) Chloroethene

(C) Benzylethene

(D) Ethylchloride

6 Which of the following is LEAST likely to be a stable isotope?

(A) Chlorine-37

(B) Sodium-23

(C) Oxygen-24

(D) Hydrogen-1

7 The reaction in an alkaline cell can be summarised by the equation:

$Zn\ (s) + 2MnO_2\ (s) \rightarrow ZnO\ (s) + Mn_2O_3\ (s)$

Which of the following statements about this reaction is correct?

(A) Zinc is reduced.

(B) The oxidation state of manganese changes from +4 to +3.

(C) The oxidation state of zinc changes from 0 to -2.

(D) Oxygen is the reducing agent.

8 When placed in the Periodic Table, the recently discovered element 115 would be found in the same group as

(A) element 9.

(B) element 16.

(C) element 83.

(D) element 87.

9 Which of the following polymers is formed from its monomer by a condensation reaction?

(A) polystyrene

(B) PVC

(C) polyethylene

(D) cellulose

10 The table shows the heats of combustion of some common fuels:

Fuel	***Heat of combustion (kJ mol $^{-1}$)***
H_2	286
CH_4	889
C_2H_6O	1360
C_8H_{18}	5460

Which of these fuels would produce the smallest amount of energy when 1kg of fuel is burnt in an ample supply of air?

(A) H_2

(B) CH_4

(C) C_2H_6O

(D) C_8H_{18}

11 Hydrogen gas can be made by the following reversible reaction:

$CH_4\,(g) + H_2O\,(g) \rightleftharpoons CO\,(g) + 3H_2\,(g) \qquad \Delta H = +172 \text{ kJ mol}^{-1}$

Which of the following conditions would maximise the yield of hydrogen?

(A) Using high temperature and high pressure

(B) Using high temperature and low pressure

(C) Using low temperature and high pressure

(D) Using low temperature and low pressure

12 A student diluted a solution of a strong acid by mixing 1 mL with 99 mL of water. If the final solution had a pH of 3.4, what would have been the pH of the initial acid solution?

(A) 1.4

(B) 2.4

(C) 4.4

(D) 5.4

13 Sodium carbonate reacted with excess hydrochloric acid and 6.08 L of gas was collected at 25ºC and 100 kPa.

What mass of sodium carbonate reacted?

(A) 26.0 g

(B) 28.4 g

(C) 52.0 g

(D) 62.4 g

14 A sample of an element was heated strongly in air and the powder produced by the reaction was added to water. When tested with a pH meter, the resulting solution had a pH of 2.3.

Which of the following elements could have been used?

(A) Na

(B) K

(C) P

(D) Ca

15 A titration was performed using 25.0 mL of a 0.100 mol L^{-1} acetic acid solution and a 0.100 mol L^{-1} solution of sodium hydroxide solution. Which of the following will be required to observe a valid endpoint for the titration?

	Indicator	***Volume of NaOH used (mL)***
(A)	methyl orange	25.0
(B)	methyl orange	< 25.0
(C)	phenolphthalein	25.0
(D)	phenolphthalein	< 25.0

16 A sample of river water, downstream from a factory, was found to have a chloride ion concentration of 7.5×10^{-4} mol L^{-1}.

Express this concentration of chloride ions in mg L^{-1}.

(A) 27 mg L^{-1}

(B) 54 mg L^{-1}

(C) 75 mg L^{-1}

(D) 150 mg L^{-1}

17 The pH of 0.1 mol L-1 solutions of acetic, citric and hydrochloric acids was measured.
Which solution has the highest pH?

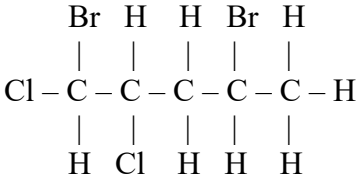
(A) Citric acid

(B) Acetic acid

(C) Hydrochloric acid

(D) The pH of the three solutions is the same.

18 What is the correct systematic name for the compound having the structure shown below?



(A) 4,5-dichloro-2,5-dibromopentane

(B) 1,4-dibromo-1,2-dichloropentane

(C) 2,5-dibromo-4,5-dichloropentane

(D) 1,2-dichloro-1,4-dibromopentane

19 A 4.51 g sample of lawn fertiliser was analysed for its sulfate content. After filtration and drying, 3.62 g of barium sulfate was recovered.

What is the % w/w of sulfate in the lawn fertiliser?

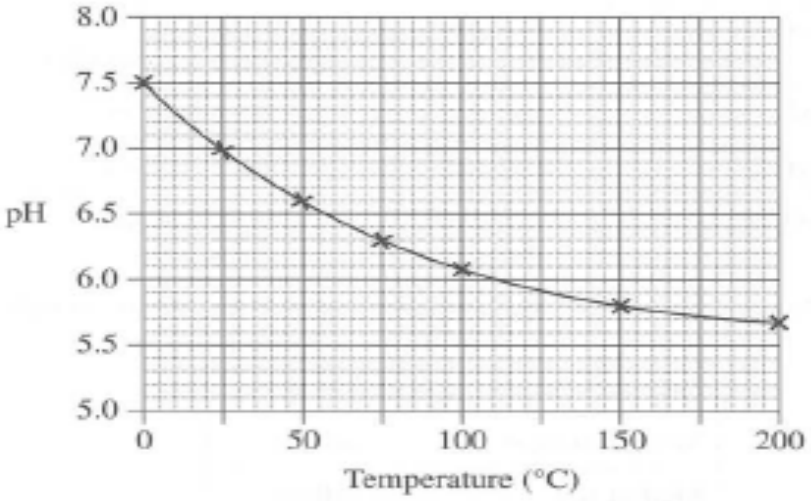
(A) 1.45

(B) 33.0

(C) 40.1

(D) 80.1

20 The graph shows the pH of a solution of a weak acid, HA, as a function of temperature.



Which of the following is the best explanation for the change in pH as the temperature INCREASES?

(A) HA becomes more ionised and the H^+ concentration increases.

(B) HA becomes more ionised and the H^+ concentration decreases.

(C) HA becomes less ionised and the H^+ concentration increases.

(D) HA becomes less ionised and the H^+ concentration decreases.

2015 HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION

Chemistry

Section I (continued)

Part B – 55 marks
Attempt Questions 21-31
Allow about 1 hour and 40 minutes for this part.

Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.

Show all relevant working in questions involving calculations.

Extra writing space is provided on pages 27 and 28. If you use this space, clearly indicate which question you are answering.

Please turn over

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Question 21 (3 marks)

Radioisotopes are found naturally occurring but can also be artificially produced.

(a) Carbon-14 is found naturally and is a beta-emitter. **1**

Write a balanced nuclear equation for this spontaneous radioactive decay.

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(b) Identify an artificially produced radioisotope and outline how it is produced. **2**

Write a nuclear equation to show the production of this isotope.

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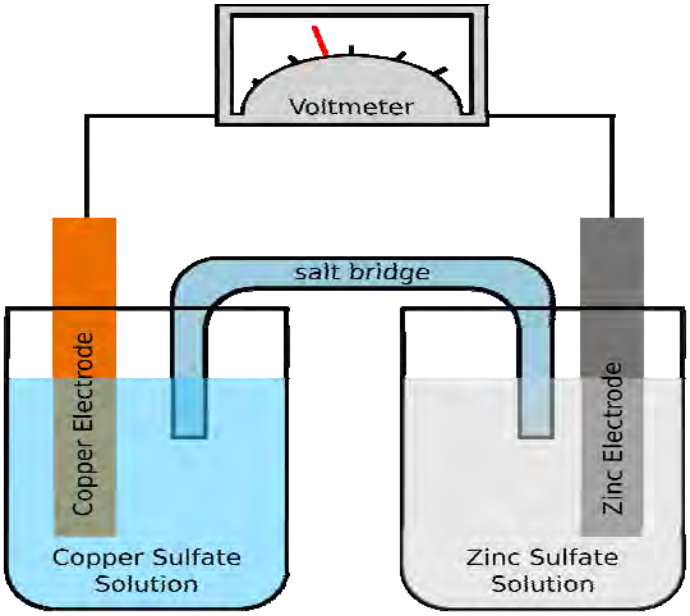
Question 22 (6 marks)

The diagram shows a galvanic cell.



(a) Label the diagram to show: **2**

- the anode
- the cathode
- the direction of electron flow
- the direction of cation and anion flow through the salt bridge.

(b) Write half-equations for the electrode reactions, an overall equation and calculate the cell voltage under standard conditions. **2**

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(c) List three observations that would be made as the reaction proceeds. **2**

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Question 23 (6 marks)

A student was asked to set up an experiment in order to distinguish between saturated and unsaturated hydrocarbons.

(a) Discuss the criteria for selecting the hydrocarbons to be used in this experiment. **2**

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(b) Identify the risks involved in this experiment and the precautions needed to reduce these risks. **2**

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(c) Write a balanced equation for the reaction used to distinguish between the hydrocarbons chosen and name the product formed. **2**

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Question 24 (5 marks)

Compare the chemical processes involved in the production of polyethene and a named biopolymer (not cellulose) and evaluate the effect on society and the environment of both types of polymer. **6**

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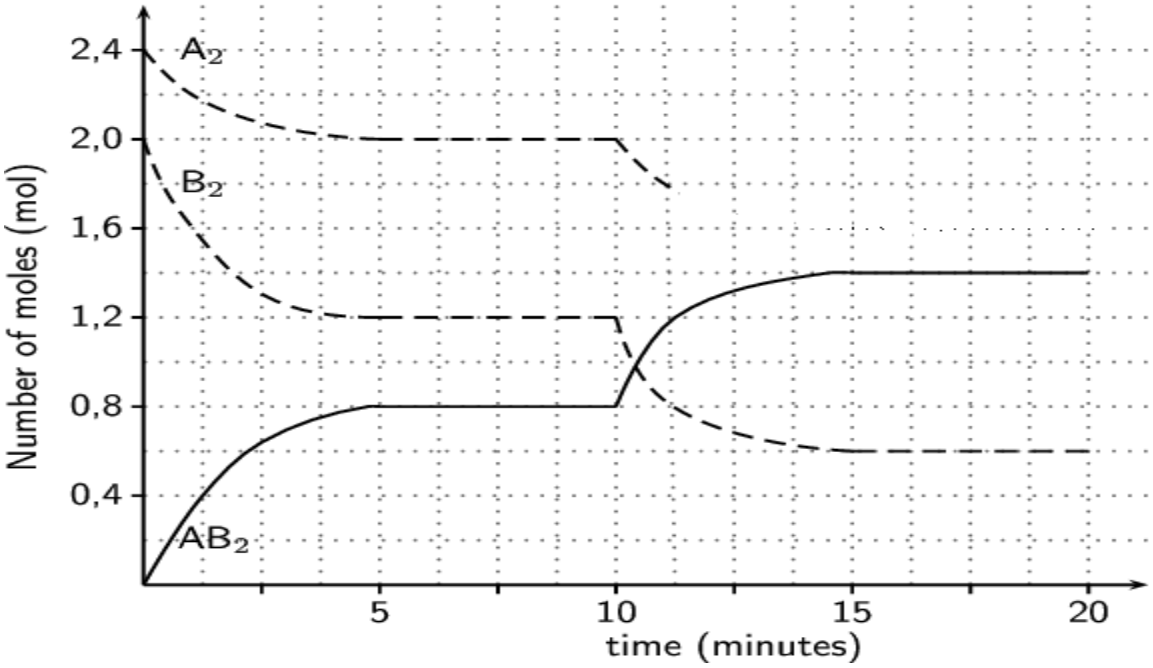
Question 25 (5 marks)

Information about the gaseous reaction between gases A_2, B_2 and AB_2 is represented below.



(a) Write a balanced equation for the reaction. **1**

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(b) Identify the periods when the gases are in equilibrium. **1**

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(c) Explain the reason for the changes in the graphs between 10 and 20 minutes. **2**

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(d) Complete the graph for gas A_2. **1**

Question 26 (6 marks)

Acids, such as citric acid and acetic acid, are often used in the food industry.

(a) Draw a diagram to show the structure of citric acid. **1**

(b) On your diagram, indicate the hydrogen atoms which would be donated in acid-base reactions. **1**

(c) Explain why acids are used as food additives. **2**

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(d) Write an equation for the reaction of acetic acid and water. Use this equation to explain why acetic acid is classified as "weak". **2**

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Question 27 (5 marks)

(a) Pure hydrogen chloride is a gas. **3**

What volume of HCl(g) (measured at 25 ºC and 100 kPa) would have to be dissolved in 2.00 L of water to produce a solution with a pH of 1.25?

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Question 27 continues on the next page

Question 27 (continued)

(b) A 25.0 mL aliquot of sodium hydroxide solution was titrated with 36.5 mL of sulfuric acid of concentration 0.105 mol L^{-1}, to reach an endpoint using phenolphthalein indicator. Calculate the concentration of the sodium hydroxide solution. **2**

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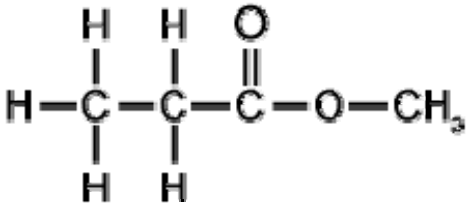
Question 28 (4 marks)

Refer to the structure shown below.



(a) Write a balanced equation, using structural formulae for the organic compounds involved, for the catalysed chemical reaction which results in the formation of this compound. **1**

(b) Explain, in terms of the intermolecular bonding forces involved, why this compound is only slightly soluble in water, even though the chemicals used in its manufacture are soluble. **3**

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Question 29 (3 marks)

(a) Draw the structure of, and name, an example of a CFC. **1**

(b) Chlorine radicals from chlorofluorocarbons are particularly dangerous to the ozone layer because one chlorine radical can initiate a chain reaction, destroying thousands of ozone molecules. **2**
Explain how this occurs, illustrating your response with appropriate relevant equations.

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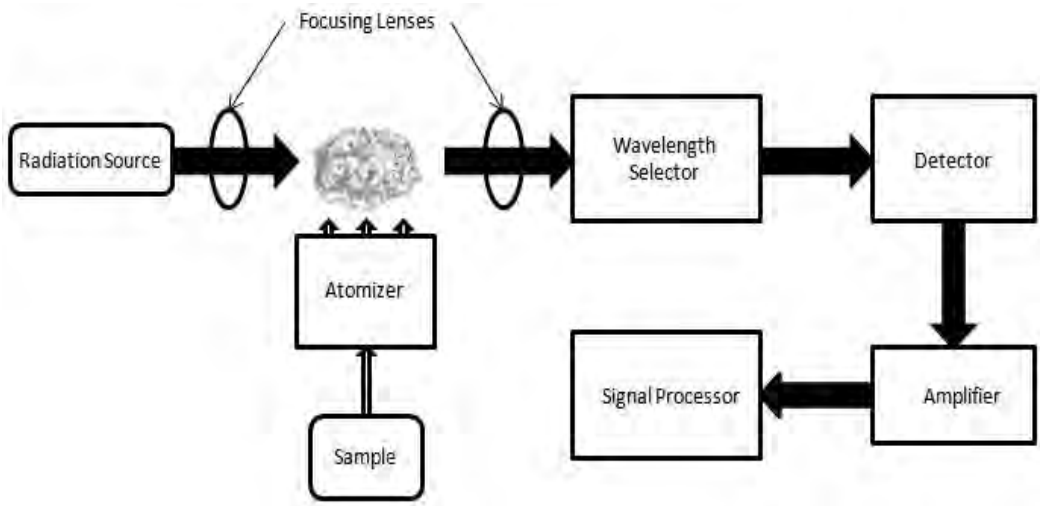
Question 30 (7 marks)



(a) Identify the technique summarised in the diagram above. **1**

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(b) Explain the relationship between the radiation source and the sample. **2**

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Question 30 continues on the next page

Question 30 (continued)

(c) Assess the impact of this technique on society and on the environment. **4**

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Question 31 (4 marks)

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A student mixed 25 mL of 0.10 mol L^{-1} HCl with 30 mL of 0.25 mol L^{-1} $Ba(OH)_2$ solution. Calculate the final pH of this mixture. Include a balanced chemical equation in your answer.

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End of Section I - Part B

Section I Part B - Extra writing space

If you use this space, clearly indicate which question you are answering.

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Section I Part B - Extra writing space

If you use this space, clearly indicate which question you are answering.

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2015 HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION

Chemistry

Section II
25 marks
Attempt ONE question from Questions 32-34
Allow about 45 minutes for this section

Write the Question Number and the name of your Option in the boxes on the Section II Writing Booklet.

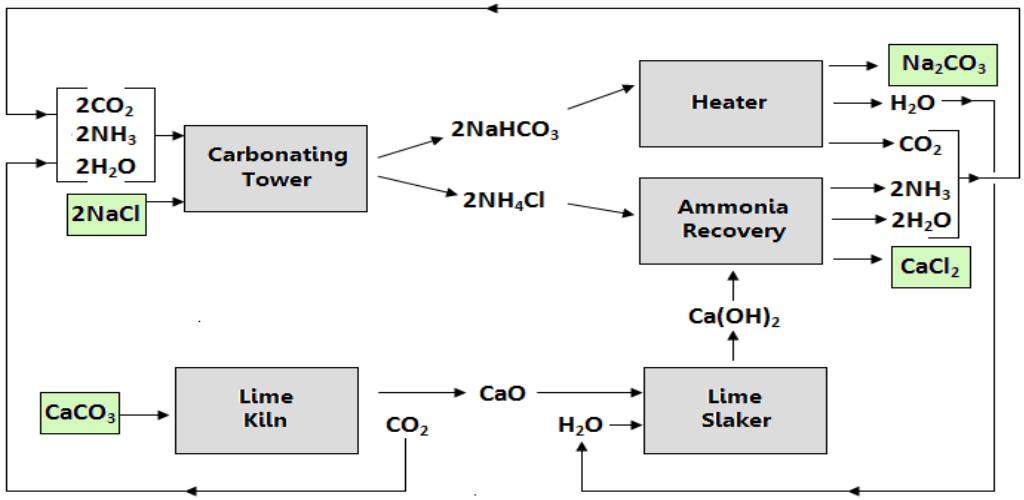
Answer parts (a)–(c) of the question in Section II Writing Booklet pages 2-4.
If you need more space for parts (a), (b) and (c), ask the supervisor for an extra writing booklet.

Answer parts (d)–(e) of the question in Section II Writing Booklet pages 6-8.
If you need more space for parts (d) and (e), ask the supervisor for an extra writing booklet.

Show all relevant working in questions involving calculations.

Question 32 – Industrial Chemistry (25 marks)

(a) The diagram shows processes involved in the industrial production of sodium carbonate.



(i) Write an equation for the overall reaction in the industrial production of sodium carbonate. **1**

(ii) "Ammonia should not be considered a raw material for this reaction." Justify this statement. **2**

(b) Sulfuric acid is an important industrial chemical.

(i) Sulfuric acid reacts with iodide ion to produce iodine. Write TWO half-equations for this reaction. **2**

(ii) Write an equation which shows sulfuric acid acting as a dehydrating agent. **1**

(iii) "The contact process in the production of sulfuric acid requires careful monitoring." Discuss this statement. **3**

Question 32 (continued)

(c) (i) Carbon monoxide and hydrogen react in the gaseous state according to the equation: **1**

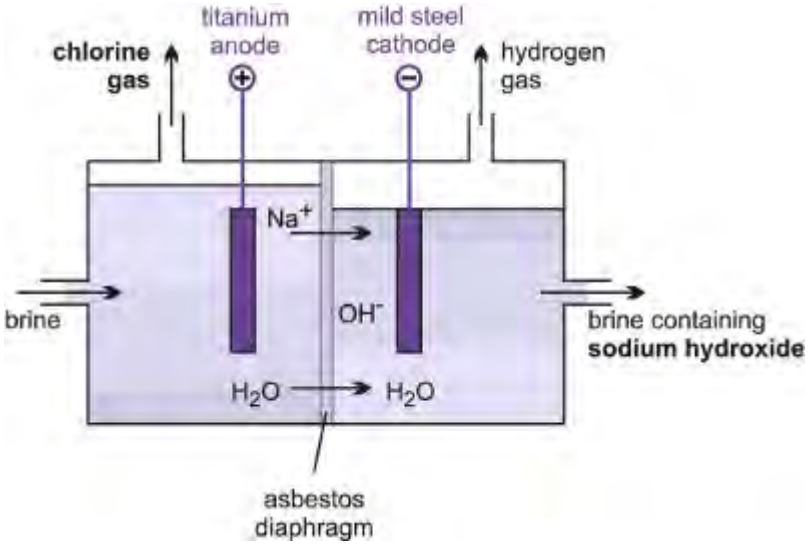
$CO\ (g) + 2H_2\ (g) \rightleftharpoons CH_3OH\ (g) \quad \Delta H = -102\ kJ\ mol^{-1}$

Write the equilibrium constant expression for this reaction.

(ii) State one way that the equilibrium constant for this reaction could be increased. **1**

(iii) A 5 L reaction flask, at 298 K, initially contained 1.0 mol of CO gas and 1.0 mol of H_2 gas. After equilibrium was established, it was found that 0.2 mol of CH_3OH had formed. Calculate the equilibrium constant under these conditions. Show all relevant working. **2**

(d) The diagram below shows an electrolytic cell used in a significant industrial process you have studied.



(i) Write an overall equation for the reaction which has occurred. **1**

(ii) Justify the use of a membrane cell, rather than the cell shown in the diagram above, for this industrial process. **4**

Question 32 continues on the next page

Question 32 (continued)

(e) (i) Describe the process of saponification, including an appropriate equation for a saponification reaction carried out in a school laboratory. **2**

(ii) "The structures of surfactants determine their uses." **5**

Assess this statement.

End of Question 32

Question 33 – Shipwrecks, Corrosion and Conservation (25 marks)

(a) Describe the work of Humphrey Davy in the field of electrochemistry, including a significant innovation AND a specific discovery he made. **3**

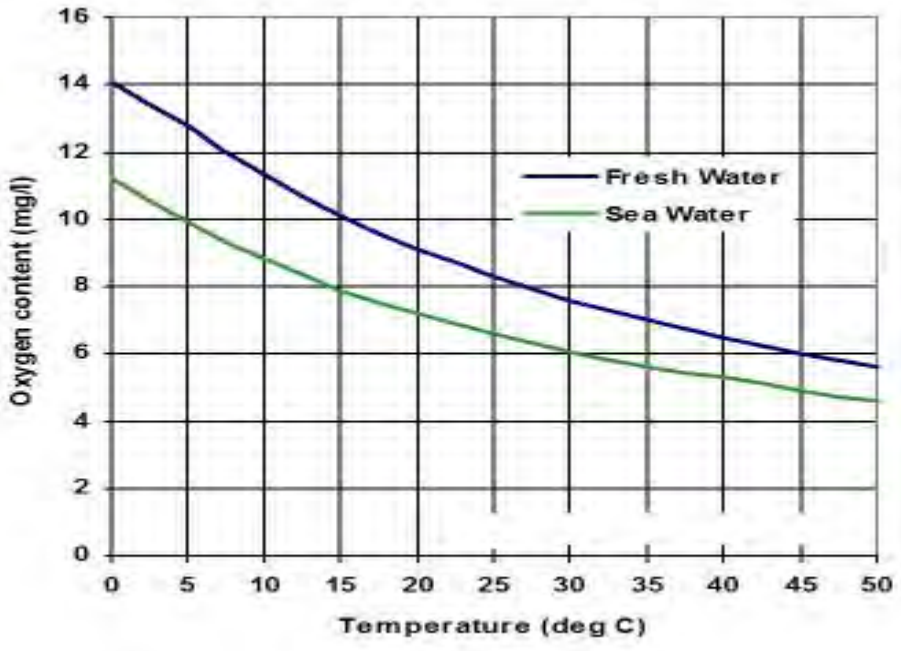
(b) Three common objects made from steel are shown in the diagrams below **3**

Paper clip Girder Drill bit

Explain how the composition of each of these steels determines its properties and therefore its specific uses. (Alternatively you may choose a different object/s of your choice made from a different form of steel)

(c) Explain how magnesium ingots attached to underground iron pipes protect the pipes from corrosion. Use a labelled diagram and equations in your response. **3**

(d) The graph shows the solubility of oxygen in fresh and seawater at different temperatures.

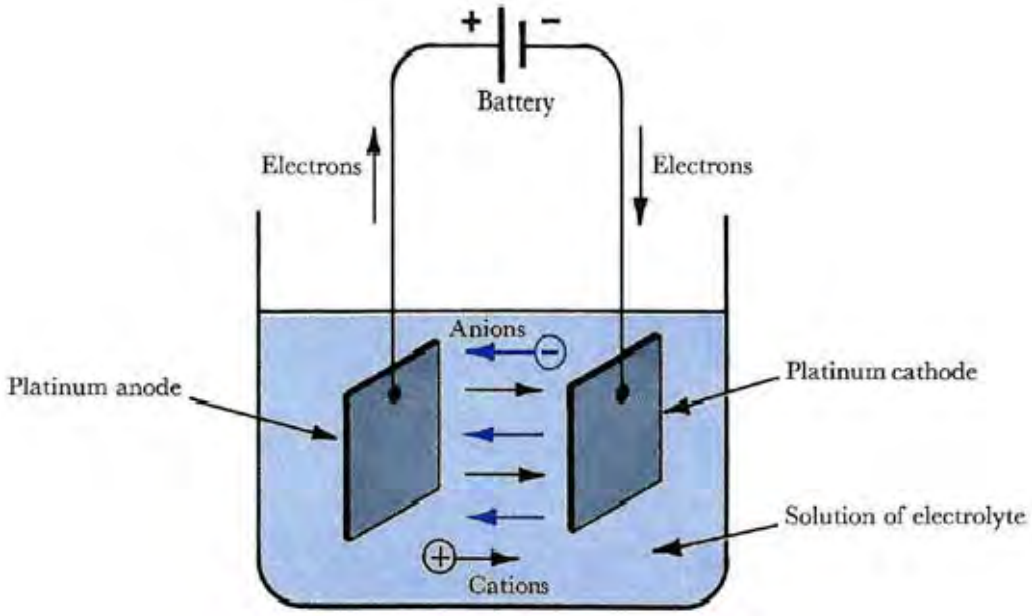


(i) Based on this information only, would you expect corrosion of shipwrecks in seawater to be greater at the surface or at depth? Explain your response. **2**

(ii) Discuss why corrosion of shipwrecks occurs both in shallow water and at depth. Use equations for the corrosion processes in your response. **4**

Question 33 (continued)

(e) The diagram shows apparatus used for electrolysis experiments.



(i) Explain TWO methods for increasing the rate of this electrolysis reaction. **2**

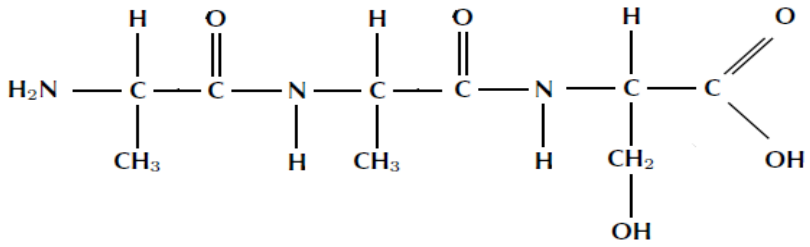
(ii) If copper (II) sulfate solution were used as the electrolyte in this cell, describe what you would observe at each electrode, as electrolysis occurs. Write half-equations for these electrode reactions. **3**

(iii) Evaluate the significance of electrolysis as a technique used in the conservation and restoration of metallic artefacts recovered from shipwrecks. Include appropriate equations or half-equations in your response. **5**

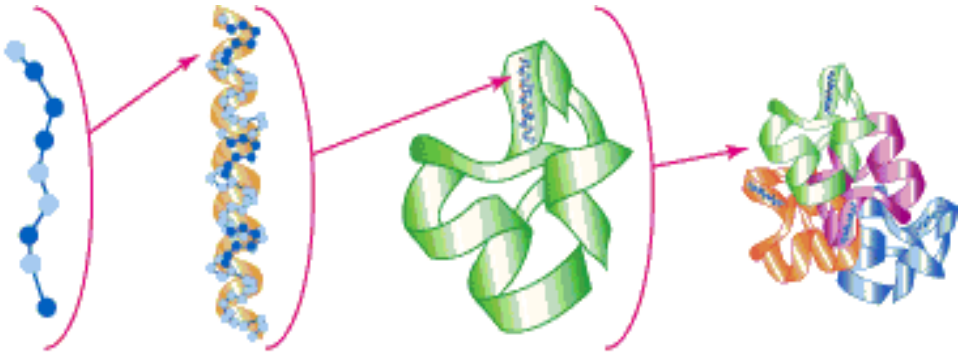
End of Question 33

Question 34 – Forensic Chemistry (25 marks)

(a) (i) Identify the structure represented below. **1**



(ii) Identify the relationship between the structures in diagrams **A**, **B**, **C** and **D** and outline the process shown by the sequence. **3**



A **B** **C** **D**

(iii) Explain how electrophoresis can be used to separate and identify amino acids. **3**

(b) A first-hand investigation was performed to distinguish between alkanols and alkanoic acids.

(i) Using named examples, draw diagrams to show the different functional groups present in these TWO classes of carbon compounds. **1**

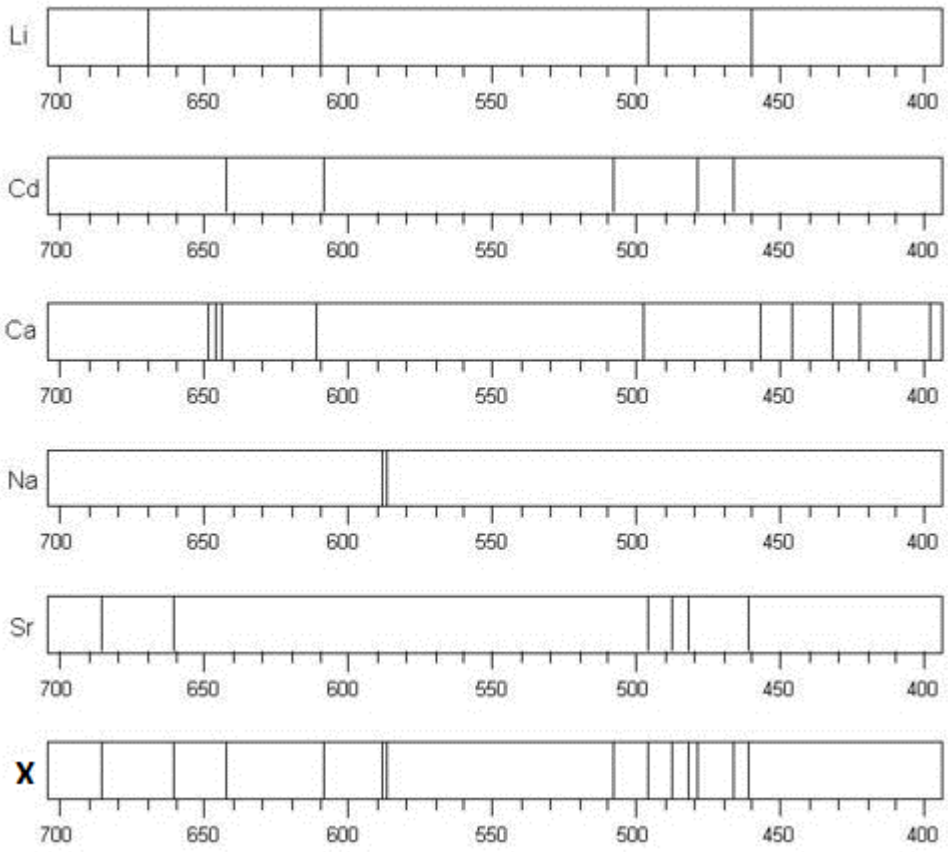
(ii) Explain the chemical reaction(s) used to distinguish between alkanols and alkanoic acids and write equations for the reactions you describe. **2**

(iii) Explain how you distinguish between organic and inorganic compounds in the laboratory. **1**

Question 34 continues on the next page

Question 34 (continued)

(c) A scientist decided to use emission spectroscopy to assist in a forensic analysis of a sample labelled **X**.



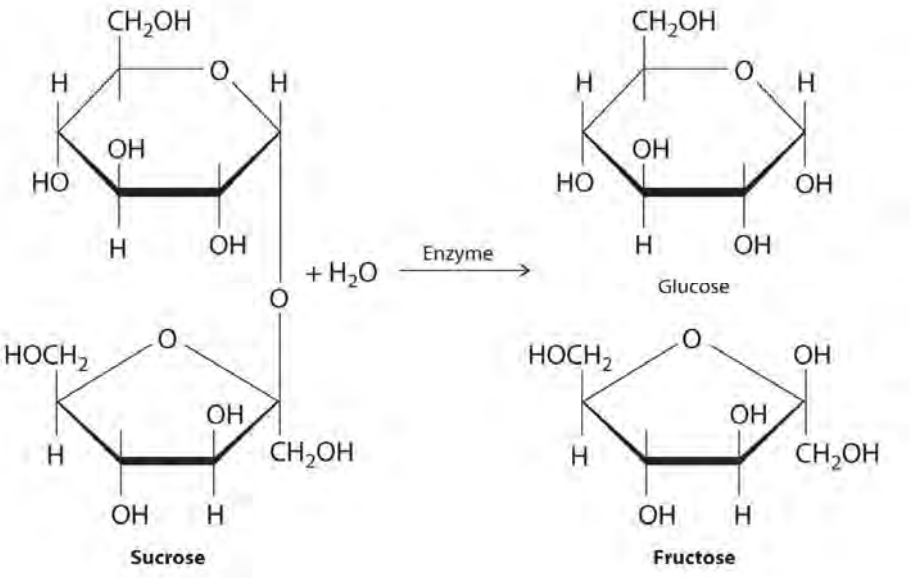
(i) Explain why each element has its own unique emission spectrum. **2**

(ii) Identify the elements present in the unknown sample **X**. **1**

Question 34 continues on the next page

Question 34 (continued)

(d) The diagram below shows the hydrolysis of sucrose.



(i) Explain why the 3 sugars can be classified as carbohydrates. **1**

(ii) Identify which of the THREE sugars can be classified as a non-reducing sugar and explain the meaning of this term. **2**

(iii) Outline the method used in the laboratory for distinguishing between reducing and non-reducing sugars. **1**

(e) Evaluate the use of instrumental techniques such as chromatography and mass spectrometry for forensic analysis, given that samples need to be retained as evidence in forensic investigations. **7**

End of Question 34

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2015 HIGHER SCHOOL CERTIFICATE TRIAL EXAMINATION

CHEMISTRY – MARKING GUIDE

Section I
Part A – 20 marks
Questions 1-20 (1 mark each)

Question	Correct Response
1	C
2	B
3	B
4	A
5	C
6	C
7	B
8	C
9	D
10	C
11	B
12	A
13	A
14	C
15	C
16	A
17	B
18	B
19	B
20	A

Section I
Part B – 55 marks
Question 21 (3 marks)
21 (a) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

21 (b) (2 marks)

Criteria	Marks
• Identifies an artificially produced isotope and outlines how it is produced, stating neutron capture or nuclear reactor AND • Writes a nuclear equation for the production of the isotope	2
• Identifies an artificially produced isotope and outlines how it is produced OR • Writes a nuclear equation for the production of the isotope	1

Sample answer
Transuranic elements (e.g. neptunium-239) are made in a reactor by bombardment of other nuclei (here uranium-238) by neutrons. An unstable isotope (uranium-239) is formed which decays to form neptunium-239.

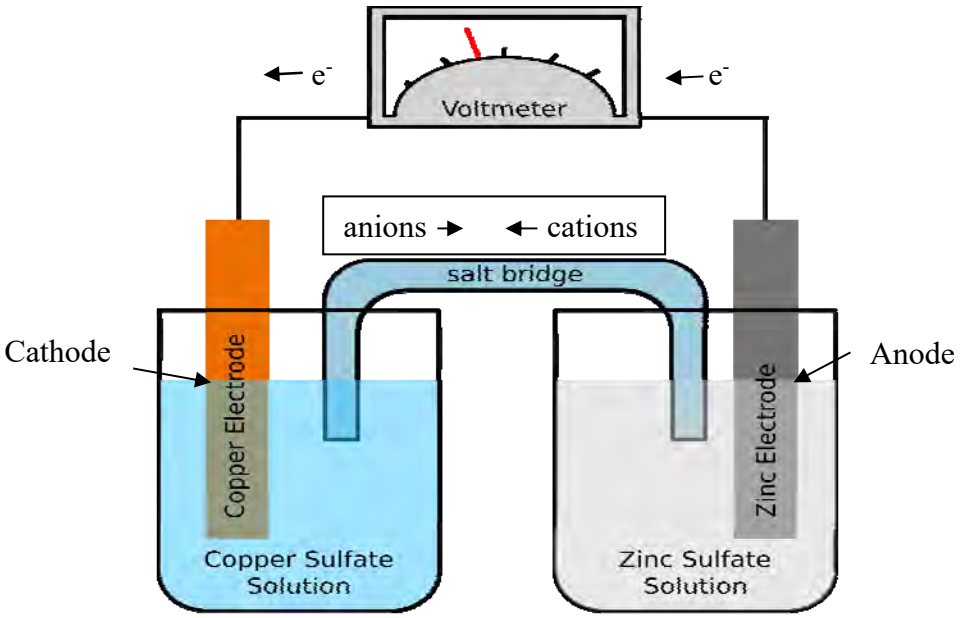
$^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U \rightarrow {}^{0}_{-1}e + {}^{239}_{93}Np$

Other good answers include the formation of technicium-99, cobalt-60, iodine-131 and americium-241

Question 22 (6 marks)
22 (a) (2 marks)

Criteria	Marks
• Labels the diagram showing FOUR correct labels	2
• Labels the diagram showing ONE correct label	1

Sample answer



22 (b) (2 marks)

Criteria	Marks
• Writes 2 correct half-equations and an overall equation AND • Calculates the standard cell voltage	2
• Writes 2 correct half-equations and an overall equation OR • Calculates the standard cell voltage	1

Sample answer
The anode half-reaction is:
$Zn\ (s) \rightleftharpoons Zn^{2+}\ (aq) + 2e^-$ +0.76 V

The cathode half-reaction is:
$Cu^{2+}\ (aq) + 2e^- \rightleftharpoons Cu\ (s)$ +0.34 V

The overall equation is: $Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$ $E^\bullet = +1.10$ V

22 (c) (2 marks)

Criteria	Marks
• Lists THREE correct observations	2
• Lists ONE correct observation	1

Sample answer
The zinc electrode would reduce in size, while the copper electrode would get larger as a solid deposit forms on its surface.
The blue solution in the cathode half-cell gets paler.
OR
The voltmeter reading will change

Question 23 (6 marks)
23 (a) (2 marks)

Criteria	Marks
• Discusses thoroughly the criteria for selecting a pair of hydrocarbons. The criteria must include 1. For a fair test only one variable can change, 2. Liquids as they are easy to use 3. Chemicals must be relatively safe	2
• Identifies an appropriate pair of hydrocarbons by name OR by structural formulae OR • Identifies that the hydrocarbons must only differ in their single vs double bonds OR • 2 criteria are identified but without discussion	1

Sample answer
Only 3 pairs are appropriate because they are liquids, available to schools and not too dangerous. The hydrocarbons chosen must **only differ** from each other in the degree of saturation (single or double bond between carbon atoms). The only appropriate pairs available to schools, which are liquids and relatively safe to use are:

- hexane, hexene (must specify which hexene)
- pentane, pentene (must specify which pentene)
- cyclohexane, cyclohexene

23 (b) (2 marks)

Criteria	Marks
• Identifies the risks involved in this experiment AND • Identifies the precautions needed to reduce these risks	2
• Identifies the risks involved in this experiment OR • Identifies the precautions needed to reduce these risks	1

Sample answer
The hydrocarbons used are flammable and need to be kept away from a naked flame. They may cause respiratory problems if inhaled and therefore should be used in a fume cabinet. Bromine is volatile and produces an acid if inhaled into lungs or other respiratory tissues or splashed into eyes. And therefore safety glasses should be worn.

23 (c) (2 marks)

Criteria	Marks
• Writes a balanced equation for the reaction of the alkene AND • Names the product formed	2
• Writes a balanced equation for the reaction of the alkene OR • Names the product formed	1

Sample answer (Answer depends on pair of hydrocarbons chosen).

C_6H_{10} *(l)* + Br_2 *(aq)* $\rightarrow$ $C_6H_{10}Br_2$ *(l)*

The product is 1,2-dibromohexane.

Question 24 (6 marks)

Marking Guidelines	Marks
• Describes similarities and differences between the chemical processes to produce polyethene and a named biopolymer AND • Explains effects of each type of polymer on society and the environment AND • Makes a judgement about each type of polymer on society and environment	**5/6**
• Describes similarities and differences between the chemical processes to produce polyethene and a named biopolymer AND • Describes an effect of each type of polymer on society and the environment AND • Makes a judgement about each type of polymer on society and environment	**3/4**
• Outlines a similarity and difference between the chemical processes to produce polyethene and a named biopolymer AND • Identifies an effect of each type of polymer on society and the environment	**2**
• Identifies a similarity or difference between the chemical processes to produce polyethene and a named biopolymer OR • Identifies an effect of one type of polymer on society and the environment	**1**

Both polyethene and polyhydroxybutyrate (PHB) are produced by a chemical process known as polymerisation, although polyethene is made by addition polymerisation and PHB by condensation polymerisation.

Polyethene is a synthetic polymer. Industrially, it is made by subjecting ethene (derived from crude oil) to high temperatures and pressures, using a peroxide-based initiator which starts the polymerisation process. The double bond of the ethene monomers 'open-out', allowing the monomers to add to each other, forming the polymer chains. This process is very different to the one used to form PHB. PHB is a biopolymer, made from bacteria. The bacteria are grown in large vats and then starved of particular nutrients. The bacteria produce PHB as a result. The monomers from which the polymer form join by condensation polymerisation, whereby functional groups on each monomer react, and a water molecule is eliminated when this occurs.

The production of polyethene has had a profound effect on society and the environment. It is a vast number of uses (eg storage containers, plastic bags, toys etc), and is relatively cheap to produce. However, it is made from non-renewable resources and is non-biodegradable and persists in the environment, contributing to ever-growing landfill and causing a variety of ecological issues (eg it has been found in the stomach of a wide range of animals).
In comparison, the production of PHB has had less impact on society-it is not being produced in large quantities and has a limited number of uses eg in disposable nappies and for biocompatible sutures. However, being made from bacteria, it is a renewable resource and it is biodegradable, thus having less impact on the environment.

Question 25 (5 marks)
25 (a) (1 mark)

Criteria	Mark
• Correct answer (states and equilibrium arrows not assessed here)	1

Sample answer
$A_2\,(g) + 2B_2\,(g) \rightleftharpoons 2AB_2\,(g)$

25 (b) (1 mark)

Criteria	Mark
• Identifies 2 time periods	1

Sample answer
The gases are in equilibrium
- between 5 minutes and 10 minutes, and
- after 15 minutes (where the concentrations of the 3 gases are not changing).

25 (c) (2 marks)

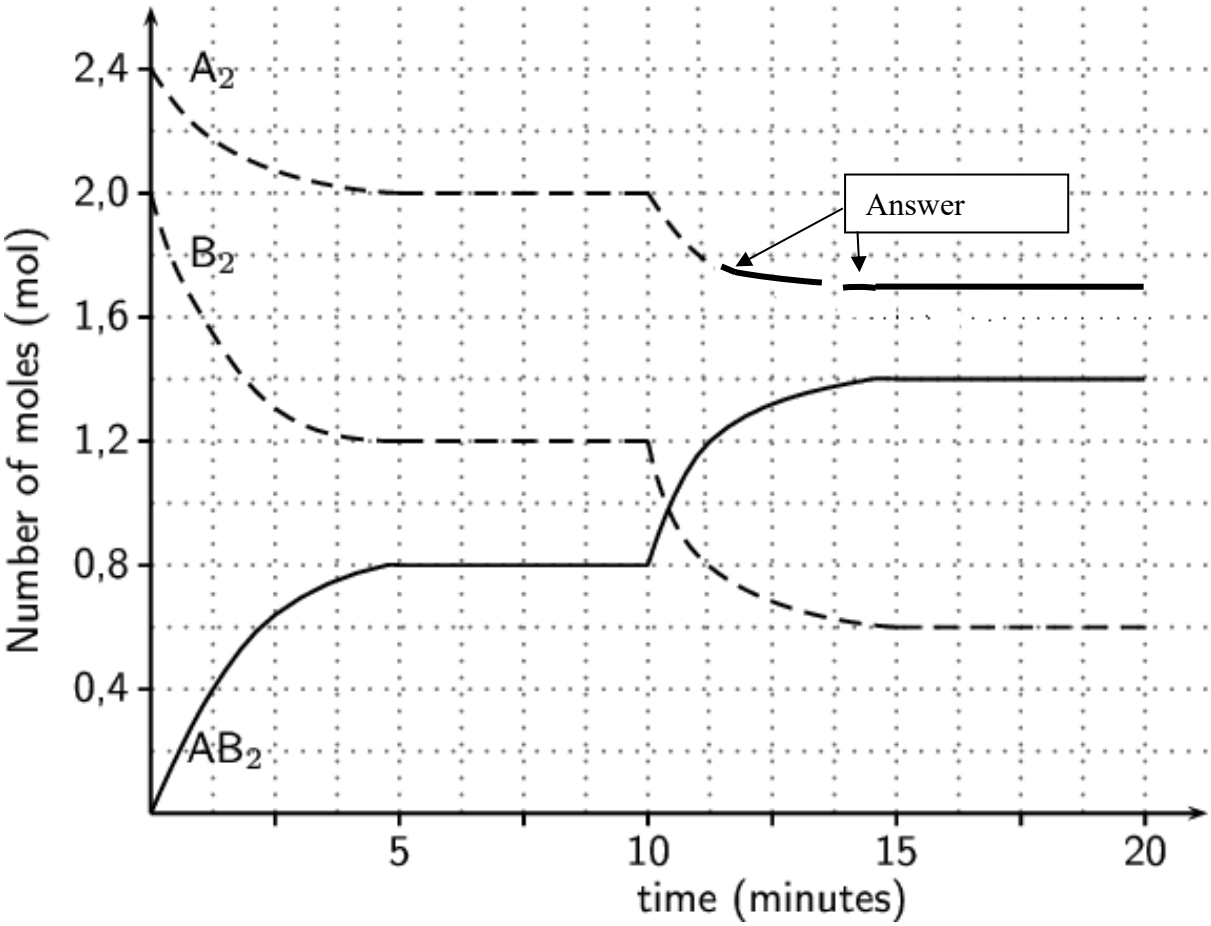
Criteria	Marks
• Explains the reason for the changes in the graphs at 10 minutes AND • Explains the reason for the changes in the graphs between 10 and 20 minutes	2
• Explains the reason for the changes in the graphs at 10 minutes OR • Explains the reason for the changes in the graphs between 10 and 20 minutes	1

Sample answer
The forward reaction is endothermic and the temperature is raised causing the forward reaction to be favoured.

25 (d) (1 mark)

Criteria	Mark
• Completes the graph correctly for gas A_2	1

Sample answer



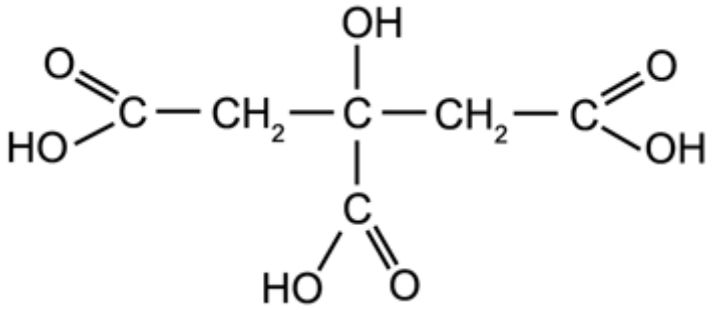
For markers:
Not required in student response, but needs to be understood to complete graph correctly
Since the balanced equation
$A_2\,(g) + 2B_2\,(g) \rightleftharpoons 2AB_2\,(g)$
has the mole ratios
1 2 2

the changes in the moles of gas, as shown in the graphs, will also be in these ratios. Since the no. of moles of AB_2 increased from 0.8 to 1.4 moles (i.e. by 0.6 mol), then the decreases in B_2 will be 0.6 mol and in A_2 by 0.3 mol.

Question 26 (6 marks)
26 (a) (1 mark)

Criteria	Mark
• Draws a diagram to show the structure of citric acid	1

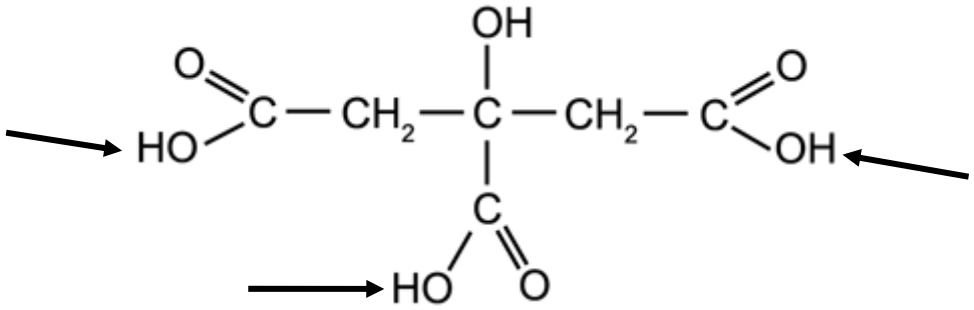
Sample answer



26 (b) (1 mark)

Criteria	Mark
• Indicates the THREE hydrogen atoms which would be donated in acid-base reactions	1

Sample answer



26 (c) (2 marks)

Criteria	Marks
• Explains TWO reasons why acids are used as food additives	2
• Explains ONE reason why acids are used as food additives	1

Sample answer

Acid is added to give a sharp taste to foods and also to act as a preservative. Acidic food preservatives prevent micro-organisms from decomposing the food.

(Acids such as ascorbic acid (vitamin C) and citric acid occur in many foods. Many drinks contain carbonic acid and some contain phosphoric acid. Other acids, such as benzoic acid and acetic acid, are added to drinks and food to act as preservatives.)

26 (d) (2 marks)

Criteria	Marks
• Writes an equation for the reaction of acetic acid with water (showing the reversible reaction) AND • Explains why acetic acid is classified as weak	2
• Writes an equation for the reaction of acetic acid with water (showing the reversible reaction) OR • Explains why acetic acid is classified as weak	1

Sample answer

$CH_3COOH\ (aq) + H_2O\ (l) \rightleftharpoons CH_3COO^-\ (aq) + H_3O^+\ (aq)$

Acetic acid is classified as weak as it only partially ionises in water. The equilibrium (shown in the equation) lies to the left. In dilute solutions of acetic acid, only about 1% of the molecules have been converted into ions.

Question 27 (6 marks)
27 (a) (3 marks)

Criteria	Marks
• Calculates the volume of HCl(g)	**3**
• Response contains one error.	**2**
• Response contains one correct step.	**1**

If pH = 1.25 then $[H^+] = 10^{-1.25} = 0.0562M$
n = CV = 0.0562 x 2 = 0.1124 moles HCl required.
V = n x MM = 0.1124 x 24.79 = 2.79L

27 (b) (2 marks)

Criteria	Marks
• Correct answer to 3 significant figures	2
• Correct answer to incorrect accuracy OR • Didn't use the correct ratio in the calculation but otherwise correct	1

Sample answer

$H_2SO_4\ (aq) + 2NaOH\ (aq) \rightarrow Na_2SO_4\ (aq) + 2H_2O\ (l)$

1 mole 2 moles

No. of moles of H_2SO_4 = cV = 0.105 x 36.5/1000 = 3.8325×10^{-3} mol

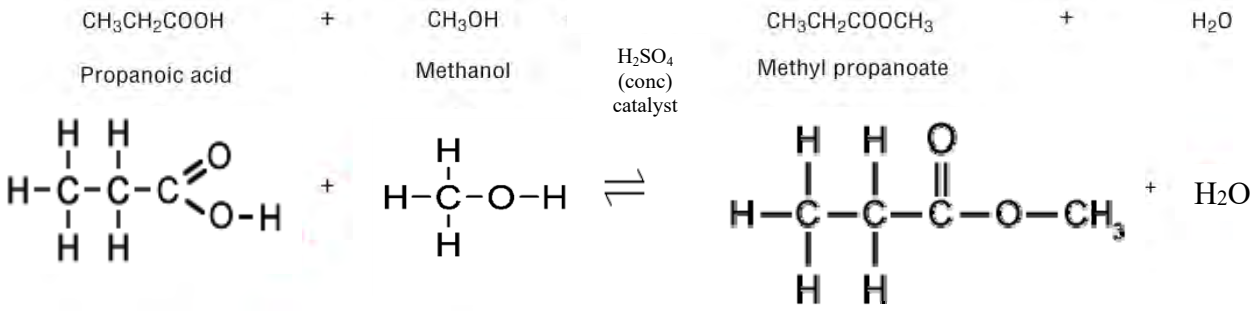
No of moles of NaOH = 2 x 3.8325 x 10^{-3} mol = 7.665×10^{-3} mol

c_{NaOH} = n/V = 7.665 x 10^{-3} / 0.025 = 0.307 mol L^{-1} (3 s.f.)

Question 28 (4 marks)
28 (a) (1 mark)

Criteria	Mark
• Writes a correctly balanced equation using structural formulae	1

Sample answer



28 (b) (3 marks)

Criteria	Marks
• Explains that the ester is polar but does not form H-bonds AND • Identifies the ester as polar, forming dipole-dipole interactions in water AND • Identifies the reactants as propanoic acid and methanol AND • Identifies the reactants as polar but forming much stronger hydrogen bonds with water	3
• TWO of the above OR • Gives a full explanation of the slightly polar nature of the ester but does not fully explain the bonding in the reactants OR • States that esters don't have H-bonds while the reactants do	2
• ONE of the above	1

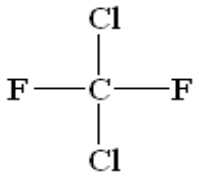
Sample answer
The solubility of a substance in water depends on the relative strength of the intermolecular forces between the substance and water, between water and water, and between the neighbouring molecules of the substance itself. Substances which dissolve readily in water, such as methanol or propanoic acid (the reactants), do so because the force of attraction between water and each of these molecules is strong enough to separate the water molecules from each other. Strong hydrogen bonds between water and the polar –OH group of the alcohol and between water and the -COOH group of the acid mean that both reactants dissolve in water.

The ester is polar but does not form hydrogen bonds with water as the ester does not have a hydrogen directly attached to an electronegative oxygen atom. The V-shape of the ester molecule means that there is some uneven distribution of charge in the ester molecule. This allows esters to be slightly polar and means that there is some attraction to water. However, the attraction of water molecules for each other means that very little ester manages to get between water molecules – i.e. the solubility is low.

Question 29 (3 marks)
29 (a) (1 mark)

Criteria	Mark
• Draws the structure of and names an example of a CFC	1

Sample answer



Name: dichlorodifluoromethane

29 (b) (2 marks)

Criteria	Marks
• Complete explanation with the equations below	2
• Incomplete explanation but partially given	1

Sample answer

The initial products from high energy UV-C light hitting a CFC molecule are a chlorine atom and an organic radical, considering CFC-11 (trichlorofluoromethane):

CCl_3F + UV-C light ➔ CCl_2F + Cl

The free chlorine atom can then react with ozone to form ClO:

$$Cl + O_3 \rightarrow ClO + O_2$$

The ClO in turn will react with nascent oxygen (O) to release a chlorine atom; thus, a continuous destruction of ozone occurs because the chlorine atoms are not sequestered into stable compounds:

$$ClO + O \rightarrow Cl + O_2$$

The CFC chlorine can take other reaction paths, but this is believed to be the predominant ozone destruction cycle.

Question 30 (7 marks)
30 (a) (1 mark)

Criteria	Mark
• Identifies AAS	1

Sample answer
Atomic absorption spectroscopy (AAS)

30 (b) (2 marks)

Criteria	**Marks**
• Explains thoroughly the source emitting the same wavelengths as the sample absorbs AND • States that the more concentrated the sample the greater the absorbance	2
• Explains that vaporised elements only absorb particular frequencies from the radiation source	1

Sample answer
Each element has its own characteristic absorption spectrum that is related to its electron energy levels.

Atomic absorption spectroscopy (AAS) detects minute concentrations of an element in a sample of solution.

AAS can analyse a sample to show whether any atoms of a particular element are present in the sample. If the element is found to be present, its concentration can be determined.

The method is based on prior knowledge (obtained from emission and absorption spectra of elements) as to which light frequencies/**wavelengths are characteristic of that element**.

The flame containing the vaporised sample absorbs light **at the particular wavelengths characteristic of the element** in the flame and re-emits it in all directions. A detector records the intensity of light emerging from the flame. The intensity of light detected drops sharply at the wavelengths of light absorbed by the element in the flame, thus producing an absorption spectrum. The relative intensity and pattern of changes of intensity within each of the bands in the absorption spectrum indicate the concentration of the element in the test sample.

Hence the radiation source must be emitting the same frequencies as will be absorbed by the element in the sample being tested.

30 (c) (4 marks)

Criteria	Marks
• Assesses the impact of AAS on society and the environment by giving pros and cons AND • States that AAS can measure very low concentrations AND • States that AAS can be used to measure concentration of pollutants namely heavy metals which are toxic AND • States that AAS can measure concentrations of trace elements which are vital to health AND • Identifies some limitations of AAS like cant measure concentrations of non-metals	4
• Most of the criteria above but not complete	3
• TWO of the above	2
• ONE of the above	1

Sample answer
Atomic absorption spectroscopy (AAS) is an instrumental technique which is very sensitive and can measure concentrations of <1 ppm of metal ions in a sample.

Prior to the invention of AAS, analytical chemists used precipitation, volumetric and gravimetric techniques to determine the concentrations of ions in samples. Samples had to be very large or the target metal ion would go undetected.

AAS can be used not only to detect the presence of pollutant metals in the environment but to determine their concentrations. Heavy metals include the transition metals, plus lead and the semi-metal arsenic. The heavy metals that are of concern because of their detrimental health effects are mercury, lead, cadmium, chromium and arsenic. Even in very small concentrations, these heavy metals can be toxic. Analytical chemists from government organisations such as the Environmental Protection Authority (EPA) carry out programs involving investigation, compliance assessment, environmental monitoring and evaluation and enforcement, in order to protect the environment by controlling and minimising pollution and waste. AAS provides a quantitative technique for determining the levels of metal ions in the environment.

Pollutants would go undetected, and hence legislation could not enforce standards by industry and the population in general, without a sensitive and accurate method of measurement. AAS is used routinely in chemical industries to check the wastes released into the environment, to ensure that the concentrations of the metals in wastes do not exceed the levels known to be detrimental to the environment.

AAS is also important in the food industry and for understanding the significance of trace elements. These elements, in small concentrations, are vital for the healthy functioning of plants and animals. Agricultural industry, medicine, the pharmaceutical industry, etc, all depend on measurement using AAS. Without a means of measurement, experimentation to find the optimum concentrations of vitamins, minerals, medications, soil additives, etc, could

not be carried out. Hence AAS allows society to benefit by knowledge which assists the healthy functioning of organisms.

While AAS is an important tool for all chemists, it has limitations, in that tests for a range of metals must be done separately and AAS is only suitable for detecting metal ions. Other pollutants, such as hydrocarbons, cannot be detected by AAS. The use of emission spectroscopy is less limiting, in that an emission spectrum will show lines for all metals in a sample at the same time.

Assessment

The development of AAS and its use to determine the optimum levels of trace elements, while detecting minute levels of environmental pollutants, has had an enormous impact on society and the environment over the past 60 years.

Question 31 (4 marks)

Criteria	*Marks*
• Includes an appropriate chemical equation, calculates the number of moles and concentration of the species in excess and calculates the final pH of the solution.	**4**
• Includes an appropriate chemical equation, calculates the number of moles and concentration of the species in excess and calculates the final pH of the solution with some errors.	**3**
• Includes an appropriate chemical equation AND calculates the number of moles of acid and base present.	**2**
• Includes an appropriate chemical equation OR calculates the number of moles of acid and base present.	**1**

Sample answer:

$$2\ HCl_{(aq)} + Ba(OH)_{2\ (aq)} \longrightarrow BaCl_{2\ (aq)} + 2\ H_2O_{(l)}$$

number of moles of H^+ $= c \times V = 0.10 \times \frac{25}{1000} = 2.5 \times 10^{-3}\ mol$
number of moles of OH^- = c x V = 0.25 x 30/1000 x 2 = 1.5 x 10^{-2} mol
From the equation:

Since the number of moles of OH^- is greater than the number of moles of H^+, OH^- is

in excess after mixing by (1.5 x 10^{-2}) – (2.5 x 10-3) = 0.0125

Concentration of OH^- = n/V = 0.0125/0.055 = 0.2273 $mol\ L^{-1}$

$$pOH = -\log\ [OH^-] = -\log\ (0.2273) = 0.64$$

pH = 14 – pOH = 14 – 0.64 = 13.36

Section II – OPTIONS
Question 32 – Industrial Chemistry (25 marks)
32 (a) (i) (1 mark)

Criteria	Mark
• Writes a correct equation	1

Sample answer

$2NaCl\ (aq) + CaCO_3\ (s) \rightarrow Na_2CO_3\ (s) + CaCl_2\ (aq)$

32 (a) (ii) (2 marks)

Criteria	Marks
• Justifies the statement by explaining that ammonia is recycled during the industrial production of sodium carbonate AND • Identifies the steps involving ammonia	2
• Justifies the statement by explaining that ammonia is recycled during the industrial production of sodium carbonate OR • Identifies the steps involving ammonia	1

Sample answer
The statement is justified as ammonia is required for the industrial production of sodium carbonate but it is recycled and recovered for further use. Hence, theoretically, it is not consumed. In reality, a trace may be released by the industrial process and over time the ammonia would need to be replenished.

The ammonia reacts in the Solvay tower to produce sodium hydrogen carbonate and ammonium chloride.

$NaCl\ (aq) + CO_2\ (g) + NH_3\ (g) + H_2O\ (l) \rightarrow NaHCO_3\ (s) + NH_4Cl\ (aq)$

In the recovery tower, ammonium chloride reacts with calcium hydroxide, and ammonia is regenerated.

$Ca(OH)_2\ (aq) + 2NH_4Cl\ (aq) \rightarrow CaCl_2\ (aq) + 2H_2O\ (l) + 2NH_3\ (g)$

32 (b) (i) (2 marks)

Criteria	Marks
• Writes TWO correct half-equations	2
• Writes ONE correct half-equation	1

Sample answer

$H_2SO_4\,(aq) + 2H^+\,(l) + 2e^- \rightleftharpoons SO_2\,(g) + 2H_2O\,(l)$

$2I^-\,(aq) \rightleftharpoons I_2\,(aq) + 2e^-$

32 (b) (ii) (1 mark)

Criteria	Mark
• Writes a correct equation	1

Sample answer

$C_{12}H_{22}O_{11}\,(s) \xrightarrow{H_2SO_4} 12C\,(s) + 11H_2O\,(g)$

32 (b) (iii) (3 marks)

Criteria	Marks
• Identifies the contact process in the production of sulfuric acid • Discusses the reasons for monitoring the contact process • Discusses the stepwise process used to achieve the optimal outcome	3
• TWO of the above	2
• ONE of the above	1

Sample answer
The contact process involves the catalysed reaction of sulfur dioxide with oxygen to form sulfur trioxide.

This reaction must be monitored to achieve a maximum yield of sulfur trioxide (and hence of sulfuric acid). To achieve this, the equilibrium must shift as far as possible to the right. This ensures that only trace amounts of the pollutant, sulfur dioxide, are released into the atmosphere.

$2SO_2\,(g) + O_2\,(g) \rightleftharpoons 2SO_3\,(g) \quad \Delta H = -198\ kJ\ mol^{-1}$

Since the equilibrium reaction is exothermic and there are fewer moles of gaseous products than of reactants, Le Chatelier's Principle can be used to predict that the highest yield of sulfur trioxide is obtained at high pressure but at low temperature, using a large excess of oxygen. However, a low temperature means that the rate of reaction would be slow. The sulfur trioxide is removed by passing it into sulfuric acid as it forms.

A compromise involves moderate temperature (400-450°C), use of a catalyst (V_2O_5), using a small excess of oxygen and a pressure not much above 1 atmosphere. The compromise

relating to pressure is more an issue of cost and safety than of rate or yield. Similarly, the compromise to use only a small excess of oxygen is one of cost.

The industrial conversion of sulfur dioxide to sulfur trioxide is done in stages, using a vanadium (V) oxide on silica catalyst:

1. A fast but low yield stage at 550°C
2. A slower but high yield stage at 400°C

These stages only achieve about 97% conversion to sulfur trioxide and the residue of 3% SO_2 is not acceptable as a waste into the atmosphere. This remaining SO_2 has to be recycled back over the catalyst until only a trace (0.3%) remains to be exhausted into the atmosphere.

These compromise conditions must be monitored to produce the maximum amount of sulfur trioxide and to ensure that the sulfur dioxide is not released into the atmosphere at greater concentrations than permitted by world-wide environmental protection legislation.

32 (c) (i) (1 mark)

Criteria	Mark
• Correct equilibrium constant expression	1

Sample answer

$$K = \frac{[CH_3OH\ (g)]}{[CO\ (g)]\ [H_2\ (g)]^2}$$

32 (c) (ii) (1 mark)

Criteria	Mark
• States ONE method of increasing the equilibrium constant	1

Sample answer
The equilibrium constant can be increased by decreasing the temperature (since the reaction is exothermic, decreasing the temperature moves the equilibrium to the right).

32 (c) (iii) (2 marks)

Criteria	Marks
• Correct answer	2
• Correct calculation of the equilibrium concentrations of all 3 gases	1

Sample answer
From the balanced equation:
Since 0.2 mol CH_3OH forms, then 0.2 moles of CO reacted and 0.4 moles of H_2 reacted.

Initially		***Equilibrium concentration***
$[CO\ (g)]$	= 1.0/5 = 0.20 mol/L	0.8/5 = 0.16 mol/L
$[H_2\ (g)]$	= 1.0/5 = 0.20 mol/L	0.6/5 = 0.12 mol/L
$[CH_3OH(g)]$	= 0 mol/L	0.2/5 = 0.04 mol/L

$$K = \frac{[CH_3OH\ (g)]}{[CO\ (g)]\ [H_2\ (g)]^2} = \frac{(0.04)}{(0.16)\ (0.12)^2} = \frac{0.04}{0.002304} = 17$$ (probably best expressed as 2×10^1)

Hence $K = 2 \times 10^1$

32 (d) (i) (1 mark)

Criteria	Mark
• Writes a correct overall equation	1

Sample answer

$2NaCl\ (aq) + 2H_2O\ (l) \rightarrow H_2\ (g) + Cl_2\ (g) + 2NaOH\ (aq)$

32 (d) (ii) (4 marks)

Criteria	Marks
• Justifies the use of a membrane cell rather than a diaphragm cell • Discusses thoroughly the benefits of the membrane cell • Discusses thoroughly the problems associated with the diaphragm cell	4
• Discusses the benefits of the membrane cell • Discusses the problems associated with the diaphragm cell	3
• Identifies the benefits of the membrane cell AND • Identifies problems associated with the diaphragm cell	2
• Identifies the benefits of the membrane cell OR • Identifies problems associated with the diaphragm cell	1

Sample answer
The industrial production of sodium hydroxide by all 3 industrial methods has involved the same overall electrolysis reaction.

The diaphragm cell used a barrier made from asbestos to separate the anode and cathode compartments. The diaphragm cell allowed some movement of ions between the anode and cathode half-cells, which reduced the purity of the final product and allowed the formation of the hypochlorite ion (OCl^-), a strong oxidant, which can kill useful micro-organisms and cause adverse chemical changes if discharged into the environment. The use of asbestos in the diaphragm introduced health problems (not known in 1896) if asbestos fibres are inhaled.

The membrane cell used new technologies to incorporate anionic groups into a membrane made from the polymer PTFE. This membrane does not allow the reaction of hydroxide ions and chlorine, so the hypochlorite ion (OCl^-) is not formed and the purity of the product is ensured.

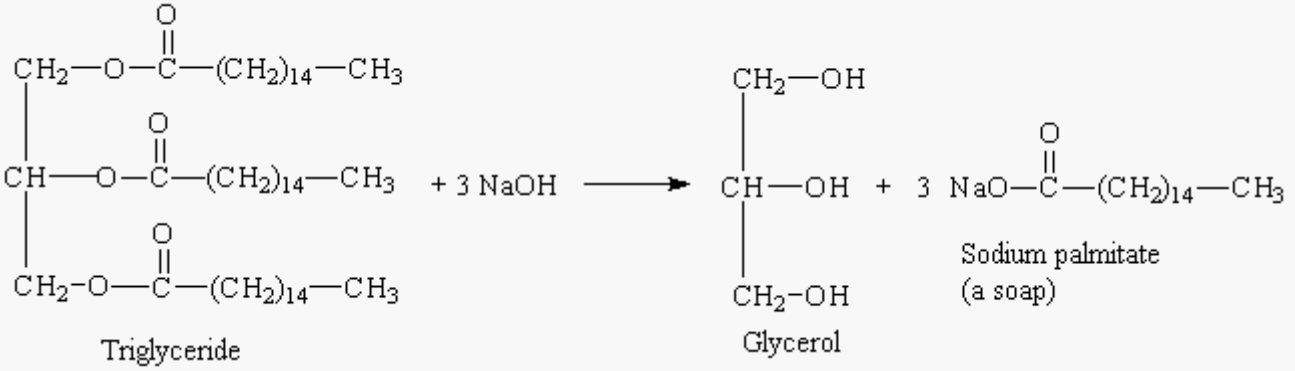
The recognition of health risks associated with the use of an asbestos diaphragm in the diaphragm cell (and with the use of a mercury cathode in the mercury cell) led to the development of a membrane cell, which overcame the environmental risks associated with the earlier production methods.

Justification
The use of the membrane cell is justified as it eliminates the environmental concerns associated with the use of asbestos and the production of the harmful hypochlorite ion. The membrane cell also produces a purer product than the earlier diaphragm cell.

32 (e) (i) (2 marks)

Criteria	Marks
• Describes the process of saponification AND • Writes an appropriate equation	2
• Describes the process of saponification OR • Writes an appropriate equation	1

Sample answer
Saponification is soap making; the formation of soap from the reaction of fats or oils with sodium hydroxide or potassium hydroxide. The soap is the sodium (or potassium) salt of a long-chain fatty acid. Fats and oils are esters of glycerol.



32 (e) (ii) (5 marks)

Criteria	Marks
• Assesses the statement • Discusses the general structure of surfactants • Relates the general structure of surfactants to the uses of surfactants • Identifies THREE different types of synthetic surfactants • Relates the different structures of the THREE types of surfactants to their different uses	5
• Discusses the general structure of surfactants • Relates the general structure of surfactants to the uses of surfactants • Identifies THREE different types of synthetic surfactants • Relates the different structures of the THREE types of surfactants to their different uses	4

• THREE of
  • Discusses the general structure of surfactants
  • Relates the general structure of surfactants to the uses of surfactants
  • Identifies THREE different types of synthetic surfactants
  • Relates the different structures of the THREE types of surfactants to their different uses
	3

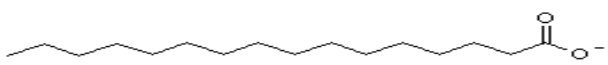
• TWO of
  • Discusses the general structure of surfactants
  • Relates the general structure of surfactants to the uses of surfactants
  • Identifies THREE different types of synthetic surfactants
  • Relates the different structures of the THREE types of surfactants to their different uses
	2

• ONE of
  • Discusses the general structure of surfactants
  • Relates the general structure of surfactants to the uses of surfactants
  • Identifies THREE different types of synthetic surfactants
  • Relates the different structures of the THREE types of surfactants to their different uses
	1

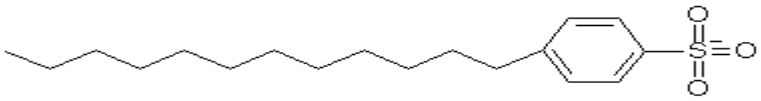
Sample answer
Surfactants are surface active chemicals, which act as emulsifiers. They act to break up one substance (usually a fat or oil) into small droplets, allowing it to be suspended within micelles and spread throughout water or an aqueous solution.

Soaps and synthetic detergents are both classified as surfactants. Soaps and detergents have a common structure in that they have a long carbon chain which is hydrophobic (lipophilic) and a charged head which is hydrophilic (lipophobic).

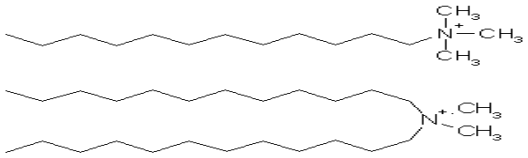
Soaps have carboxylate groups ($-COO^-$) as their negatively charged head.



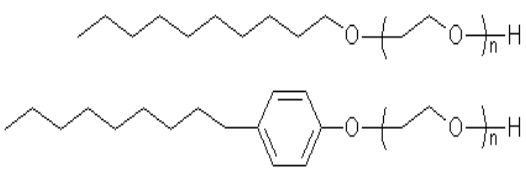
Anionic detergents are similar to soaps in that their charged head is negative. The negative head varies in different anionic detergents but is often a benzene sulfonate group.



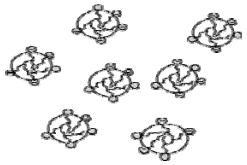
Cationic detergents have a positively charged head, usually an alkyl ammonium group. Generally there are one or two long hydrocarbon chains and two or three methyl groups attached to a charged nitrogen atom.



Non-ionic surfactants have a long hydrocarbon chain (the tail of the detergent) and a polar segment, acting as the head. They are molecules, not ions.



In water, surfactants allow oil or dirt to form droplets (micelles), with the head of the surfactant on the outer surface of the micelle, attracted to the water, and the tail embedded in the grease or oil in the middle of the micelle.



Because all surfactants have similar structures (hydrocarbon tail and polar or ionic head), all soaps and detergents are able to clean objects. They act as emulsifiers, breaking up the dirt while allowing it to be suspended within micelles and spread throughout water. The micelle is attracted to the water and goes down the drain with the water. Surfactants also decrease the surface tension of water (they get between the water particles and reduce the force of attraction between them). This reduction in surface tension allows the water particles to wet (spread out over) the surface of a dirty object rather than stay together as a drop of water.

These properties make surfactants extremely useful chemicals in modern society.
Soaps are biodegradable and are made from naturally occurring fats and oils and useful in soft water for personal hygiene. However, soaps can form insoluble scum in hard water.
Synthetic surfactants are more soluble than soaps and are used as laundry detergents, as hair conditioners, as disinfectants and as industrial emulsifiers.

The differences in structure of different surfactants determine their specific uses.

Anionic detergents are not made from natural fats and oils. These synthetic surfactants are used in laundry detergents and dishwashing liquids. Like soaps, they act in the same way as cleaning agents and emulsifiers, but the synthetic agents are more effective and remove too much oil from the skin and hair, so are not used for personal hygiene.

Cationic detergents are used to condition fabrics or to clean and condition hair. The –ve charges on the surface of wet fabric attract the cationic head groups which bind strongly. The surface of the fabric then becomes coated with the long hydrocarbon tails which act to reduce static and fibre tangling. They are also biocides (kill micro-organisms) so are used in disinfectants.

The main uses of non-ionic surfactants are as emulsifiers in paints, adhesives, pesticides and cosmetics. Non-ionic surfactants are also used in preference to anionic surfactants when low foam situations are required (dishwashers, front-loading washing machines). Non-ionic surfactants do not cause a build-up of foam bubbles on a surface, whereas the ionic ends of anionic and cationic surfactants allow stable layers of bubbles to persist, separated from each other by repulsive forces between the charged ends of the surfactant molecules.

Assessment
The statement is correct as the common structure of soaps and synthetic detergents determines the similarity in their uses, as surfactants, as emulsifiers and as cleaning agents. However, the differences in their structures determine the specific uses of soap or a particular synthetic detergent.

Question 33 – Shipwrecks, Corrosion and Conservation (25 marks)

33 (a) (4 marks)

Criteria	Marks
• Describes the nature of Davy's work and includes the significant innovation of the very large Voltaic Pile battery AND • a specific discovery he made in electrochemistry, namely the electrolysis of molten compounds to isolate group 1 metals AND • 2 examples of metals he isolated OR • Electrolysis of water to produce hydrogen and oxygen	3
• Describes the nature of Davy's work and includes a significant innovation OR a specific discovery he made in electrochemistry	2
• Describes the nature of Davy's work OR includes a significant innovation OR a specific discovery he made in electrochemistry	1

Sample answer

Davy investigated the effects of electricity on chemical compounds. He constructed the largest battery ever built based on Volta's device and used it to electrolyse aqueous salt solutions to produce hydrogen and oxygen.
Using these ideas he built simple molten salt electrolytic cells and used them to isolate previously undiscovered elements such as potassium, sodium, calcium and strontium. He suggested that zinc attached to copper could prevent its corrosion.

33 (b) (3 marks)

Criteria	Marks
• Identifies the main constituents of the three steels AND • Relates the preferential use of each to the differences in composition	3
• Relates the preferential use of three of them to the differences in composition	2
• Identifies the main constituents of the three steels OR • Gives properties of all three	1

Sample answer

Mild steel contains iron and <0.2% carbon.
Structural steel contains iron and 0.2 to 0.6% carbon.
Tool steel contains iron and 0.6 to 1.5% carbon.

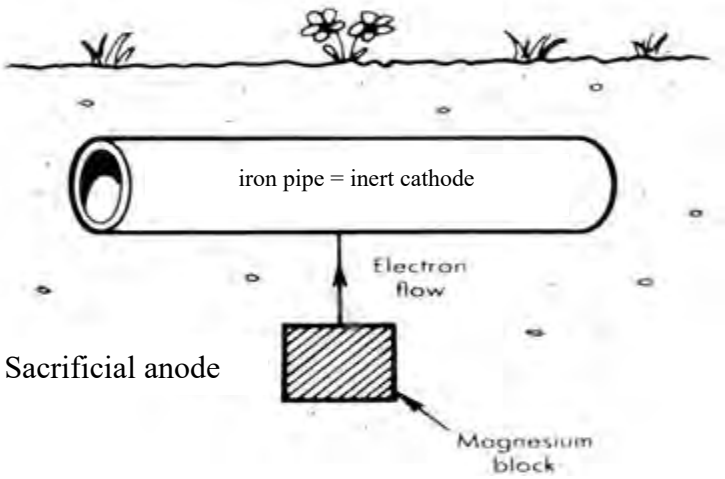
Mild steel is soft and malleable because it has only iron and a low percentage of carbon and it corrodes rapidly. It is highly malleable and easily worked and is therefore used to make paper clips, ships hulls and car bodies
Structural steel is harder but maintains a fair degree of malleability and is used in the building industry to make girders and beams.
Tool steel is very hard and can withstand abrasion and is useful to make drill bits and tools like hammer heads.

33 (c) (3 marks)

Criteria	Marks
• Identifies that magnesium acts as a sacrificial anode and corrodes in preference to the iron pipe AND • Draws an appropriate labelled diagram indicating the anode and cathode AND • Writes half-equations for the electrode reactions	3
• TWO of the above	2
• ONE of the above	1

Sample answer

The iron pipe is protected from corrosion by the presence of the magnesium ingot which is in electrical contact with the pipe. Magnesium corrodes preferentially (since magnesium is oxidised more readily than iron in the marine environment). Hence the iron pipe is protected (it acts as an inert cathode; the magnesium block acts as a sacrificial anode). Electrons move through the connecting wire to the iron surface, preventing the oxidation of iron to iron (II) ions. The electrons react with oxygen and water at the surface of the inert cathode.



At the anode: $Mg\ (s) \rightleftharpoons Mg^{2+}\ (aq) + 2e^-$ $E° = +2.36$ V

At the cathode: $O_2\ (g) + 2H_2O\ (l) + 4e^- \rightleftharpoons 4OH^-\ (aq)$ $E° = +0.40$ V

33 (d) (i) (2 marks)

Criteria	Marks
• Identifies that the graph shows that the concentration of oxygen is greater at depth AND • Explains that oxygen is the necessary oxidant for the corrosion of iron in shipwrecks	2
• Identifies that oxygen is more soluble at low temperatures	1

Sample answer
The graph plots the solubility of oxygen against temperature and shows that more oxygen dissolves at lower temperature. Since the temperature of seawater is, in general, lower at greater depth, then corrosion of shipwrecks which occurs by an aerobic process would be expected to be greater at depth (if the same concentration of oxygen were available at all depths).

33 (d) (ii) (4 marks)

Criteria	Marks
• Discusses thoroughly why corrosion of shipwrecks occurs both in shallow water and at depth • Explains why corrosion due to oxygen and water is greater in shallow water and identifies where the oxygen is originating from and identifies that surface waters are warmer hence faster reaction rate, including equation(s) • Explains why corrosion occurs at depth, by anaerobic processes, including equation(s)	4
• Explains why corrosion due to oxygen and water is greater in shallow water, including equation(s) • Explains why corrosion occurs at depth, by anaerobic processes, including equation(s)	3
• Explains why corrosion due to oxygen and water is greater in shallow water AND • Explains why corrosion does occur at depth	2
• Explains why corrosion due to oxygen and water is greater in shallow water OR • Explains why corrosion does occur at depth	1

Sample answer
Corrosion of iron in shallow water occurs by the reaction of iron with the water and with oxygen.
All reactions occur faster as the temperature rises and the temperature of water is generally warmest near the surface.
Oxygen is in ample supply near the surface as it is derived (i) from oxygen in the air and (ii) from photosynthesis of marine plants. As depth increases, the concentration of oxygen in water decreases, as it is increasingly further below the oxygen source (the atmosphere) and oxygen production from photosynthesis falls as the penetration of sunlight decreases (limiting the ability of marine plants to photosynthesise).
Oxygen is also removed from the water by aerobic respiration of organisms living in shallow water (associated with food chains dependent on photosynthesis), so there is little oxygen available to diffuse to greater depth.

$Fe\ (s) \rightleftharpoons Fe^{2+}\ (aq) + 2e^-$ (oxidation)
$O_2\ (g) + 2H_2O\ (l) + 4e^- \rightleftharpoons 4OH^-\ (aq)$ (reduction)

However, at depth, corrosion occurs by a different chemical process and different products are formed.

At depth, sulfate-reducing bacteria are present, which reduce sulfate ions to hydrogen sulfide ions according to the following reduction equation:

$SO_4^{2-}\ (aq) + 5H_2O\ (l) + 8e^- \rightleftharpoons HS^-\ (aq) + 9OH^-\ (aq)$

So, despite the absence of oxygen, iron can be oxidised at great depth:

$Fe\ (s) \rightleftharpoons Fe^{2+}\ (aq) + 2e^-$

33 (e) (i) (1 mark)

Criteria	Mark
• Explains TWO methods for increasing the rate of the electrolysis reaction	2
• Identifies TWO methods but both not fully explained	1

Sample answer
The rate of reaction can be increased by increasing the concentration of the electrolyte, increasing the voltage, increasing the surface area of the electrodes and decreasing the distance between the electrodes.
By increasing the voltage there is more push on electrons.
By increasing the surface area of electrodes there are more successful collisions between reactants.

33 (e) (ii) (3 marks)

Criteria	Marks
• Describes observations at BOTH electrodes AND • Writes half-equations for BOTH electrode reactions	3
• Describes observations at BOTH electrodes AND • Writes a half-equation for ONE electrode reaction	2
• Describes observations at ONE electrode OR • Writes a half-equation for ONE electrode reaction	1

Sample answer
At the anode:
Water is oxidised to form oxygen, so bubbles of gas would be observed.

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

At the cathode:
Copper ions are reduced to copper metal, so a deposit of copper metal building up on the cathode would be observed, associated with a reduction in the blue colour of the electrolyte solution around the cathode.

$Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$

33 (e) (iii) (5 marks)

Criteria	Marks
• Evaluates the significance of electrolysis in the conservation and restoration of metallic artefacts recovered from shipwrecks, including: • Artefact is the cathode and anode is stainless steel mesh • Anode is wrapped around cathode for even coverage • Chloride ions are removed by electrolysis • Iron ions are reduced back to iron metal • Electrolyte is NaOH for stabilisation as well • Water is reduced on the artefact and the hydrogen bubbles help to clean • Give oxidation half-equation for oxidation of hydroxide	5
• Discusses thoroughly the processes of conservation and restoration of a metal artefact by electrolysis • Gives most of the criteria above • Writes appropriate equations or half-equations for the electrolysis reaction	4
• Discusses soundly the processes of conservation and restoration of a metal artefact by electrolysis • Gives some of the criteria • Writes appropriate equations or half-equations for the electrolysis reaction	3
• TWO of: • Outlines the processes of conservation and restoration of a metal artefact by electrolysis • Gives two of the criteria • Writes an appropriate equations or half-equations for the electrolysis reaction	2
• ONE of: • Outlines the processes of conservation and restoration of a metal artefact by electrolysis • Outlines the processes other than electrolysis involved in conservation and restoration • Writes appropriate equations or half-equations for the electrolysis reaction	1

Sample answer
Conservation and restoration of metallic artefacts involves removal of adhering concretions, removal of ions (in particular chloride), conversion of corrosion products adhering to the artefact back to the original metal and preventing further corrosion by coating the artefact in an impermeable and unreactive coating.

The removal of concretions of calcium carbonate is achieved by placing the artefact in dilute solutions of a very weak acid.

The artefact is carefully washed in fresh water over a long time frame to leach chloride ions from the artefact without removal of coatings such as Fe(OH)Cl or Cu(OH)Cl.

The electrolysis step involves connection of the artefact to the negative terminal of a power source, as the cathode in an electrolytic cell.

At the cathode, reduction of the corrosion product occurs, which releases the chloride ion and restores the original metal to the surface of the artefact (where the corrosion product would

have been attached). Hence the shape and engravings on metal objects can be restored to their original condition.

As a result, the artefact is both conserved and restored by the electrolysis process.

If the metal is iron, the half-equation for the cathode reaction is:

$Fe(OH)Cl\ (s) + 2e^- \rightarrow Fe\ (s) + OH^-\ (aq) + Cl^-\ (aq)$

If the metal is copper, the half-equation is:

$Cu(OH)Cl\ (s) + 2e^- \rightarrow Cu\ (s) + OH^-\ (aq) + Cl^-\ (aq)$

The anode reaction, if an inert electrode is used, is:

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

To prevent further corrosion, the metallic object should then be preserved by coating with a clear acrylic lacquer.

Evaluation

Without electrolysis, conservation and restoration of metallic artefacts could not be achieved. The electrolysis process, by releasing the chloride ions from the coatings, also removes chloride ions which could otherwise cause future corrosion of the artefact by the formation of hydrochloric acid.

Hence, electrolysis is significant both for conservation and restoration of metallic artefacts recovered from shipwrecks.