



CHEMISTRY

Stage 3

WACE Examination 2010

Final Marking Key

This 'stand alone' version of the WACE Examination 2010 Final Marking Key is provided on an interim basis.

The Standards Guide for this examination will include the examination questions, marking key, question statistics and annotated candidate responses. When the Standards Guide is published, this document will be removed from the website.

Section One: Multiple-choice

25% (25 Marks)

Question No.	Answer
1	A
2	D
3	D
4	C
5	B
6	D
7	B
8	B
9	A
10	A
11	B
12	C
13	C
14	A
15	D
16	C
17	C
18	C
19	B
20	B
21	A
22	C
23	C
24	B
25	B

End of Section One

Section Two: Short answer

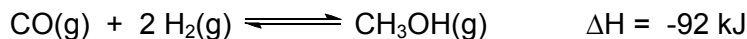
35% (70 Marks)

Statements in square brackets are optional – they are better answers but not required for full marks.

Question 26

(6 marks)

Consider the following system.



- (a) Predict whether the following changes will increase, decrease or have no effect on the rate of attainment of equilibrium. (3 marks)

Change	Effect
Decreasing the temperature	Decrease
Increasing the pressure of hydrogen	Increase
Adding a catalyst	Increase

Up and down arrows are acceptable for increase and decrease.

A dash for no change is not acceptable

Description	Marks
1 mark for each correct answer for a possible total of 3 marks.	1-3
Question incorrectly answered or not attempted.	0
Total	3

- (b) Predict whether the following changes will increase, decrease or have no effect on the equilibrium yield of the reaction. (3 marks)

Change	Effect
Increasing the temperature	Decrease
Increasing the pressure of the system	Increase
Adding a catalyst	No effect

Description	Marks
1 mark for each correct answer for a possible total of 3 marks.	1-3
Question incorrectly answered or not attempted.	0
Total	3

Up and down arrow are acceptable for increase and decrease.

A dash is not acceptable for no change.

Left and right arrows are not acceptable.

Question 27

(2 marks)

Write the equilibrium constant expression for the following equilibria.

- (a) (1 mark)

Equation	$\text{BaSO}_4\text{(s)} \rightleftharpoons \text{Ba}^{2+}\text{(aq)} + \text{SO}_4^{2-}\text{(aq)}$
Equilibrium constant expression	$K = [\text{Ba}^{2+}(\text{aq})][\text{SO}_4^{2-}(\text{aq})]$

Description	Marks
Correct answer	1
Question incorrectly answered or not attempted.	0
Total	1

The 'K=' is no required for full marks

State symbols not required.

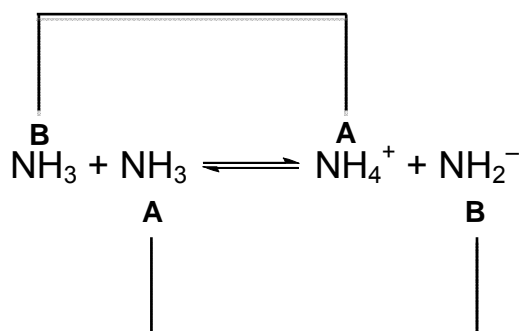
(b) (1 mark)

Equation	$2 \text{CrO}_4^{2-}(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{H}_2\text{O}(\ell)$
Equilibrium constant expression	$K = \frac{[\text{Cr}_2\text{O}_7^{2-}(\text{aq})]}{[\text{CrO}_4^{2-}(\text{aq})]^2 [\text{H}^+(\text{aq})]^2}$

Description	Marks
Correct answer	1
Question incorrectly answered or not attempted.	0
Total	1

Question 28 (4 marks)

(a) Identify the conjugate acid and base pairs in the reaction. Join each pair with a line, and label the conjugate acid and base of each pair appropriately. (1 mark)



A = conjugate acid
B = conjugate base

Description	Marks
Correct answer	1
Question incorrectly answered or not attempted.	0
Total	1

Students can use the term conjugate acid/base or CA/CB

(b) At standard temperature and pressure, the equilibrium constant, K , for this reaction is about 1×10^{-30} . The self-ionisation of ammonia is an endothermic process. Will the value of K be less than or greater than 1×10^{-30} at temperatures greater than 0°C ? Explain. (3 marks)

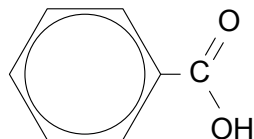
The reaction is endothermic. At $T > 0^\circ\text{C}$ (the temperature for which the equilibrium constant is given), the forward reaction will be favoured. This will increase the concentration of products relative to reactants, meaning that the value of K will increase. i.e. the value of K will be greater than 1×10^{-30} at temperatures greater than 0°C .

Description	Marks
Answer as above. Important points are (i) forward reaction is favoured , meaning (ii) concentration of products increased [relative to reactants] , therefore (iii) $K > 1 \times 10^{-30}$ or greater or larger	1-3
Question incorrectly answered or not attempted.	0
Total	3

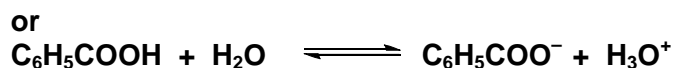
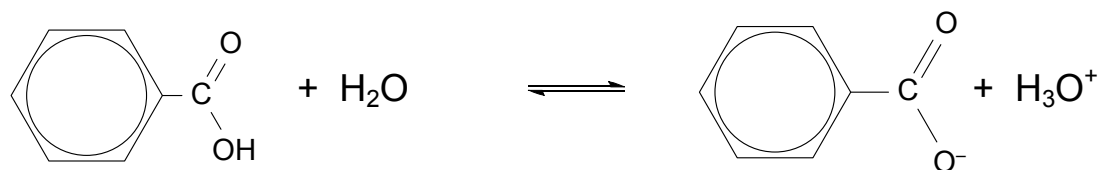
Question 29

(8 marks)

Benzoic acid is found in many berries and some other fruits, and is used as a food preservative. The structure of benzoic acid is shown below. In an aqueous environment, benzoic acid ionises and exists in equilibrium with the benzoate ion.

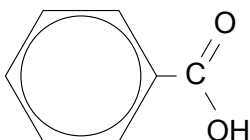


- (a) Write the equation for the reaction between benzoic acid and water. (1 mark)



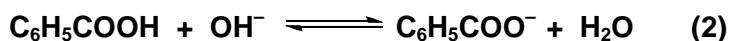
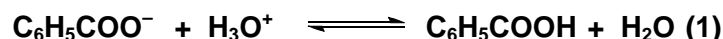
Description	Marks
Correct answer	1
Question incorrectly answered or not attempted.	0
Total	1

- (b) Draw the structure (either benzoic acid or the benzoate ion) that would predominate in the acidic environment of the stomach. (1 mark)



Description	Marks
structure of benzoic acid	1
Question incorrectly answered or not attempted.	0
Total	1

- (c) Show, using equations and the principles of equilibrium, how a solution of benzoic acid and the benzoate ion may behave as a buffer. (3 marks)



Added hydrogen ($\text{H}^+/\text{H}_3\text{O}^+$) ions are consumed by reaction (1). Added hydroxide ions (OH^-) are consumed by reaction (2). In this way, addition of $\text{H}^+/\text{H}_3\text{O}^+$ and/or OH^- is counteracted, and equilibrium and a constant pH is maintained.

Description	Marks
Answer as above. Important inclusions: i) a relevant equation/s ii) consumption of added species (either $\text{H}^+/\text{H}_3\text{O}^+$ and/or OH^-) iii) pH change is resisted.	1-3
Question incorrectly answered or not attempted.	0
Total	3

- (d) The ease with which a substance is excreted from the body is determined in part by its solubility in water. Is benzoic acid more or less miscible with water than acetic (ethanoic) acid, and hence more or less readily excreted from the body? Explain. (3 marks)

Low miscibility compared to acetic acid (and not readily excreted). The benzoic acid molecule contains a carboxylate group and a benzene ring. Although the carboxylic acid/carboxylate (species present depends on pH and pK_a) group is miscible with water, the benzene ring is non-polar. Because of the non-polar nature of the benzene ring, there will be very little interaction between benzoic acid and water, therefore it will have low miscibility with water and therefore will not be readily excreted from the body. This contrasts with acetic acid, which has a carboxylic acid/carboxylate that is miscible and a proportionately small alkyl group that will be less miscible with water. Overall miscibility of acetic acid is greater than that of benzoic acid.

(Note that candidates may alternatively give a discussion of intermolecular forces between benzoic acid/ethanoic acid and water, which is also acceptable. Any reasonable answer demonstrating an understanding of relative miscibilities in water of each of the substances is acceptable.)

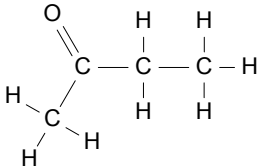
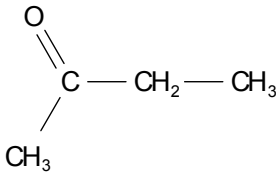
Description	Marks
Low miscibility/low solubility (not readily excreted) and correct explanation stating all three of the following important points: • carboxylic acid/carboxylate group polar, • benzene ring non-polar and • balance of polarity and non-polarity would make benzoic acid less miscible with water than ethanoic acid.	3
Low miscibility but with incomplete explanation (only two of the three important points stated, or some incorrect points)	2
Low miscibility (low solubility) but no or incorrect explanation or High miscibility, but some valid points raised.	1
Question incorrectly answered or not attempted.	0
Total	3

Question 30

(6 marks)

Consider the following reactions and complete the tables that follow.

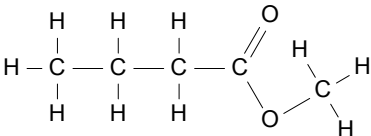
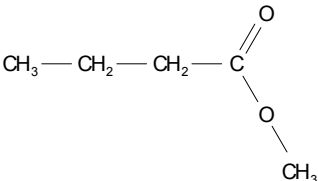
- (a) An excess of 2-butanol is oxidised by acidified
- $\text{Na}_2\text{Cr}_2\text{O}_7$
- . (3 marks)

Observations	The solution turns from orange to green/blue (this occurs in the lab at times).
Structural formula of organic product (show all atoms)	 
Name of organic product	Butanone Butan-2-one 2-butanone also acceptable

N.B. One mark deducted in total for this question if no hydrogen atoms shown for structures of organic products in parts (a) and/or (b)
If deducting one mark for lack of Hs – take from part (a)

Description	Marks
1 mark for each correct answer for a possible total of 3 marks	1-3
Question incorrectly answered or not attempted	0
Total	3

- (b) Butanoic acid reacts with methanol in the presence of
- H_2SO_4
- . (3 marks)

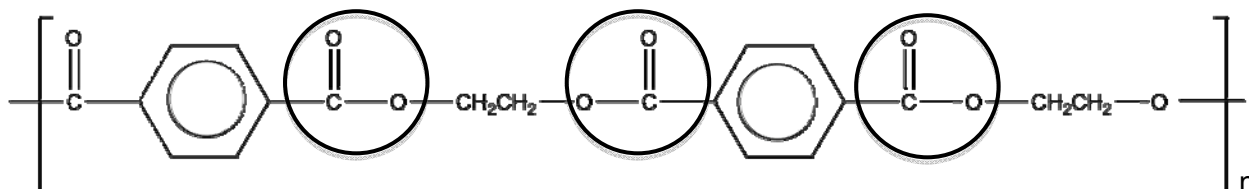
Observations	A fruity smell develops Specific fruit (any fruit) Sweet smell [Single layer forms]
Structural formula of organic product (show all atoms)	Condensed structure also acceptable  
Name of organic product	Methylbutanoate (methyl butanoate)

Description	Marks
1 mark for each correct answer for a possible total of 3 marks.	1-3
Question incorrectly answered or not attempted.	0
Total	3

Question 31

(3 marks)

Condensation polymers form from two monomers, each with functional groups at their terminal carbon atoms (that is, the monomers are difunctional). Examine the polyester structure below.

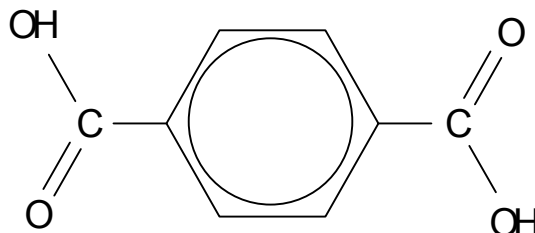


- (a) Circle **all** the ester linkages (functional groups that link the monomers) represented in the above structure. (1 mark)

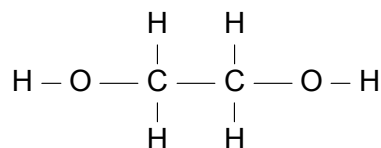
Description	Marks
All ester linkages identified and circled (end linkages may also be circled).	1
Question incorrectly answered or not attempted or not all linkages circled.	0
Total	1

- (b) Identify the two monomer compounds (A and B) used in the production of this polymer and draw their molecular structures. (2 marks)

Monomer A



Monomer B



Description	Marks
Both monomers correctly identified and drawn.	2
One correct monomer or both monomers slightly incorrectly drawn.	1
Question incorrectly answered or not attempted.	0
Total	2

Question 32

(12 marks)

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as : or as — **and** state or draw the shape of the molecule **and** state the polarity of the molecule.

(for example, water $\text{H}:\ddot{\text{O}}:\text{H}$ or $\text{H}-\ddot{\text{O}}-\text{H}$ or $\text{H}-\overset{\ominus}{\text{O}}-\text{H}$ bent polar)

Species	structure (showing all valence shell electrons)	Shape (sketch or name)	Polarity of molecule (polar or non-polar)
nitrogen trichloride NCl_3	$\begin{array}{c} \text{:}\ddot{\text{Cl}}\text{---}\ddot{\text{N}}\text{---}\ddot{\text{Cl}}\text{:} \\ \\ \text{:}\ddot{\text{Cl}}\text{:} \end{array}$	pyramidal	polar
methanal HCHO	$\begin{array}{c} \text{:}\ddot{\text{O}}\text{:} \\ // \\ \text{H}-\text{C} \\ \backslash \\ \text{H} \end{array}$	trigonal planar	polar
sulfur dioxide SO_2	$\begin{array}{c} \text{:}\ddot{\text{O}}\text{=}\ddot{\text{S}}\text{=}\ddot{\text{O}}\text{:} \\ \text{or} \\ \text{:}\ddot{\text{O}}\text{:} \quad \text{S} \quad \text{:}\ddot{\text{O}}\text{:} \\ \quad \quad \quad // \\ \quad \quad \quad \text{S} \end{array}$	bent	polar
carbon dioxide CO_2	$\text{:}\ddot{\text{O}}\text{=}\text{C}=\ddot{\text{O}}\text{:}$	linear	non-polar

Description	Marks
1 mark for each correct answer for a possible total of 12 marks.	1-12
Question incorrectly answered or not attempted.	0
Total	12

-1 if non-bonding electrons missing overall

Question 33

(4 marks)

Using the information in the table below, identify the substances A, B, C and D from the following list:

	Electrical conductivity in the solid state	Electrical conductivity in the liquid state	Solubility in water	Phase at 25°C	Colour at 25°C	Name of substance
A	nil	conducts	soluble	solid	white	potassium chloride
B	conducts	conducts	insoluble	solid	silver	aluminium
C	nil	nil	insoluble	liquid	colourless	octane
D	nil	nil	insoluble	solid	white	silicon dioxide

-1 overall if formulas used instead of names (and are correct)

Description	Marks
1 mark for each correct answer for a possible total of 4 marks.	1-4
Question incorrectly answered or not attempted.	0
Total	4

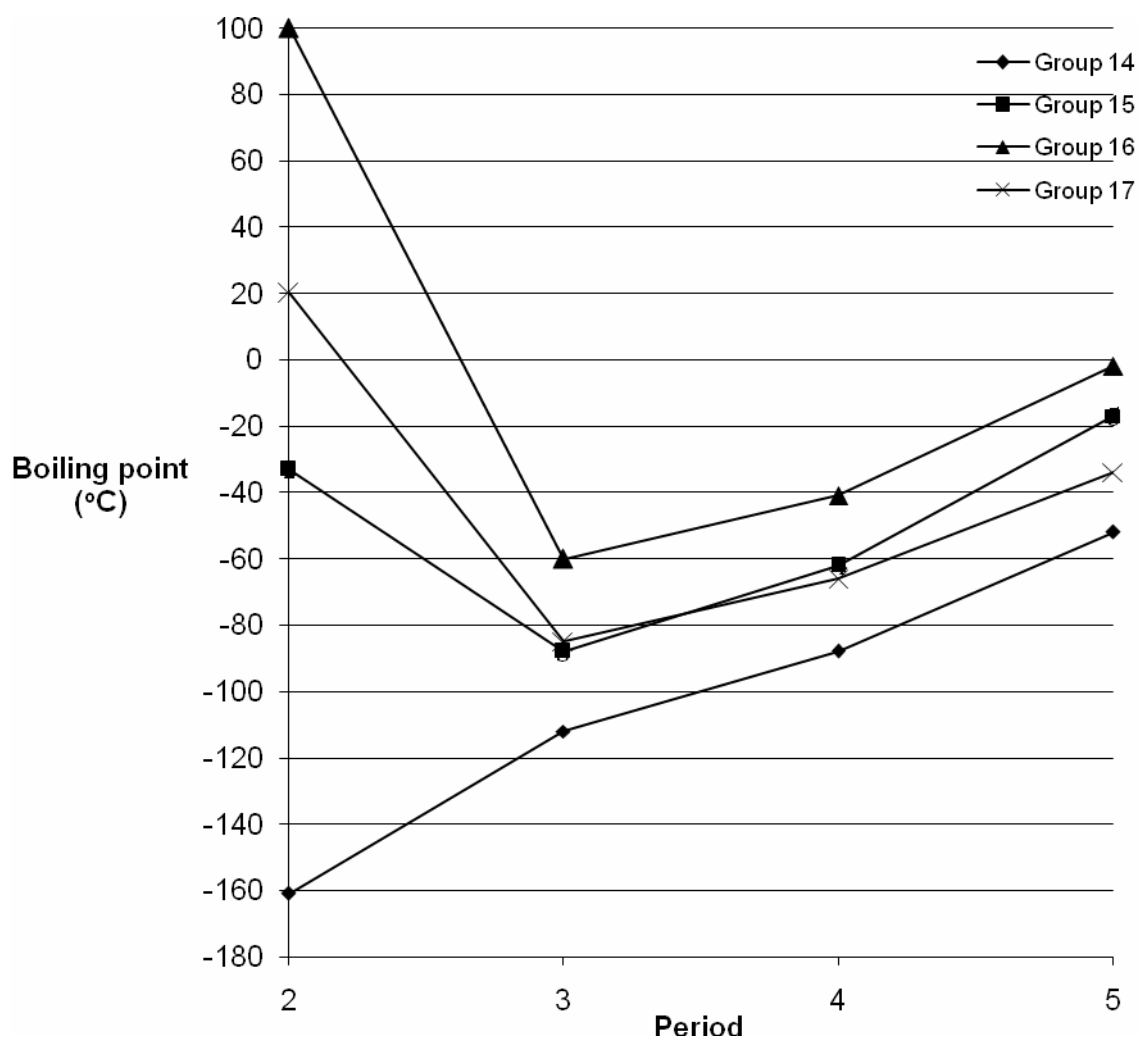
Question 34

(11 marks)

The approximate boiling points of the Group 14, 15, 16 and 17 hydrides are listed below.

- (a) Plot the boiling points for each group on the axes below. The data for Group 14 have been plotted as an example. (3 marks)

Description	Marks
1 mark for each series plotted correctly. (Each data point need not be labelled. A legend must be included. Deduct one mark if data plotted correctly but legend not included.)	1-3
Question incorrectly answered or not attempted or not all linkages circled.	0
Total	3



(b) The hydrides of Group 14 are non-polar molecules.

(i) Give the name of the shape of a Group 14 hydride molecule

or

Draw a diagram to illustrate the shape of a Group 14 hydride molecule. (1 mark)

Tetrahedral

Description	Marks
Tetrahedral (name or diagram)	1
Question incorrectly answered or not attempted.	0
Total	1

- (ii) Apply your understanding of intermolecular interactions to explain the steadily increasing boiling points of the Group 14 hydrides CH_4 , SiH_4 , GeH_4 and SnH_4 . (2 marks)

Molecular size/mass increases $\text{CH}_4 < \text{SiH}_4 < \text{GeH}_4 < \text{SnH}_4$. The dispersion forces between molecules increase in strength as the size of the molecule (and therefore number of electrons) increases. There is a corresponding increase in boiling point. This is why the boiling points of these hydrides increase in the way they do.

Description	Marks
Importance of dispersion forces recognised;	1
Relationship between molecular size/or number of electrons, dispersion forces and boiling point.	1
Question incorrectly answered or not attempted.	0
Total	2

- (c) The Group 15, 16 and 17 hydrides are polar molecules. Consider the Group 17 hydrides HCl , HBr and HI .

- (i) List HCl , HBr and HI in order of increasing polarity. (1 mark)



Description	Marks
Correct answer as above	1
Question incorrectly answered or not attempted.	0
Total	1

- (ii) Compare the trend in polarities of HCl , HBr and HI with the observed trend in their boiling points. Briefly explain your reasoning. (2 marks)

The boiling points increase in the order $\text{HCl} < \text{HBr} < \text{HI}$. This is not consistent with the order of polarity, which increases in the reverse order ($\text{HI} < \text{HBr} < \text{HCl}$). The reason for this (apparent) inconsistency is that, although these molecules are polar and there are polar forces acting between molecules, these are not the predominant forces influencing boiling point. The molecular size/mass (and therefore number of electrons) increases moving down the group in the same order as the boiling points, so clearly it is dispersion forces (which increase with molecular size/mass/number of electrons) influencing the boiling points.

Description	Marks
An answer recognising that the order of polarity is the reverse of the order of boiling points and recognising the importance of dispersion forces in influencing the boiling points.	2
Answer recognises order of polarity is reverse of the order of boiling points but does not provide explanation of this (i.e. does not recognise importance of dispersion forces).	1
Question incorrectly answered or not attempted.	0
Total	2

- (d) The first member of each hydride series (NH₃ in Group 15, H₂O in Group 16 and HF in Group 17) has a much higher boiling point than the next hydride in its series. Apply your understanding of intermolecular interactions to explain the anomalous boiling points of NH₃, H₂O and HF. (2 marks)

The higher boiling points of these hydrides can be accounted for by hydrogen bonding. Hydrogen bonding occurs between hydrogen and nitrogen, oxygen and fluorine atoms (i.e. between a hydrogen bonded to a nitrogen, oxygen or fluorine atom in one molecule and a nitrogen, oxygen or fluorine bonded to a hydrogen in another molecule). This is a strong dipole-dipole force and produces a strong intermolecular attraction – substantially stronger than the other types of interactions occurring between the other hydrides in each series.

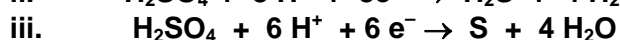
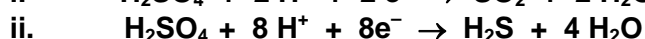
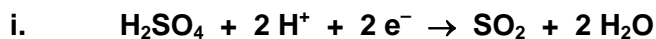
Description	Marks
Correct answer with recognising i) the presence of hydrogen bonding and ii) the strength of hydrogen bonding relative to dispersion/other intermolecular forces, thus the higher boiling points. (An explanation of hydrogen bonding is not necessary.)	2
An answer recognising the presence of hydrogen bonding, but not making a comparison between the strength of hydrogen bonding as an intermolecular force versus dispersion forces.	1
Question incorrectly answered or not attempted.	0
Total	2

Question 35**(5 marks)**

Concentrated sulfuric acid can behave as an oxidising agent. Depending upon conditions, it can react in one of three ways to form

- (i) sulfur dioxide gas;
- (ii) hydrogen sulfide gas; or
- (iii) elemental sulfur.

- (a) Write half-equations showing each of these three possible reactions. (3 marks)



SO₄²⁻ and HSO₄⁻ are also acceptable if correctly balanced

Description	Marks
1 mark for each correct equation for a possible total of 3 marks.	1-3
Question incorrectly answered or not attempted.	0
Total	3

- (b) Write half-equations and an overall redox equation for the reaction between concentrated sulfuric acid and hydrogen iodide to form hydrogen sulfide, iodine and water. (2 marks)

Reduction half-equation: $\text{H}_2\text{SO}_4 + 8 \text{H}^+ + 8 \text{e}^- \rightarrow \text{H}_2\text{S} + 4 \text{H}_2\text{O}$

Oxidation half-equation: $2 \text{HI} \rightarrow \text{I}_2 + 2 \text{H}^+ + 2\text{e}^-$ or $2\text{I}^- \rightarrow \text{I}_2 + 2\text{e}^-$

Overall redox-equation: $\text{H}_2\text{SO}_4 + 8 \text{HI} \rightarrow \text{H}_2\text{S} + 4 \text{I}_2 + 4 \text{H}_2\text{O}$

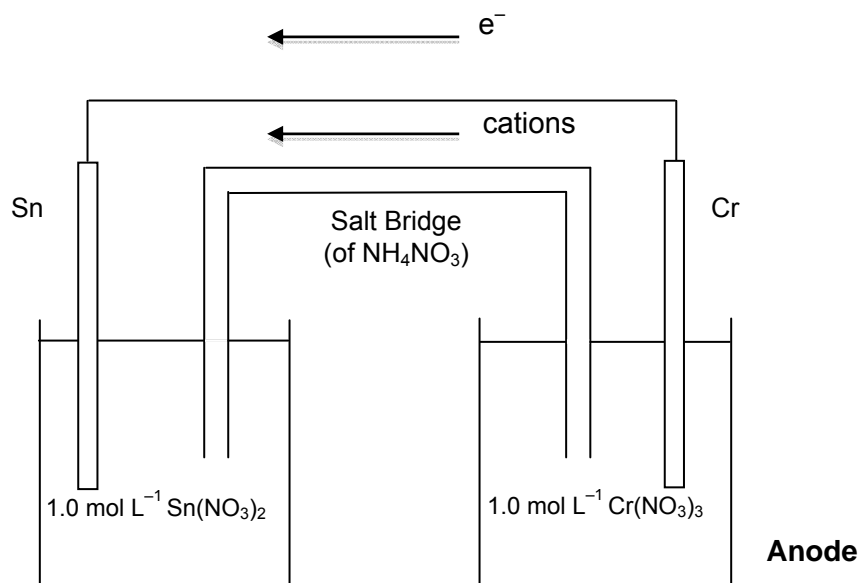
Full marks if incorrect equation from previous question used, but overall equation balanced correctly for that equation.

Description	Marks
1 mark each for oxidation half equation and overall redox equation.	2
Oxidation half or overall redox or both equations but incorrectly balanced.	1
Question incorrectly answered or not attempted.	0
Total	2

Question 36

(9 marks)

An electrochemical cell consists of a tin electrode in a solution of 1.0 mol L^{-1} tin(II) nitrate, to create a Sn/Sn^{2+} half cell, and a similarly constructed half cell composed of a chromium electrode in a solution of 1.0 mol L^{-1} chromium(III) nitrate. The two electrodes are joined by a piece of copper wire. A salt bridge, as shown in the diagram below, joins the two solutions.



- (a) On the diagram, label (3 marks)

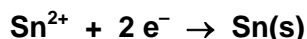
- the anode
- the direction of electron flow
- the direction of cation flow in the salt bridge.

Description	Marks
One mark for each correct answer for a possible total of 3 marks.	1-3
Question incorrectly answered or not attempted.	0
Total	3

- (b) Write the balanced anode and cathode reactions. (2 marks)
- (i) Anode:



- (ii) Cathode:



Description	Marks
1 mark for each correct equation for a possible total of two marks.	1-2
Question incorrectly answered or not attempted.	0
Total	2

- (c) Would sodium carbonate be suitable as a salt for the salt bridge? Explain. (2 marks)

No. A precipitate would form with Cr^{3+} and Sn^{2+} , preventing ion flow.

Description	Marks
Correct answer (<i>i.e.</i> no) and correct explanation.	2
Correct answer with no explanation or correct answer but incorrect explanation.	1
Question incorrectly answered or not attempted.	0
Total	2

- (d) Why does the rate of production of electrical current from an electrochemical cell decrease as it operates? (1 mark)

The rate of reaction decreases as reactants are consumed. Therefore, the rate of production of electrical current decreases.

Description	Marks
Correct answer as above.	1
Question incorrectly answered or not attempted.	0
Total	1

- (e) During the operation of an electrochemical cell, why is it important that the anode and cathode do not come into contact with each other? (1 mark)

If the anode and cathode come into contact with each other, the system will be short circuited and electrical current (and ions) will not flow. *i.e.* current will not be forced to flow through an external circuit.

Electron exchange only occurs at the metal surface

Description	Marks
Correct answer as above, or any statement that demonstrates an understanding of what will occur.	1
Question incorrectly answered or not attempted.	0
Total	1



Section Three: Extended answer

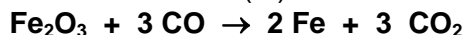
40% (80 Marks)

Question 37

(12 marks)

A blast furnace is a large furnace operated at very high temperatures to convert iron(III) oxide (in iron ore) to iron using carbon monoxide, which is itself converted to carbon dioxide during the process.

- (a) Write the equation for the reaction of iron(III) oxide with carbon monoxide. (1 mark)



Description	Marks
Correct answer as above. Equation must be balanced.	1
Question incorrectly answered or not attempted.	0
Total	1

- (b) Identify the oxidant and reductant in the above process. (1 mark)

Oxidant: Fe_2O_3

Reductant: CO

Description	Marks
Both oxidant and reductant correctly identified.	1
Question incorrectly answered or not attempted.	0
Total	1

- (c) 1.00 tonne of iron ore containing 96.5% iron(III) oxide is fed into the blast furnace with 2.70×10^6 L of carbon monoxide at 1.12 atm pressure and 1986°C .

Note: 1 tonne = 1×10^6 g

- (i) Determine the limiting reactant for this reaction. (4 marks)

$$n(\text{Fe}_2\text{O}_3) = \frac{0.965 \times 1000 \text{ kg tonne}^{-1} \times 1000 \text{ g kg}^{-1}}{M(\text{Fe}_2\text{O}_3)}$$

$$= \frac{9.65 \times 10^5 \text{ g}}{159.7 \text{ g mol}^{-1}}$$

$$= 6.04258 \times 10^3 \text{ mol Fe}_2\text{O}_3$$

$$PV = nRT \therefore n(\text{CO}) = \frac{1.12 \text{ atm} \times 101.3 \text{ kPa atm}^{-1} \times 2.70 \times 10^6 \text{ L}}{(8.315 \text{ J K}^{-1})(1986 + 273)}$$

$$= 1.6308 \times 10^4 \text{ mol CO}$$

$$n(\text{CO}) \text{ needed} = 3 \times n(\text{Fe}_2\text{O}_3) = 3 \times 6.042 \times 10^3 \text{ mol} = 1.8126 \times 10^4 \text{ mol CO needed}$$

mol CO available (1.6308×10^4) < mol CO needed (1.8126×10^4),
therefore CO is limiting reactant.

Description	Marks
1 mark each for $n(\text{CO})$ and $n(\text{Fe}_2\text{O}_3)$ calculated	1-2
Comparison of stoichiometric ratio to actual ratio.	1
CO is limiting reactant with any valid method for determining limiting reactant supporting this conclusion.	1
Question incorrectly answered or not attempted.	0
Total	4

- (ii) What mass of iron is theoretically produced in this reaction? (2 marks)

$$n(\text{Fe}) \text{ produced} = \frac{2}{3}n(\text{CO}) = \frac{2}{3}(1.6308 \times 10^4) = 1.0872 \times 10^4 \text{ mol}$$

$$n(\text{Fe}_2\text{O}_3) \text{ in excess} = 6.06 \times 10^2 \times M(\text{Fe}_2\text{O}_3) = 6.06 \times 10^2 \times 159.7 \\ = 9.6778 \times 10^4 \text{ g} = 9.68 \times 10^4 \text{ g Fe}_2\text{O}_3 \text{ in excess}$$

$$n(\text{Fe}) \text{ produced} = 1.0872 \times 10^4 \text{ mol} \times 55.85 \text{ g mol}^{-1} \\ = 6.07201 \times 10^5 \text{ mol} \\ = 6.07 \times 10^5 \text{ g}$$

Description	Marks
6.07 × 10 ⁵ g Fe produced (accept answers between 6.01 × 10 ⁵ g and 6.13 × 10 ⁵ g).	2
No. moles Fe calculated but mass not calculated or mass incorrectly calculated.	1
Question incorrectly answered or not attempted.	0
Total	2

- (iii) Calculate the mass of the reactant in excess. (3 marks)

$$n(\text{Fe}_2\text{O}_3) \text{ consumed} = \frac{1}{3}n(\text{CO}) \text{ consumed} = \frac{1}{3} 1.6308 \times 10^4 \\ = 5.436 \times 10^3 \text{ mol Fe}_2\text{O}_3 \text{ consumed}$$

$$n(\text{Fe}_2\text{O}_3) \text{ in excess} = (6.042 \times 10^3 - 5.436 \times 10^3) \text{ mol} = 6.06 \times 10^2 \text{ mol}$$

Description	Marks
9.68 × 10 ⁴ g Fe ₂ O ₃ in excess (accept answers between 9.58 × 10 ⁴ g and 9.78 × 10 ⁴ g).	3
n(Fe ₂ O ₃) in excess and mass not calculated or incorrectly calculated.	2
n(Fe ₂ O ₃) consumed.	1
Question incorrectly answered or not attempted.	0
Total	3

- (d) If 5.56 × 10⁻¹ tonne of iron is actually produced, what is the overall percentage yield of the process? (1 mark)

Description	Marks
% yield = $\frac{0.556}{0.607} \times 100 = 91.6\%$ 91.6 % (accept answers between 90.6 % and 92.6 %).	1
Question incorrectly answered or not attempted.	0
Total	1

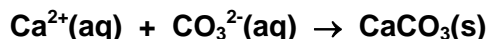
Follow through marks awarded if incorrect limiting reagent identified in first part of question.

Question 38

(13 marks)

Sodium carbonate is produced by the five-step Solvay process.

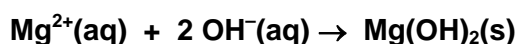
- (a) (i) Write the equation for the precipitation of the calcium ions in Step 1. Show only those species participating in the reaction. (1 mark)



N.B. One mark deducted in total if no state symbol for the solid given in parts (a) and/or (b)

Description	Marks
Correct answer as above	1
Question incorrectly answered or not attempted.	0
Total	1

- (ii) Write the equation for the precipitation of the magnesium ions in Step 1. Show only those species participating in the reaction. (1 mark)



Description	Marks
Correct answer as above	1
Question incorrectly answered or not attempted.	0
Total	1

- (b) (i) How many moles of calcium carbonate are consumed to produce one mole of sodium carbonate? (1 mark)

Description	Marks
2 [mol]	1
Question incorrectly answered or not attempted.	0
Total	1

- (ii) If a company plans to produce 1.00×10^4 tonnes of sodium carbonate each week, what mass of calcium carbonate will be needed if the overall process is 85.0% efficient?

Note: 1 tonne = 1×10^6 g (6 marks)

$$n(\text{Na}_2\text{CO}_3) = \frac{1.00 \times 10^4 \text{ tonne} \times 1000 \text{ kg tonne}^{-1} \times 1000 \text{ g kg}^{-1}}{M} = \frac{1 \times 10^{10} \text{ g}}{105.99 \text{ g mol}^{-1}}$$

$$= 9.4348523 \times 10^7 \text{ mol Na}_2\text{CO}_3$$

$$n(\text{CaCO}_3) = 2 \times n(\text{Na}_2\text{CO}_3) = 1.88697046 \times 10^8 \text{ mol CaCO}_3$$

$$\text{Theoretical mass CaCO}_3 = n \times M = 1.88697046 \times 10^8 \text{ mol} \times 100.09 \text{ g mol}^{-1}$$

$$= 1.888668742 \times 10^{10} \text{ g CaCO}_3$$

$$85\% \text{ efficient } \therefore 1.88697046 \times 10^{10} \text{ g} \times \frac{100}{85} = 2.22196 \times 10^{10} \text{ g CaCO}_3$$

Fast mark

Description	Marks
mass $\text{CaCO}_3 = 2.22 \times 10^{10} \text{ g CaCO}_3$ (accept answers between $2.20 \times 10^{10} \text{ g}$ and $2.4224 \times 10^{10} \text{ g}$). Full marks for any valid method of determining the concentration.	6
Question incorrectly answered or not attempted.	0
Total	6

Part mark

Description	Marks
Conversion of mass Na ₂ CO ₃ from tonnes to g;	1
Number of moles Na ₂ CO ₃ (9.43×10^7 mol [3 s.f.]);	1
Stoichiometric relationship (mol CaCO ₃ = 2 × mol Na ₂ CO ₃);	1
Number of moles CaCO ₃ (1.88×10^8 [3 s.f.]);	1
Theoretical mass CaCO ₃ (1.88×10^{10} [3 s.f.]);	1
Actual mass CaCO ₃ = 2.22×10^{10} g CaCO ₃ (accept answers between 2.20×10^{10} g and 2.42×10^{10} g).	1
Question incorrectly answered or not attempted.	0
Total	6

- (c) What volume of ammonia gas at 40.0°C and 1.00 atm pressure can be recovered if 8.50×10^3 tonnes of calcium oxide is obtained from Step 2? (4 marks)

$$n(\text{CaO}) = \frac{8.50 \times 10^3 \text{ tonne} \times 1000 \text{ kg tonne}^{-1} \times 1000 \text{ g kg}^{-1}}{56.08} = 1.51569 \times 10^8 \text{ mol}$$

$$n(\text{Ca(OH)}_2) = n(\text{CaO})$$

$$n(\text{NH}_3) = 2 \times n(\text{Ca(OH)}_2) = 2 \times 1.51569 \times 10^8 = 3.03 \times 10^8 \text{ mol}$$

$$PV = nRT \therefore V = \frac{nRT}{P} = \frac{3.0313837 \times 10^8 \text{ mol} \times 8.315 \text{ JK}^{-1} \text{ mol}^{-1} \times 313 \text{ K}}{101.3 \text{ kPa}} = 7.7882 \times 10^9$$

$$= 7.79 \times 10^9 \text{ L NH}_3$$

Fast mark

Description	Marks
volume = 7.79×10^9 L NH ₃ (accept answers between 7.71×10^9 L and 7.79×10^9 L) Full marks for any valid method of determining the concentration.	4
Question incorrectly answered or not attempted	0
Total	4

Part mark

Description	Marks
Number moles CaO (1.51×10^8 [3 s.f.]);	1
Number of moles NH ₃ (3.03×10^8 [3 s.f.]) (but volume not calculated or incorrectly calculated).	1
7.79×10^9 L NH ₃ (accept answers between 7.71×10^9 L and 7.87×10^9 L) (1 mark for converting °C to K, 1 mark for calculation).	1-2
Question incorrectly answered or not attempted.	0
Total	4

Question 39

(12 marks)

- (a) The figure below shows the graduations on the measuring cylinder used to collect the gas. Has the student recorded the volume data with an appropriate level of precision (an appropriate number of decimal places) in the table above? Explain.

(2 marks)

No. The student has recorded too many significant figures; the measuring cylinder is not graduated with the level of precision that allows measurement to one decimal place. Each graduation represents 2 mL, therefore can record to the nearest mL only (i.e. half way between a graduation).

Description	Marks
NO or YES	0
Explanation that supports the choice with 2 points	2
Question incorrectly answered or not attempted.	0
Total	2

- (b) Using all of the student's data, calculate the average number of moles of carbon dioxide in a 360 mL bottle of this brand of drink. (The vapour pressure of water may be ignored.)

(3 marks)

$$V_{\text{ave}}(\text{CO}_2) = 237.7 \text{ mL}$$

$$PV = nRT \quad \therefore n = \frac{PV}{RT} = \frac{(102.4 \text{ kPa})(0.2377 \text{ L})}{(8.31 \text{ J K}^{-1})(301 \text{ K})} = 9.73 \times 10^{-3} \text{ mol CO}_2$$

Description	Marks
$V_{\text{ave}}(\text{CO}_2) = 237.7 \text{ mL}$	1
$9.72 \times 10^{-3} \text{ mol CO}_2$ (accept answers between $9.62 \times 10^{-3} \text{ mol}$ and $9.81 \times 10^{-3} \text{ mol}$).	1-2
Question incorrectly answered or not attempted.	0
Total	3

The student measured the pH of the drink immediately upon opening and found it to be 3.19.

- (c) What is the hydrogen ion concentration of the drink?

(1 mark)

$$\text{pH} = -\log[\text{H}^+], [\text{H}^+] = 10^{-3.19} = 6.4565 \times 10^{-4} = 6.46 \times 10^{-4} \text{ mol L}^{-1} \text{ (3 s.f.)}$$

Description	Marks
$6.46 \times 10^{-4} \text{ mol L}^{-1}$	1
Question incorrectly answered or not attempted.	0
Total	1

- (d) How many moles of glucose are provided by the drink?

(2 marks)

$$n(\text{C}_6\text{H}_{12}\text{O}_6) = \frac{40 \text{ g}}{M} = \frac{40 \text{ g}}{180.156 \text{ g mol}^{-1}} = 2.2202 \times 10^{-1} \text{ mol C}_6\text{H}_{12}\text{O}_6$$

Description	Marks
$2.22 \times 10^{-1} \text{ mol C}_6\text{H}_{12}\text{O}_6$ (accept answers between $2.20 \times 10^{-1} \text{ mol}$ and $2.24 \times 10^{-1} \text{ mol}$);	2
$M(\text{C}_6\text{H}_{12}\text{O}_6) = 180.156 \text{ g mol}^{-1}$	1
Question incorrectly answered or not attempted.	0
Total	2

- (e) How much energy is released by the respiration of one mole of glucose? (2 marks)

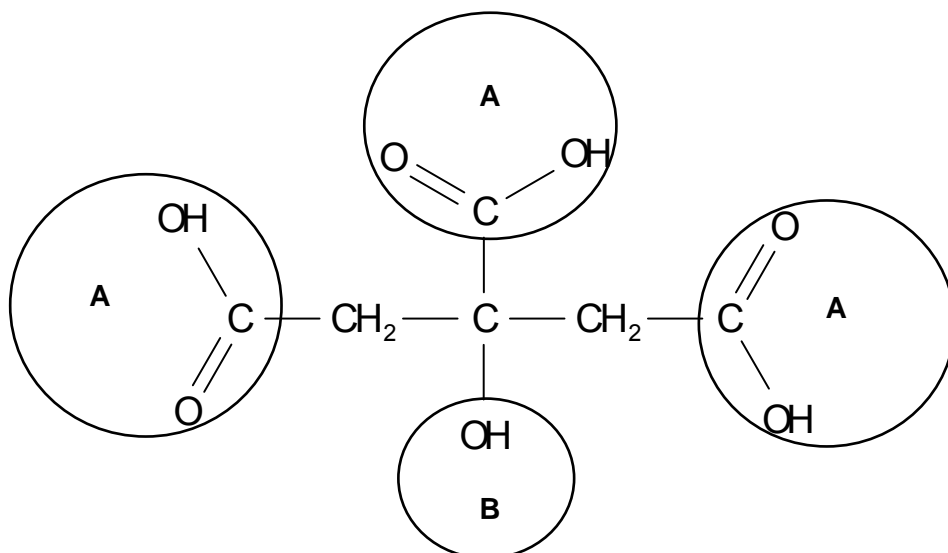
$$2.22 \times 10^{-1} \text{ mol glucose releases } 697 \text{ kJ}$$

$$1 \text{ mole glucose releases } x \text{ moles energy}$$

$$x = \frac{697 \times 1}{2.22 \times 10^{-1}} = 3.14 \times 10^3 \text{ kJ}$$

Description	Marks
$3.14 \times 10^3 \text{ kJ}$ (accept answers between $3.17 \times 10^3 \text{ kJ}$ and $3.11 \times 10^3 \text{ kJ}$);	2
$2.22 \times 10^{-1} \text{ mol glucose releases } 697 \text{ kJ}$;	1
Question incorrectly answered or not attempted.	0
Total	2

- (f) The label on the bottle lists food acid 330 as an ingredient. This is citric acid and has the structure given below:



- (i) Circle and label with the letter A **all** the carboxylic acid functional groups in this compound. (1 mark)

Description	Marks
All carboxylic acid groups circled and labelled.	1
Question incorrectly answered or not attempted.	0
Total	1

- (ii) Circle and label with the letter B **all** the alcohol functional groups in this compound. (1 mark)

Description	Marks
Single alcohol group circled and labelled.	1
Question incorrectly answered or not attempted.	0
Total	1

Question 40

(13 marks)

The manufacturer of the soft drink referred to in question 39 also produces a diet version of the drink, containing artificial sweetener. The quality assurance procedures of the soft drink manufacturer require that incoming batches of the artificial sweetener be analysed to ensure compliance with standards. A combustion analysis of a 1.021 g sample of sweetener produced 1.715 g CO₂, 0.2521 g H₂O, 0.2558 g NO₂ and 0.3568 g SO₂. The sweetener contains the elements C, H, O, N and S. Determine its empirical formula.

$$n(\text{C}) = n(\text{CO}_2) = \frac{1.715\text{g}}{44.01 \text{ g mol}^{-1}} = 3.8968 \times 10^{-2} \text{ mol}$$

$$n(\text{H}) = 2 \times n(\text{H}_2\text{O}) = 2 \times \frac{0.2521 \text{ g}}{18.016 \text{ g mol}^{-1}} = 2.799 \times 10^{-2} \text{ mol}$$

$$n(\text{N}) = n(\text{NO}_2) = \frac{0.2558\text{g}}{46.01 \text{ g mol}^{-1}} = 5.5597 \times 10^{-3} \text{ mol}$$

$$n(\text{S}) = n(\text{SO}_2) = \frac{0.3568\text{g}}{64.06 \text{ g mol}^{-1}} = 5.5698 \times 10^{-3} \text{ mol}$$

$$m(\text{C}) = 4.680 \times 10^{-1} \text{ g}$$

$$m(\text{H}) = 2.821 \times 10^{-2} \text{ g}$$

$$m(\text{N}) = 7.7891 \times 10^{-2} \text{ g}$$

$$m(\text{S}) = 1.786 \times 10^{-1} \text{ g}$$

$$m(\text{O}) = 1.021 - (4.680 \times 10^{-1} + 2.821 \times 10^{-2} + 7.7891 \times 10^{-2} + 1.786 \times 10^{-1}) \text{ g} = 0.2685 \text{ g}$$

$$n(\text{O}) = \frac{0.2685 \text{ g}}{16.00 \text{ g mol}^{-1}} = 1.6781 \times 10^{-2} \text{ mol}$$

Element	C	H	O	N	S
No. mol	3.868×10^{-2}	2.799×10^{-2}	1.6787×10^{-2}	5.560×10^{-3}	5.574×10^{-3}
Mole ratio	$\frac{3.868 \times 10^{-2}}{5.560 \times 10^{-3}}$	$\frac{2.799 \times 10^{-2}}{5.560 \times 10^{-3}}$	$\frac{1.6781 \times 10^{-2}}{5.560 \times 10^{-3}}$	$\frac{5.560 \times 10^{-3}}{5.560 \times 10^{-3}}$	$\frac{5.574 \times 10^{-3}}{5.560 \times 10^{-3}}$
	6.99	5.02	3.01	0.997	1
Round	7	5	3	1	1

Empirical formula is C₇H₅O₃NS

Fast mark

Description	Marks
Empirical formula = C ₇ H ₅ O ₃ NS Full marks for any valid method of determining the empirical formula.	13
Question incorrectly answered or not attempted.	0
Total	13

Part mark

Description	Cumulative marks
1 mark each for number of moles of C (3.868×10^{-2}), H (2.799×10^{-2}), N (5.560×10^{-3}) and S (5.574×10^{-3});	1-4
1 mark each for mass of C ($4.680 \times 10^{-1} \text{ g}$), H ($2.821 \times 10^{-2} \text{ g}$), N ($7.7891 \times 10^{-2} \text{ g}$), S ($1.786 \times 10^{-1} \text{ g}$) and O ($2.6846 \times 10^{-1} \text{ g}$);	5-9
1 mark for $n(\text{O}) = 1.6787 \times 10^{-2}$	10
1 mark for ratio	11
1 mark for rounding	12
1 mark for empirical formula	13
Total	13

Question 41

(20 marks)

A student set out to compare the effectiveness of a given quantity of two antacid preparations, one containing $\text{Mg}(\text{OH})_2$ and the other $\text{Al}(\text{OH})_3$, purchased from his local pharmacy. He titrated each of the preparations against a hydrochloric acid solution to determine how much acid each could neutralise, and to determine the concentration of active ingredient in each of the preparations. He first standardised the hydrochloric acid solution available in the laboratory against a primary standard, and chose anhydrous sodium carbonate as the primary standard.

- (a) Did the student select an appropriate primary standard? Explain. (2 marks)

Yes. Na_2CO_3 has the properties required of a primary standard: i) it can be obtained with a high degree of purity and has a known formula; ii) it undergoes reactions according to known chemical equations; iii) it is stable (to air); iv) it has a high formula mass; v) reacts rapidly with acids; vi) dissolves readily to give standard solutions

Description	Marks
Yes	0
Any two of the six listed properties of primary standards.	2
Question incorrectly answered or not attempted.	0
Total	2

The student prepared 1.00 L of a $0.0248 \text{ mol L}^{-1}$ Na_2CO_3 solution. He titrated three 25.0 mL aliquots of this solution against the HCl and found an average titre of 24.35 mL.

- (b) Calculate the concentration of the standardised HCl solution. (4 marks)



$$n(\text{Na}_2\text{CO}_3) = 0.025 \text{ L} \times 0.0248 \text{ mol L}^{-1} = 6.2 \times 10^{-4} \text{ mol Na}_2\text{CO}_3$$

$$n(\text{HCl}) = 2 \times 6.2 \times 10^{-4} = 1.24 \times 10^{-3} \text{ mol}$$

$$c(\text{HCl}) = \frac{1.24 \times 10^{-3} \text{ mol}}{0.02435 \text{ L}} = 0.05092 = 5.09 \times 10^{-2} \text{ mol L}^{-1}$$

Fast mark

Description	Marks
concentration = $5.09 \times 10^{-2} \text{ mol L}^{-1}$ Full marks for any valid method of determining the concentration.	4
Question incorrectly answered or not attempted.	0
Total	4

Part mark

Description	Marks
balanced reaction equation	1
$n(\text{Na}_2\text{CO}_3) = 6.20 \times 10^{-4} \text{ mol}$	1
$n(\text{HCl}) = 1.24 \times 10^{-3} \text{ mol}$	1
$5.09 \times 10^{-2} \text{ mol L}^{-1}$ (accept answers between $5.04 \times 10^{-2} \text{ mol L}^{-1}$ and $5.14 \times 10^{-2} \text{ mol L}^{-1}$)	1
Question incorrectly answered or not attempted.	0
Total	4

The antacid suspension was thoroughly shaken and 20.0 g was weighed out and transferred to a 250.0 mL volumetric flask, which was made up to the mark with deionised water and shaken vigorously. 10.0 mL aliquots of this diluted suspension were transferred for titration, using an appropriate indicator, to conical flasks. The titration data for the $Al(OH)_3$ suspension are shown in the table below.

Titration Result	Volume HCl (mL)			
	Trials			
	1	2	3	4
Final reading	23.20	44.96	22.12	42.18
Initial reading	0.58	22.98	0.20	20.26
Titre	22.62	21.98	21.92	21.92

- (c) Complete the table and determine the average titre value for the HCl solution. (1 mark)

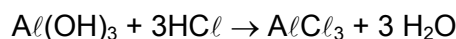
21.94 mL

Description	Marks
21.94 mL	1
Question incorrectly answered or not attempted.	0
Total	1

- (d) The densities, in grams per millilitre, of the original antacid preparations are given below.

Suspension	Density (g mL ⁻¹)
Mg(OH) ₂	1.06
Al(OH) ₃	1.12

- (i) Calculate the concentration, in mg per mL, of Al(OH)₃ in the original Al(OH)₃ suspension. (7 marks)



$$n(HCl) = 0.05092 \text{ mol L}^{-1} \times 0.02194 \text{ L} = 1.1171848 \times 10^{-3} \text{ mol}$$

$$n(Al(OH)_3) = \frac{1.1171848 \times 10^{-3} \text{ mol}}{3} = 3.723949 \times 10^{-4} \text{ mol}$$

$$\begin{array}{l} 3.723949 \times 10^{-4} \text{ mol in 10 mL} \\ \times \qquad \qquad \qquad \text{mol in 250 mL} \end{array}$$

$$x = \frac{3.723949 \times 10^{-4} \times 250}{10} = 9.3098733 \times 10^{-3} \text{ mol in 250 mL}$$

i.e. $9.3098733 \times 10^{-3} \text{ mol Al(OH)}_3$ in 20 g of antacid

$$\text{Volume of 20 g suspension} = m/\rho = 20.0 \text{ g}/1.12 \text{ g mL}^{-1} = 17.8571 \text{ mL}$$

$$\begin{aligned} \text{Mass (Al(OH)}_3) \text{ in 17.8571 mL} &= 9.3098733 \times 10^{-3} \text{ mol} \times M(\text{Al(OH)}_3) \\ &= 9.3098733 \times 10^{-3} \text{ mol} \times 78.004 \text{ g mol}^{-1} \\ &= 0.72607 \text{ g} \end{aligned}$$

$$\text{Mass in 1 mL} = 0.72607 \text{ g}/17.8571 \text{ mL} = 40.6679 \text{ mg mL}^{-1} = 40.7 \text{ mg mL}^{-1} \text{ (3 s.f.)}$$

Fast mark

Description	Marks
mass in 1 mL = 40.7 mg mL ⁻¹ Full marks for any valid method of determining the mass in 1 mL.	7
Question incorrectly answered or not attempted	0
Total	7

Part mark

Description	Marks
Balanced equation	1
n(HCl) (1.12 × 10 ⁻³) (3 s.f.)	1
n(Al(OH) ₃) (3.72 × 10 ⁻⁴) (3 s.f.)	1
n(Al(OH) ₃) in 20 g antacid (9.31 × 10 ⁻³ mol) (3 s.f.)	1
vol. 20 g antacid suspension (17.9 mL) (3 s.f.)	1
Calculation of mass in 17.9 mL (7.26 × 10 ⁻¹ g)	1
Calculation of mass in 1 mL 40.7 mg mL ⁻¹ (accept answers between 40.3 mg mL ⁻¹ and 41.11 mg mL ⁻¹).	1
Question incorrectly answered or not attempted.	0
Total	7

- (ii) From his titration of the Mg(OH)₂ diluted suspension, the student found the mass of Mg(OH)₂ in the 250 mL **diluted** suspension to be 1.13 g. Determine the concentration of Mg(OH)₂ in the original **undiluted** suspension and express your answer in mg per mL. (2 marks)

Volume of 20 g suspension = $m/\rho = 20.0 \text{ g}/1.06 \text{ g mL}^{-1} = 18.8679 \text{ mL}$
i.e. 1.13 g Mg(OH)₂ in 18.8679 mL antacid suspension

Mass in 1 mL = 1.13 g/18.8679 mL = 59.9 mg mL⁻¹

Description	Marks
Vol. of 20 g antacid suspension (18.9 mL) (3 s.f.) and calculation of mass in 18.9 mL.	1
59.9 mg mL⁻¹ (accept answers between 59.3 mg mL ⁻¹ and 60.5 mg mL ⁻¹).	1
Question incorrectly answered or not attempted.	0
Total	2

- (e) The directions for use on each of the antacid preparations suggest a standard adult dose of 10.0 mL. Which of the preparations would be more effective (neutralise the most HCl) per standard dose? Show your working. (4 marks)

10 mL Mg(OH)₂ antacid contains

$$m(\text{Mg}(\text{OH})_2) = 59.9 \text{ mg mL}^{-1} \times 10 \text{ mL} = 599 \text{ mg} = 0.599 \text{ g Mg}(\text{OH})_2$$

$$n(\text{Mg}(\text{OH})_2) = 0.599/58.326 = 0.0102699 \text{ mol Mg}(\text{OH})_2$$

Mg(OH)₂ neutralises 2 mol of HCl per mole = $2 \times 1.02699 \times 10^{-2} \text{ mol} = 2.05 \times 10^{-2} \text{ mol HCl}$
 neutralised

10 mL $\text{Al}(\text{OH})_3$ antacid contains

$$m(\text{Al}(\text{OH})_3) = 40.7 \text{ mg mL}^{-1} \times 10 \text{ mL} = 407 \text{ mg} = 0.407 \text{ g Al}(\text{OH})_3$$

$$n(\text{Al}(\text{OH})_3) = 0.407/78.004 = 0.00521768 \text{ mol Al}(\text{OH})_3$$

$\text{Al}(\text{OH})_3$ neutralises 3 mol of HCl per mole = $3 \times 5.218 \times 10^{-3} \text{ mol} = 1.57 \times 10^{-2} \text{ mol HCl}$ neutralised

$\text{Mg}(\text{OH})_2$ will be more effective

There are alternative but equally valid methods for showing this. Please look for appropriate logic.

Follow through marks for this question if incorrect concentrations calculated for $\text{Mg}(\text{OH})_2$ and $\text{Al}(\text{OH})_3$.

Fast mark

Description	Marks
Correct answer (<i>i.e.</i> $\text{Mg}(\text{OH})_2$) and working (any valid method <i>e.g.</i> candidate may do a calculation based on 1 mL of antacid rather than 10 mL).	4

Part mark

Description	Marks
1 mark each for number of moles of HCl neutralised by each antacid	2
1 mark each for $n(\text{Mg}(\text{OH})_2)$ and $n(\text{Al}(\text{OH})_3)$ in 10 mL of each of the antacids.	1
	1
Question incorrectly answered or not attempted.	0
Total	4

Question 42

(10 marks)

Nitric acid is manufactured by the Ostwald process.

Use your understanding of reaction rates and chemical equilibrium to explain the conditions used in the Ostwald process. Your answer should include at least three (3) paragraphs, and should be 1 to 1½ pages in length.

Description	Marks
<p>Answer format:</p> <ul style="list-style-type: none">This question asks the candidate to explain the relationship between process parameters and chemical models and theories, therefore it is implied that a descriptive extended answer will be written. A number of paragraphs could reasonably be expected.<u>Marks should be awarded for relevant chemical</u> content and the ability to write coherent sentences.Diagrams, graphs and equations may be used to help where appropriate.	-1 for outstanding answer in dot points

Description	Marks
<p>Content: The candidate must give an expansive answer. For example, a statement that a reaction rate increases with increasing temperature should be supported by an explanation of why this is the case. A student must address temperature, pressure and catalyst in step 1 (6 marks) Student must address temperature in step 2 (2 marks) Student must address water drops in step 3(2 marks) Each condition must be addressed from a rate and equilibrium perspective</p> <p>The following may be included as explanations for the chosen conditions.</p> $4 \text{NH}_3(\text{g}) + 5 \text{O}_2(\text{g}) \rightleftharpoons 4 \text{NO}(\text{g}) + 6 \text{H}_2\text{O}(\text{g}) + \text{heat}$ <ul style="list-style-type: none">The high temperature will favour the reverse reaction (as the forward reaction is exothermic), but influences the rate of the reaction (<i>i.e.</i> increases the rate).	

Description	Marks
<ul style="list-style-type: none"> Le Chatelier's principle will predict that the reverse reaction will be favoured. The rate of both forward and reverse reactions will be increased if temperature is increased, but the reverse reaction will be favoured as equilibrium is re-established. A greater fraction of molecules will possess the activation energy at higher temperature; therefore rates of forward and reverse reactions increase. There will be a greater frequency of collisions at increased temperatures, thus increasing the chance of a successful collision (i.e. a collision that results in a reaction). The pressure (10 atm) would also favour the reverse reaction, and again would be applied to influence reaction rate (effectively increases the concentration of reactants). The increased pressure leads to a greater frequency of collisions and increased chance of successful collisions (as above). The presence of a catalyst also improves the rate of attainment of equilibrium. A catalyst provides an alternative reaction pathway with an activation energy that is lower than the uncatalysed reaction. A greater fraction of collisions will result in a reaction as a greater fraction of particles will have the (lower) activation energy. Some candidates may note that the reaction must be very slow at ambient temperature and pressure, as both of these parameters are increased in this process before an acceptable reaction rate is realised. 	
$2 \text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{NO}_2(\text{g}) + \text{heat}$ <ul style="list-style-type: none"> Oxidation of NO to NO₂ at low (relative to that used in first step) temperature (50°C); comparatively low temperature favours the forward, exothermic reaction, leading to a high reaction yield. Le Chatelier's principle predicts that the system will shift to counteract the low temperature; forward reaction is therefore favoured. 	1-6
<p>Candidates may include a discussion of reaction rates, noting that reaction rate may decrease at this lowered temperature (and with a discussion, as above, of the models that explain the relationship between reaction rate and temperature). Students may also mention that perhaps the reaction is reasonably fast at ambient conditions.</p>	7-8
$4 \text{NO}_2(\text{g}) + \text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\ell) \rightleftharpoons 4 \text{HNO}_3(\text{aq})$ <ul style="list-style-type: none"> Use of sprinklers to introduce the water in the above step increases the rate of the reaction, as the surface area (state of subdivision) of one of the reactants (water) is increased (relative to 'bulk' water). An increase in the surface area of a reactant allows more of it to be exposed to collisions with particles of the other reactant, thus increasing the rate of reaction. 	9-10
Question incorrectly answered or not attempted	0
Total	10

End of questions