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SECTION TWO – Short answers **35% [70 marks]**

This section has 10 questions. Answer all questions in the spaces provided.

Suggested working time: 60 minutes

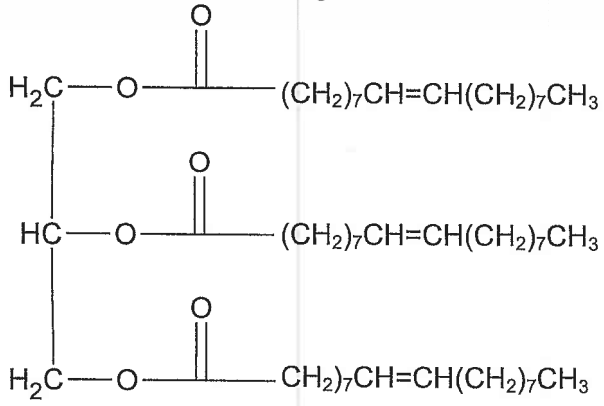
When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to three significant figures and include appropriate units where applicable.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Question 26 **(5 marks)**

Biodiesel is a fuel that can be synthesised from natural oils and fats. The molecule below is a triglyceride present in vegetable oil that can be used for this process.



Biodiesel can be synthesised using a base-catalysed reaction with methanol. The triglyceride breaks down into fatty acids and these undergo esterification with methanol to form methyl esters. The methylesters are the main components of biodiesel.

(a) State why the compound above is described as an unsaturated oil. (1 mark)

Contains C=C Double Bonds

(b) Draw the structural formula of the methyl ester formed from the section of the molecule circled in the above diagram. (1 mark)

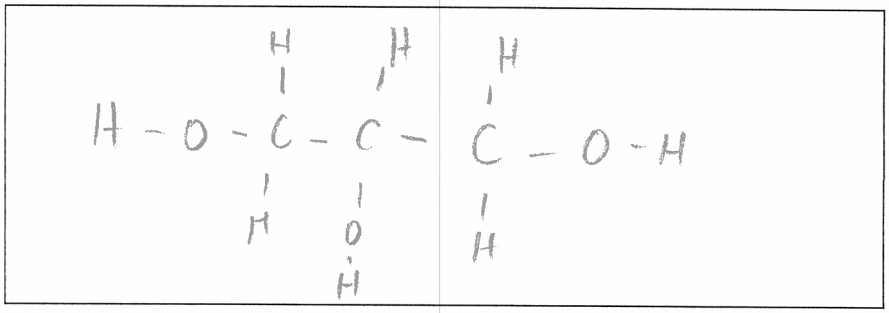
10 Circle so all given 1 mark

$CH_3OCO-(CH_2)_7-CH=CH-(CH_2)_7-CH_3$.

(c) Name a catalyst that can be used in this process. (1 mark)

Sodium / Potassium Hydroxide.

(d) As well as the methyl esters (the biodiesel), there is one other product of this reaction. Name and draw the structural formula of this product. (2 marks)



Name glycerol

Question 27 **(5 marks)**

(a) Calculate the pH of a solution of 0.500 mol L^{-1} hydrochloric acid? (2 marks)

$c(H^+) = 0.500 \text{ mol/L}$ (1)

$pH = -\log(H^+)$

$= -\log(0.5) = 0.69$ ✓ (1)

(b) A student was asked to dilute 50.0 mL of this solution to produce a solution of hydrochloric acid with a pH of 2.00. Calculate the volume of distilled water that she would need to add.

(3 marks)

$c(H^+) = 10^{-2.00} = 0.01 \text{ mol L}^{-1}$ (1)

$C_1V_1 = C_2V_2$

$0.05 \times 0.05 = 0.01 \times V_2$

$V_2 = 250 \text{ mL}$ (1)

Required to add $250 - 30 = \underline{200 \text{ or } 2.00 \times 10^2 \text{ mL}}$ (1)

Question 28 **(8 marks)**

Although many new secondary cells have been developed, isolated houses still use the lead accumulator battery to store solar energy generated by photovoltaic cells. The discharge reaction of the lead accumulator cell is given below.

$$Pb_{(s)} + PbO_{2(s)} + 2H_2SO_{4(aq)} \rightarrow 2PbSO_{4(s)} + 2H_2O(l) \qquad E^\circ = 2.05\ V$$

(a) Which substance is undergoing oxidation in the above reaction?

$Pb_{(s)}$ (1 mark)

(b) Write the half-reaction for the reduction.

$PbO_{2(s)} + 4H^+_{(aq)} + SO_4^{2-}{}_{(aq)} + 2e^-_{(aq)} \rightleftarrows PbSO_{4(s)} + 2H_2O_{(l)}$ (2 marks)

(c) In order to generate the 12 V used in many solar-powered houses, how many cells must be connected in series?

6 (1 mark)

(d) If the cell is discharging, describe what is happening at the lead electrode.

Lead sulfate is deposited. (1 mark)

(e) Write the oxidation half-reaction occurring during recharging of the battery.

$2PbSO_{4(s)} + 2H_2O_{(l)} \rightleftarrows 2PbO_{2(s)} + 4H^+_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 2e^-$ (2 marks)

(f) What will be happening to the pH of the battery during recharging?

pH will decrease (1 mark)

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Question 29 **(8 marks)**

Consider the equation for the following reversible chemical system. Gaseous hydrogen and bromine were injected into an empty flask and allowed to establish equilibrium at 25 °C.

$$H_2(g) + Br_2(g) \rightleftharpoons 2\,HBr(g) \qquad \Delta H = -104 \text{ kJ mol}^{-1}$$

The activation energy for this reaction is 188 kJ mol $^{-1}$. The value of K_c for this reaction at 25 °C is 2.0×10^{19}.

(a) Does this question refer to an open or closed system? Explain. (2 marks)

- closed (1)
- question states that equilibrium was established (1)

(b) What information does the value of K_c provide about the; (2 marks)

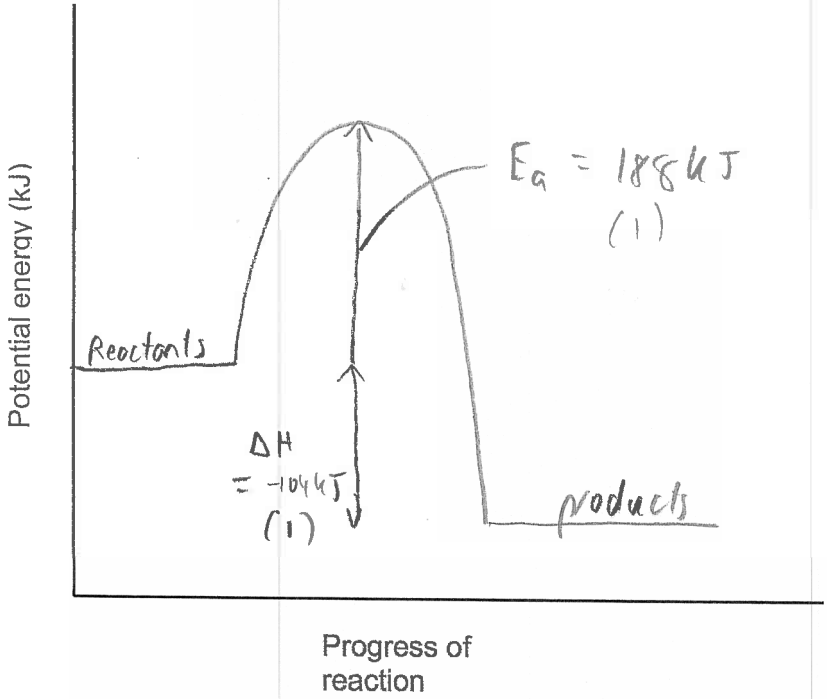
(i) equilibrium position?

strongly favours product at 25°C (1)

(ii) rate of reaction?

nothing (1)

(c) Draw an energy profile diagram for this reaction. Label the activation energy and the enthalpy change. (4 marks)



(1) exothermic

(1) proportion of ΔH / E_A is approx.

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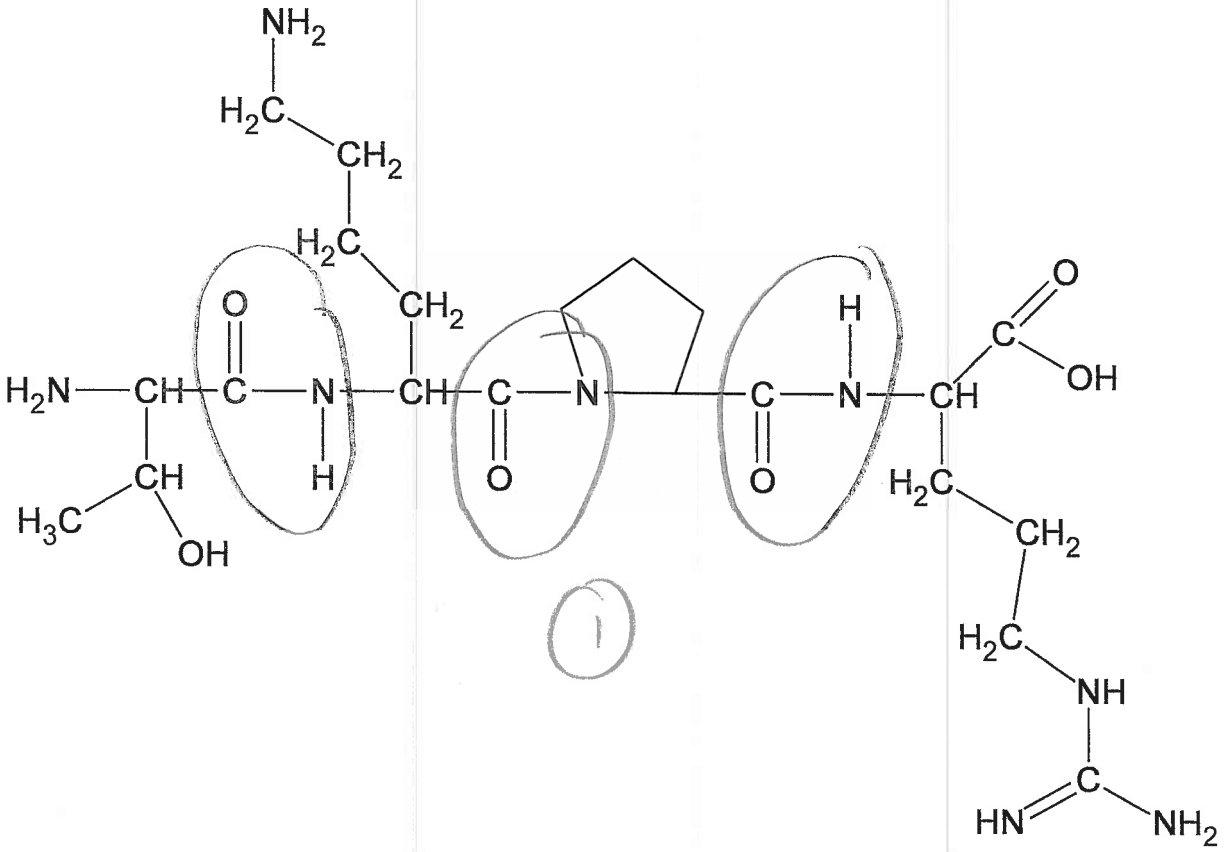
Question 30 **(8 marks)**

Tuftsin is a tetrapeptide (a molecule consisting of four amino acid residues) which is produced by the spleen. It has been found that people with low levels of tuftsin in their bodies are susceptible to repeated frequent infections of the skin, lymph nodes and lungs. Low tuftsin levels can be inherited genetically or can be the result of a spleen operation. The tuftsin tetrapeptide molecule is shown below.



(a) On the diagram above, circle the peptide bonds and then complete the primary sequence of tuftsin below using the standard three letter abbreviations. (3 marks)

thr – lys – pro – arg (2)

One medical study has shown that some people have a genetic mutation which causes the lysine residue in tuftsin to be replaced with a glutamic acid residue instead.

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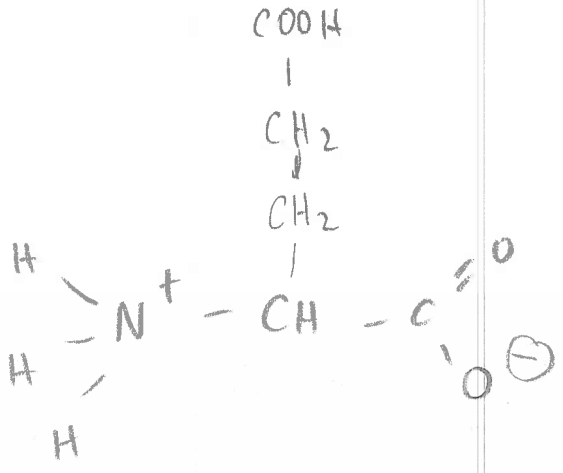
(b) Draw a diagram of glutamic acid in zwitterion form and use this example to explain what a zwitterion is. (2 marks)



(1)

Zwitteon is a species with both a positive and negative charge, however overall charge of species remains zero (1)

In the mutated form of tuftsin, the primary sequence of the tetrapeptide has been changed, altering its function.

(c) In general terms, explain how alteration of the primary sequence of a protein can affect its secondary and tertiary structures. (3 marks)

- Secondary structures such as α-helices and β sheets form due to H-bonding between amino acid chains
- the various tertiary structures (e.g. Disulfide bridges) also form due to amino acid side chain interactions
- alteration of primary structure means different amino acids with different side chains are incorporated, therefore the same secondary and tertiary structures will not be able to form.

Question 31 **(6 marks)**

Tin is a metallic element located in Group 14 of the periodic table. It is used to make many different alloys such as bronze and solder, as well as finding application in the plating of steel to produce 'tin cans' for storage.

A chemistry student had 1.0 mol L^{-1} solutions of the following four substances;

$Ni(NO_3)_2$ $Zn(NO_3)_2$ $Pb(NO_3)_2$ $Mg(NO_3)_2$

(a) Which of these solutions could **not** be stored in a tin container? Explain your answer using a relevant chemical equation. (3 marks)

- $Pb(NO_3)_2$ (1)
- metal displacement would occur as Pb^{2+} has higher E° value than Sn^{2+} (1)
- $Pb^{2+}_{(aq)} + Sn_{(s)} \rightarrow Pb_{(s)} + Sn^{2+}_{(aq)}$ (1)

When tin metal is placed in an acidified solution containing the weak acid hydrogen chromate ($HCrO_4^-$) a deep green solution containing chromium(III) ions is formed, and the tin metal dissolves producing tin(II) ions.

(b) Write the oxidation and reduction half-equations and the overall redox equation for this reaction. (3 marks)

Oxidation half-equation	$Sn \rightarrow Sn^{2+} + 2e^-$ (1)
Reduction half-equation	$HCrO_4^- + 7H^+ + 3e^- \rightarrow Cr^{3+} + 4H_2O$ (1)
Overall redox equation	$2HCrO_4^- + 14H^+ + 3Sn \rightarrow 2Cr^{3+} + 3Sn^{2+} + 8H_2O$ (1)

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Question 32 **(8 marks)**

A variety of substances are listed below. Use these substances to answer the following questions. Not all substances must be used, but each substance can only be used once.

Na_2CO_3	Na	H_3PO_4	NaCl
Au	H_2SO_4	Na_3PO_4	Cu
$CuCl_2$	Na_2SO_4	Ni	

(a) Which two substances could be mixed together to form a buffer? (1 mark)

H_3PO_4 + Na_3PO_4

(b) Which two substances could be mixed together in water to form a green precipitate? (1 mark)

$CuCl_2$ + Na_2CO_3

or (Na_3PO_4) if Q a) was wrong

(c) Which substance could be classified as a 'basic salt'? Write a hydrolysis equation to support your answer. (2 marks)

Na_2SO_4 (1)

$SO_4^{2-} + H_2O \rightleftharpoons HSO_4^- + OH^-$ (1)

or (Na_2CO_3 / Na_3PO_4 if part a/b are wrong)

(d) Which substance would react with acid to produce hydrogen gas? (1 mark)

Ni (Na if part c is wrong)

(e) Which substance would react with water to produce hydrogen gas? (1 mark)

Na

(f) Which metal would displace the silver ions from a solution of silver nitrate? Write the equation for this reaction including only those species that react. (2 marks)

Cu (1)

$Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$ (1)

or Ni/Na is part d/e is wrong.

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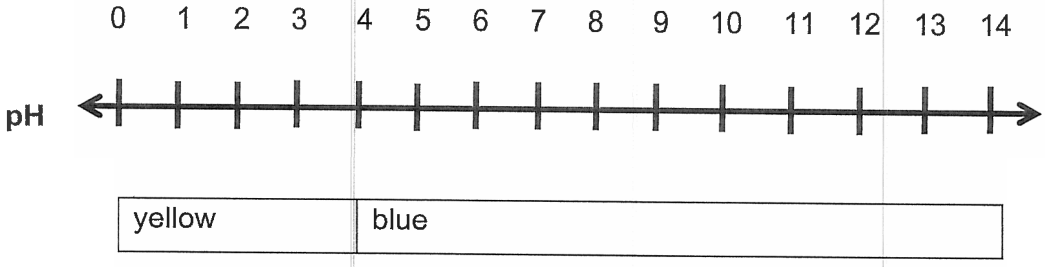
Question 33 **(6 Marks)**

Bromocresol green is an indicator that can be used in biological laboratories when growing microorganisms, as well as for titrations or as a tracking dye. It displays two colours, yellow and blue, as shown in the diagram below.



(a) What colour would the following aqueous solutions turn, if a few drops of bromocresol green was added to each? Explain your answers, using a chemical equation where appropriate.
(4 marks)

Solution	Colour	Chemical equation
$Mg(NO_3)_2(aq)$	blue (1)	NR (1)
$Na_2SO_3(aq)$	blue (1)	$SO_3^{2-} + H_2O \rightleftharpoons HSO_3^- + OH^-$

A standardised solution of hydrochloric acid, HCl (aq), was being used in a titration with a sodium hydrogencarbonate solution, $NaHCO_3$ (aq), of unknown concentration.

(b) Would bromocresol green be an appropriate indicator for this titration? Justify your answer.
(2 marks)

- yes (1)

- equivalence point would be acidic due to $(O_2 gas)$ production, so indicator with acidic end point is needed (1)

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Question 34 **(8 marks)**

The final step in the production of methanol is shown in the equation below.

$$CO\,(g) + 2\,H_2\,(g) \leftrightarrows CH_3OH\,(g) + \text{heat}$$

This reaction is carried out at a high pressure of 50-100 atmospheres, using a $Cu/ZnO/Al_2O_3$ catalyst.

(a) Explain how the use of high pressure will affect the reaction rate. (2 marks)

- increase reaction rate (1)
- high pressure results in greater N° of collisions (1)

(b) Explain how the use of high pressure will affect the yield of methanol. (3 marks)

- increase the yield (1)
- high pressure will increase conc of gas particles (1)
- therefore forward reaction will be favoured to decrease number of gas molecules (1)

(c) What conditions of temperature would increase the yield of methanol? (1 mark)

low temp

(d) State two (2) benefits of using a catalyst in an industrial process. (2 marks)

- Increase reaction rate (1)
- saves money (only small amount needed + can be re-used) (1)

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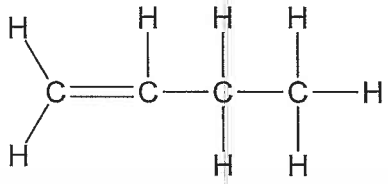
Question 35 **(9 marks)**

But-2-ene is produced from crude oil and its main use is in the production of petrol.

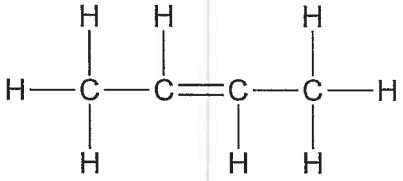
(a) Explain why but-2-ene exhibits *cis-trans* (geometric) isomerism while but-1-ene does not.

(3 marks)

but-1-ene



but-2-ene



* but-1-ene has two identical H atoms attached to C_1, therefore if they are swapped no alternate isomer is formed (1)

* but-2-ene has two different groups attached to C_2 + C_3. (1)
therefore allowing trans and cis isomers (1)

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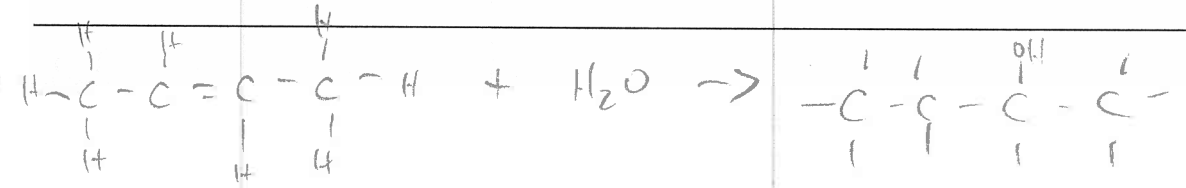
A chemistry fact sheet about but-2-ene stated, *"But-2-ene is often used to produce the solvent butanone via hydration to butan-2-ol followed by oxidation"*.

(b) Elaborate on this statement, by giving a brief description of the reaction processes involved and using chemical equations to illustrate the reaction sequence described. (6 marks)

* hydration of but-2-ene refers to addition reaction with H_2O to form 2-butanol (1)



(1)

* Oxidation then requires reaction with acidified MnO_4^- / $Cr_2O_7^{2-}$ (1)
* this results in -OH group being oxidised to a =O carbonyl group forming butanone (1)
* $CH_3CH_2CHOHCH_3 \rightarrow CH_3CH_2COCH_3 + 2H^+ + 2e^-$ (1)
* $3CH_3CH_2CHOHCH_3 + Cr_2O_7^{2-} + 8H^+ \rightarrow 3CH_3CH_2COCH_3 + 2Cr^{3+} + 7H_2O$

or (2)

$5CH_3CH_2CHOCH_3 + 2MnO_4^- + 6H^+ \rightarrow 5CH_3CH_2COCH_3 + 2Mn^{2+} + 8H_2O$

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Section Three: Extended answer **40% (80 marks)**

This section contains **five (5)** questions. You must answer **all** questions. Write your answers in the spaces provided below.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression. Lists or dot points are unlikely to gain full marks.

Final answers to calculations should be expressed to the appropriate number of significant figures.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 70 minutes.

Question 36 **(22 marks)**

Aspartic acid ($C_4H_7O_4N$) is a diprotic α-amino acid. Aspartic acid has solubility of 4.5 g L^{-1} at 25 °C and a Ka value of 1.26 x 10^{-4}. Aspartic acid increases resistance to fatigue and is often found in food supplements, especially those used by athletes and body builders.

A chemist was asked to analyse the contents of a food supplement to check the manufacturer's claims that it contained 97.0% aspartic acid by mass. To check this claim, the following experiment was carried out. (It can be assumed that aspartic acid is the only active ingredient in the supplement)

1. 1.546 g of the supplement powder was weighed and dissolved in warmed distilled water in a beaker.
2. The solution was transferred to a 500.0 mL volumetric flask and was made up to the mark with distilled water.
3. 25.00 mL aliquots of the resulting solution were titrated, using phenolphthalein indicator, against 0.0570 mol L^{-1} sodium hydroxide solution.

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The results obtained are shown below.

Burette readings	Titrations			
(mL)	1	2	3	4
Final Volume	20.30	40.05	19.80	39.50
Initial Volume	0.00	20.30	0.00	19.80
Titration Volume (Titre)				

(a) Calculate the percentage purity of the supplement. (7 marks)

average titre = 19.75 mL = 0.01975 L (1)

$n(NaOH) = CV = 0.0570 \times 0.01975 = 1.1257 \times 10^{-3}$ (1)

$n(\text{Aspatic Acid in 25 mL}) = (\frac{1}{2}) \times n(NaOH) = \frac{1}{2} \times 1.1257 \times 10^{-3}$

$= 5.6287 \times 10^{-4}$ mol (1)

$n(\text{Aspatic Acid in 500 mL}) = \frac{500}{25} \times 5.6287 \times 10^{-4}$

$= 0.011257$ mol (1)

$M(\text{Aspatic Acid}) = nM = 0.011257 \times 133.106$

$= 1.4989$ (1)

% purity $= \frac{1.498}{1.546} \times 100 = 96.9\%$ (1)

3 sig figs (1)

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(b) Consider the method used in this experiment.

(i) In Step 1, suggest a reason why the distilled water was warmed. (1 mark)

to improve solubility

(ii) In Step 2, the solution was transferred from a beaker into the volumetric flask. Explain why this process could be a source of systematic error. (2 marks)

1. if some solution was left in the beaker the conc of the solution would be weaker than it should be (1)

2. Therefore the values for the amount of aspartic acid will always be less than the actual value (1)

(iii) Phenolphthalein changes colour at between pH 9 –10. Methyl orange changes colour at between pH 4 –5. In Step 3, predict and explain the effect on the final result if methyl orange was used as the indicator instead of phenolphthalein. (3 marks)

- the end point will be observed before the equivalence point (1)
- Vol of NaOH added will be lower than expected value (1)
- the amount of aspartic acid will be less than actual value (1)

(c) (i) Due to the low solubility of the aspartic acid, it was suggested to the students that they use a 'back titration'. This would require the addition of a known amount of sodium hydroxide (in excess) to the aspartic acid and the titration of the unreacted hydroxide against a standard solution of acid.

Sodium hydroxide solution with a concentration of 0.978 mol L-1 is used and there is a standard solution of 0.100 mol L-1 hydrochloric acid available.

There are three pipettes to choose from (20.00 mL, 25.00 mL or 50.00 mL) for adding sodium hydroxide solution to the 1.546 g of the supplement powder.

Calculate which volume pipette the student should use to add the sodium hydroxide in order to get a titration volume (titre) of approximately 20 mL of the hydrochloric acid.

(7 marks)

Assume sample is 97% pure

$m(\text{aspartic acid}) = \frac{97}{100} \times 1.546 = 1.4996\text{g}$ (1)

$n(\text{aspartic acid})_{total} = \frac{1.4996}{133.106} = 1.127 \times 10^{-2}\text{ mol}$ (1)

$n(\text{NaOH})_{\text{to react with aspartic}} = 2 \times n(\text{aspartic acid}) = 2 \times 1.127 \times 10^{-2} = 0.02253$ (1)

$n(\text{NaOH})_{\text{excess to react with HCl}} = CV = 0.1 \times 0.02 = 0.002\text{ mol}$ (1)

$n(\text{NaOH})_{\text{total required}} = 0.02253 + 0.002 = 0.02453\text{ mol}$ (1)

$V(\text{NaOH})_{\text{total required}} = n/c = 0.02453/0.978 = 0.02508\text{ L}$ (1)

∴ 25 mL pipette is needed (1)

(ii) Explain why having a titre of less than 20 mL could increase the random error in this experiment. (2 marks)

- the uncertainty/error when reading a burette is fixed (1)
- the lower the volume measured in the burette the more significant the error becomes (1)

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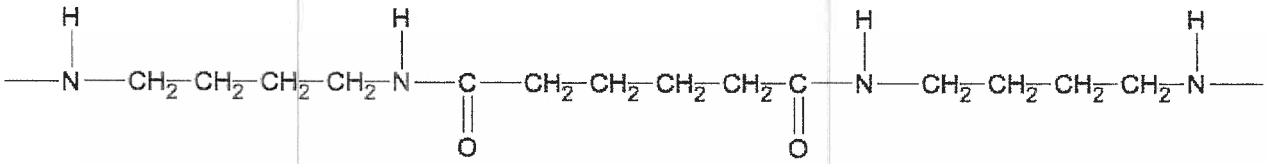
Question 37 **(15 marks)**

'Nylon 4/6' is a polymer which can be obtained as a fibre, film, rod or sheet. It has wide ranging applications owing to its high heat and chemical resistance in comparison with other nylons. It is most often used for electrical and electronic components, in particular those that must withstand high temperatures for a long period of time.

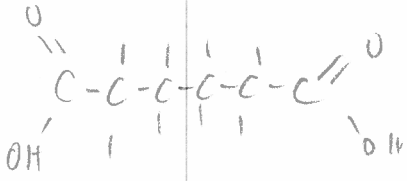
A segment of nylon 4/6 is shown in the diagram below.

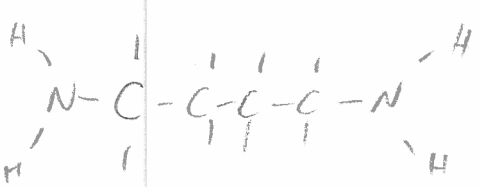


(a) Nylons have the ability to form hydrogen bonds between polymer strands. How does this bonding affect the physical properties of nylon polymers? (2 marks)

Any 2 of
• very strong • high tensile strength • resist wear + tear
• can be made into weather proof substances • made into materials that resist breaking

(b) Draw the two (2) monomers from which nylon 4/6 is composed. (2 marks)





(c) Name and briefly describe the process by which these monomers are able to form this nylon polymer. (2 marks)

- condensation polymerisation (1)
- water molecule is eliminated (OH from each carboxylic acid group + H from each amine group) as the monomers link together to form nylon.

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A pure sample of an amine (containing only the elements carbon, hydrogen and nitrogen) was analysed to determine its composition. The amine was combusted in oxygen and produced 6.43 g of carbon dioxide, 3.93 g of water and 2.04 g of nitrogen gas.

(d) Calculate the empirical formula of the amine. (7 marks)

	C	H	N
$M = \frac{12.01}{44.01} \times 6.43$ $\frac{2.016}{18.016} \times 3.93$			2.04
	$= 1.754699$ (1)	$= 0.439769$ (1)	2.04g
$n = \frac{1.754699}{12.01}$ $\frac{0.439769}{1.008}$ $\frac{2.04}{14.01}$			
	$= 0.146103$ (1)	$= 0.4362787$ (1)	$= 0.1456103$
Ratio	1	3	1 (1)

EF = CH_3N

(e) Did this analysis provide sufficient information to identify whether this amine is one of the monomers used to produce nylon 4/6? Explain. (2 marks)

- yes the information proves that amine is not one of the monomers in the 4/6 polymer (1)
- The MF of the polymer is $C_4H_{12}N_2$ which requires EF to be C_2H_6N

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Question 38 **(15 marks)**

Chromium, the sixth most abundant transition metal in the Earth's crust was discovered in 1797. It was named after the Latin *chroma* meaning 'colour'. Chromium metal is extracted in large part from an ore containing chromite, $FeCr_2O_4$, via a multistep process. It is estimated that 70% of the world's chromite reserves are located in South Africa, with additional deposits in India, Kazakhstan and Zimbabwe.

One process used to extract chromium metal from the chromite ore is shown below.

In the first step, the aerial oxidation of chromite ($FeCr_2O_4$) takes place in molten alkali, producing sodium chromate (Na_2CrO_4).

Step 1: $4\ FeCr_2O_4 + 8\ Na_2CO_3 + 7\ O_2 \rightarrow 8\ Na_2CrO_4 + 2\ Fe_2O_3 + 8\ CO_2$

In the second step, the sodium chromate is converted to sodium dichromate ($Na_2Cr_2O_7$) by an acid.

Step 2: $2\ Na_2CrO_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + Na_2SO_4 + H_2O$

In the third step, the sodium dichromate is reduced to chromium (III) oxide (Cr_2O_3) with carbon.

Step 3: $Na_2Cr_2O_7 + 2\ C \rightarrow Cr_2O_3 + Na_2CO_3 + CO$

The fourth step involves converting the chromium (III) oxide to the final pure chromium via an aluminothermic reaction.

Step 4: $Cr_2O_3 + 2\ Al \rightarrow 2\ Cr + Al_2O_3$

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A 4.11 tonne sample of chromite ore, known to be 58.2% pure, was reacted with 482 kL of oxygen gas at a pressure of 209 kPa and temperature of 356 °C (in the presence of excess sodium carbonate).

(a) Calculate the limiting reagent. (5 marks)

$m(FeCr_2O_4) = \frac{58.2}{100} \times 4.11 = 2.39202\ t$

$= 2392020\ g$

$FeCr_2O_4$ O_2

$n(\text{present}) = n = m/M$ $n = PV/RT$

$= 2392020 / 223.85$ $= (209 \times 482000) / (8.314 \times 629)$

$= 10685.81639\ mol$ (1) $= 19263.3874$ (1)

$\text{STOIC RATIO} = \frac{O_2}{FeCr_2O_4} = \frac{7}{4} = 1.75$ (1)

$\text{ACT RATIO} = \frac{O_2}{FeCr_2O_4} = \frac{19263.3747}{10685.81639} = 1.803$ (1)

$\therefore$ LR is $FeCr_2O_4$ (1)

(b) Calculate the mass of excess reagent. (3 marks)

$n(O_2 \text{ used}) = n(Fe_2Cr_2O_4) \times \frac{4}{1} = 10685.81639 \times \frac{4}{1}$ (1)

$= 18700.17868$

$n(O_2 \text{ excess}) = 19263.3874 - 18700.17868$ (1)

$= 563.209\ mol$

$m(\text{excess } O_2) = 563.209 \times 32 = 18022.689$

$= 1.80 \times 10^4\ g$ (1)

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(c) Calculate the mass of chromium (III) oxide produced if the combined yield of the first three steps is 73.4%. (3 marks)

$n(Cr_2O_3) = n(FeCr_2O_4) \times 73.4/100$
$= 10685.8163 \times 0.734$
$= 7843.89$ mol (1)

$m(Cr_2O_3) = n \times M$
$= 7843.89 \times 152$
$= 1192195.128$ (1)
$= 1.19 \times 10^6$ g (1)

The factory owner wishes to obtain 0.75 tonne of pure chromium from this sample of ore.

(d) What would the minimum possible yield of the fourth step need to be, to ensure this target is reached? (3 marks)

$n(Cr_2O_3$ produced$) = 7843.89$

$n(Cr$ theoretical$) = n(Cr_2O_3) \times 2 = 15686.778$ mol (1)

$m(Cr$ theoretical$) = 15686.778 \times 52$
$= 815712$ g $= 0.815712$ tonnes (1)

% yield $= \frac{\text{actual}}{\text{theoretical}} \times 100$ $\frac{0.75}{0.815712} \times 100$

$= 91.9\%$ (1)

(e) In step 4, is the chromium oxidised or reduced? Explain. (1 mark)

reduced - ox N° goes from +3 → 0 (1)

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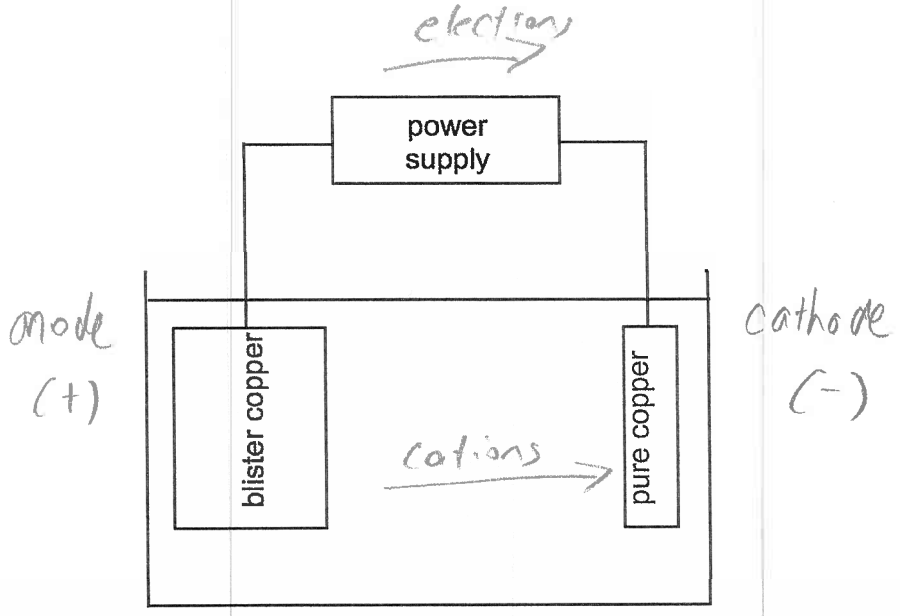
Question 39 **(13 marks)**

A group of chemistry students set up an experiment to replicate the electrolytic refining of copper metal. They obtained some impure 'blister copper' as well as a thin piece of pure copper and set up an electrochemical cell as shown in the diagram below.



(a) Explain the chemical principles of an electrolytic cell. (2 marks)

*electrolytic cell utilises an external applied voltage (1)

& this drives a non-spontaneous redox reaction to occur (1)

(b) On the diagram above label; (4 marks)

(i) the anode and cathode (1)
(ii) the sign of each electrode (1)
(iii) the direction of cation flow (1)
(iv) the direction of electron flow (1)

(c) State two (2) safety considerations the students would have to take into account when conducting this experiment. (2 marks)

Any 2 • safety glasses • avoid contact with $CuSO_4$ electrolyte • keep voltage low to avoid production of H_2 • take care when using electrical devices

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The students recorded the mass of the blister copper and pure copper electrodes before allowing the cell to run for a period of time. They then recorded the mass of each electrode again. Their results are shown in the table below.

	Blister copper	Pure copper
Initial mass (g)	65.8	11.9
Final mass (g)	52.3	25.1

(d) Calculate the percent purity of the blister copper. (3 marks)

Decrease in mass of blistr copper
= 65.8 − 52.3 = 13.5g (1)

Increase in mass of pure copper
= 25.1 − 11.9 = 13.2g (1)

% purity = 13.2/13.5 × 100
= 97.8% (1)

(e) What factors or problems with an experiment can cause; (2 marks)

(i) random error? uncontrollable effects of equipment, procedure or environment (1)

(ii) systematic error? identifiable and quantifiable uncertainty (1) (techniques, measurement, etc)

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Question 40 **(15 marks)**

This question is about the production of sulfuric acid (H_2SO_4). This process is carried out through a number of steps:

Step 1

Liquid sulfur is reacted with dry air to produce sulfur dioxide (SO_2).

Step 2

The sulfur dioxide is oxidised to sulfur trioxide using vanadium(V) oxide as a catalyst. This step is called the Contact Process. The equation for the reaction is shown below.

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g) \qquad \Delta H = -196\ kJ\ mol^{-1}$$

Step 3

Concentrated sulfuric acid (98.0 % by mass) is used to dissolve sulfur trioxide where it forms oleum ($H_2S_2O_7$).

Step 4

The oleum is mixed with water to obtain more sulfuric acid.

A team of chemical engineers carried out step 2 at a variety of temperatures to inform decisions about the optimum conditions for the reaction. Their results are shown on the next page.

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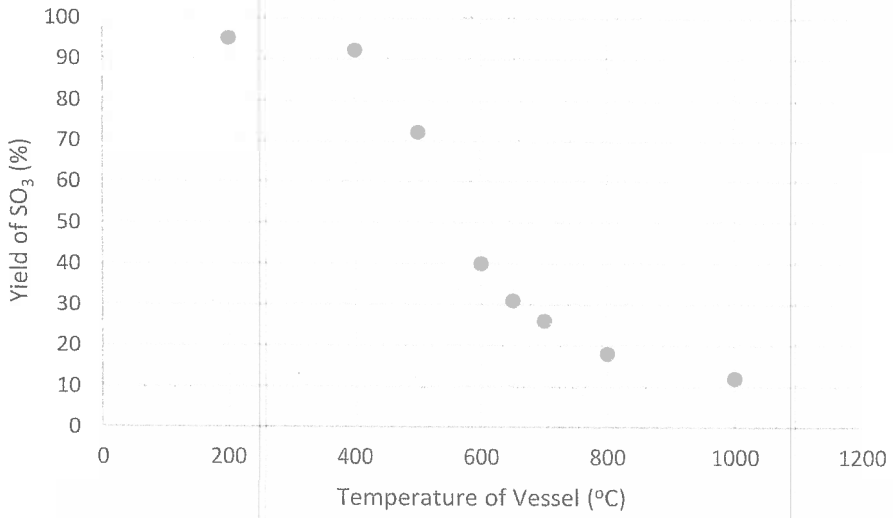
Table 1. Yield of sulphur trioxide for contact process reaction carried out at 150 kPa pressure, with a V_2O_5 catalyst at a range of temperatures.

Temperature of reaction vessel (°C)	**Yield of SO_3 (%)**
200	95
400	92
500	72
600	40
650	31
700	26
800	18
1000	12

The data is displayed in the graph on the grid below.



(b) Use your graph to predict the yield of the reaction at 550 °C. (1 mark)

54 – 58% (1)

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(c) Describe the trend shown by these results. (2 marks)

- yield decrease with increasing temp (1)
- some description in relation to shape
  - yield changes significantly between 30°-90° but little change at high + low temp (1)

(d) As a result of these findings, the chemical engineer decided to operate the sulfuric acid plant at a temperature of 200 °C. However, the amount of sulphur dioxide produced was very low. Suggest a reason for this. (1 mark)

the reaction would be too slow at this temperature (1)

(e) After further tests, it was decided to operate the plant at 400 °C. With reference to your graph, explain why this temperature, and not a higher temperature, was chosen. (2 marks)

- relatively high yield at this temp (92%) (1)
- yield drops a lot at temp's higher tha 400°C (1)

(f) Assuming a yield of 92.0%, Calculate the volume of oxygen, at 400 °C and a pressure of 150 kPa, required to produce 1.00 tonne (1.00×10^6 g) of sulphur trioxide in the Contact Process: (4 marks)

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$$

$n(SO_3) = \frac{m}{M} = \frac{1.00 \times 10^6}{80.07} = 1.2489 \times 10^4$ mol (1)

$n(O_2 \text{ required}) = \frac{1}{2} \times n(SO_3) \times (100/92) = 0.5 \times 1.2489 \times 10^4 \times \frac{10}{9} = 6.787 \times 10^3$ mol (2)

$PV = nRT \quad V = \frac{nRT}{P} = \frac{6.787 \times 10^3 \times 8.315 \times 693.15}{150}$ (1)

$= 2.53 \times 10^5$ L

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(g) Sulfuric acid is used to produce agricultural fertiliser, including superphosphate, which is a mixture of two calcium salts. The reaction is shown below:

$$Ca_3(PO_4)_2(s) + 2\,H_2SO_4(aq) + 4\,H_2O(\ell) \rightarrow Ca(H_2PO_4)_2(s) + 2\,CaSO_4{\cdot}2H_2O(s)$$

If 98.0 % (by mass) sulfuric acid is used, calculate the mass of the super phosphate that can be produced from 1.00 tonne of the sulfuric acid. (assume 100% yield)

(5 marks)

$m(H_2SO_4) = \frac{98}{100} \times 1.00\times10^6 = 9.80\times10^5\ g$ (1)

$n(H_2SO_4) = \frac{m}{M} = \frac{9.80\times10^5}{98.056} = 9.991\times10^3\ mol$ (1)

$n(Ca_3(PO_4)_2) = \frac{1}{2} \times n(H_2SO_4) = \frac{1}{2} \times 9.991\times10^3$
$= 4.996\times10^3$

$m(Ca_3(PO_4)_2) = n\times M = 4.996\times10^3 \times 234.052 = 1.169\times10^6\ g$ (1)

$n(CaSO_4.2H_2O) = n(Ca_3(PO_4)_2 = 9.91\times10^3$

$m(CaSO_4.2H_2O) = n\times M = 9.91\times10^3 \times 172.182 = 1.720\times10^6\ g$ (1)

Total mass $= 1.169\times10^6 + 1.720\times10^6$

$= 2.89\times10^6\ g$ (1)

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