Exam Choice

Student Number

2024 | TRIAL EXAMINATION

Chemistry

General Instructions

- Reading time – 5 minutes.
- Working time – 3 hours.
- Write using black pen.
- Draw diagrams using pencil.
- For questions in Section II, show all relevant working in questions involving calculations.
- NESA approved calculators may be used.

Total marks: 100

Section I – 20 marks (pages 2 – 15)

- Attempt questions 1 – 20.
- Allow about 35 minutes for this section.

Section II – 80 marks (pages 16 – 36)

- Attempt questions 21 – 30
- Allow about 2 hours and 25 minutes for this section.

Section I – 20 marks

Attempt Questions 1-20

Allow about 35 minutes for this section

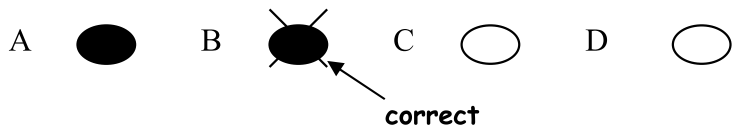
Use the multiple-choice answer sheet.

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

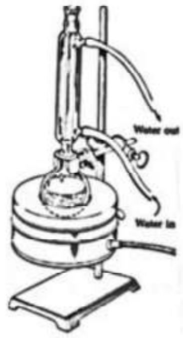
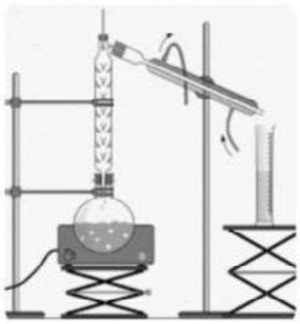
Sample: 2 + 4 = (A) 2 (B) 6 (C) 8 (D) 9

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

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



1. Which diagram below best shows the main equipment required to isolate a pure sample of a prepared synthetic ester?

(A)	(B)
	
(C)	**(D)**
	

2. Which of the following is the correct net ionic equation for the reaction between aqueous solutions of KOH and H_3PO_4?

(A) $H^+(aq) + OH^-(aq) \rightarrow \mathrm{H_2O}(l)$

(B) $3K^+(aq) + \mathrm{PO_4^{3-}}(aq) \rightarrow K_3PO_4\,(aq)$

(C) $3H^+(aq) + 3OH^-(aq) \rightarrow 3\mathrm{H_2O}(l)$

(D) $3K^+(aq) + 3OH^-(aq) + 3H^+(aq) + \mathrm{PO_4^{3-}}(aq) \rightarrow K_3PO_4\,(aq) + 3\mathrm{H_2O}(l)$

3. Students 'A' and 'B' conducted an independent gravimetric analysis on the same sulfate based lawn fertiliser, following identical instructions provided by their teacher.

The table below shows the data collected by the students in each of four trials.

Mass of dry $BaSO_4$ collected (g)				
	TRIAL 1	**TRIAL 2**	**TRIAL 3**	**TRIAL 4**
Student A	5.36	5.39	5.32	5.41
Student B	5.05	5.67	4.80	5.15

Based on a knowledge of the sulfate content of the lawn fertiliser analysed, the teacher had calculated the theoretical mass of $BaSO_4$ each trial should produce to be 5.10 g.

Which statement below is correct?

(A) Student A has more accurate and reliable data.

(B) Student B has more accurate and reliable data.

(C) Student A has more accurate but less reliable data.

(D) Student B has more accurate but less reliable data.

4. Which species has the highest concentration in any solution of sulfuric acid?

(A) SO_4^{2-}

(B) H_3O^+

(C) HSO_4^-

(D) H_2SO_4

5. The equation below describes a chemical system able to reach a state of dynamic equilibrium.

$$NH_3\,(g) + H_2O\,(l) \leftrightharpoons NH_4^+\,(aq) + OH^-(aq)$$

The K for this reaction is an example of:

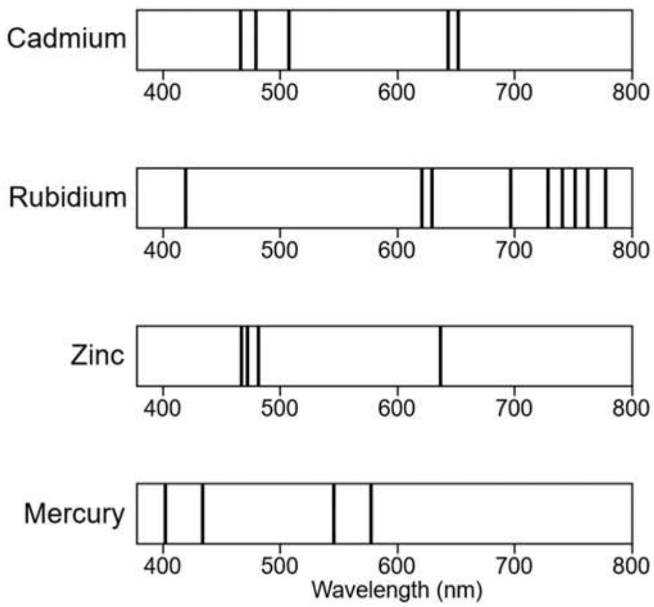
(A) an acid dissociation constant (K_a).

(B) a base dissociation constant (K_b).

(C) the self-ionisation constant of water (K_w).

(D) a solubility product constant (K_{sp}).

6. The absorbance lines of four metals are shown in the diagram below.



Which wavelength would be a suitable choice for measuring the concentration of cadmium in an AAS experiment?

(A) 470 nm

(B) 480 nm

(C) 508 nm

(D) 640 nm

7. One reaction in the industrial process to manufacture sulfuric acid is represented by the following equation.

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

Which change would increase the yield of this reaction, assuming the volume of the reaction chamber is held constant during the change?

(A) Decreasing the temperature of the reaction vessel.

(B) Decreasing the partial pressure of the reacting gases.

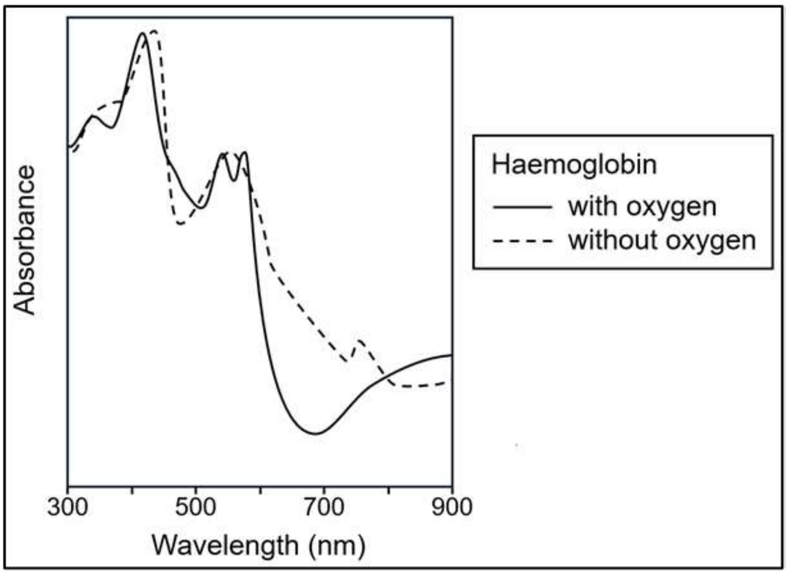
(C) Adding a vanadium oxide catalyst to the reaction vessel.

(D) Addition of an inert gas to increase the pressure in the vessel.

8. Which alternative below correctly identifies the effect of decreasing the volume of a vessel containing a homogeneous gaseous system initially at equilibrium?

	Effect on rate of forward reaction	**Effect on equilibrium yield of product**
(A)	Increases regardless of the relative moles of gaseous reactant and product	Increases regardless of the relative moles of gaseous reactant and product
(B)	Increases regardless of the relative moles of gaseous reactant and product.	Increases if the forward reaction produces fewer moles of gas.
(C)	Decreases if the forward reaction produces more moles of gas.	Increases if the forward reaction produces more moles of gas.
(D)	Decreases if the forward reaction produces more moles of gas.	Increases if the forward reaction produces fewer moles of gas.

9. Haemoglobin is a protein that transports oxygen in blood. The image below shows the UV-visible spectrum of haemoglobin when it is carrying oxygen, and when it is not.



Medical spectrometers can measure the change in absorbance at one wavelength over time.

In a UV-visible spectrometry experiment, which wavelength would produce the greatest change in absorbance as haemoglobin delivers oxygen to cells?

(A) 410 nm

(B) 480 nm

(C) 690 nm

(D) 890 nm

10. An aqueous solution contains 5.0% ethanoic acid (by mass) and has a density of 0.96 g mL^{-1}.

What is the closest molar concentration of ethanoic acid in this solution?

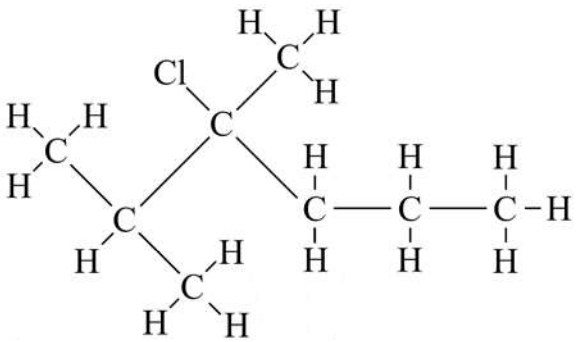
(A) 0.087 mol L^{-1}

(B) 0.80 mol L^{-1}

(C) 4.80 mol L^{-1}

(D) 12.0 mol L^{-1}

11. What is the systematic name for this compound?



(A) 1,1-dimethyl-2-chloro-2methylpentane

(B) 2-chloro-1,1,2-trimethylpentane

(C) 2,3-dimethyl-3-chlorohexane

(D) 3-chloro-2,3-dimethylhexane

12. Designing industrial synthesis processes to maximise the number of reactions that have a high '**atom economy**' is one aim of 'green chemistry', which is a movement towards lowering the environmental impact of the chemical industry and the products it creates.

The atom economy for a chemical reaction is a measure of the amount of atoms from the starting materials that are present in the useful products at the end of the reaction. Having a high atom economy means any by-products of a reaction, which may not have a significant use, are minimised.

Of the general reactions below, which would have the highest atom economy?

(A) Addition of bromine to an alkene.

(B) Elimination of water from alkanols.

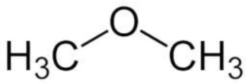
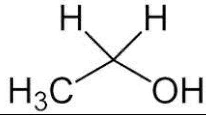
(C) Hydrolysis of an alkyl alkanoate.

(D) Substitution of an alkane by reaction with a halogen.

13. Ethers are a family of organic compounds which contain only carbon, hydrogen and oxygen.

The oxygen atom in an ether is joined to carbon atoms on either side by single bonds, as shown in the example of dimethyl ether in the table below.

Some information about dimethyl ether and ethanol is also shown in the table.

	Dimethyl ether	**Ethanol**
Structural formula		
Formula weight	46.068	46.068
Boiling point (K)	308	351
Solubility in water (g/100 g water)	6.1	infinitely soluble

Which explanation best accounts for the differences in the properties of dimethyl ether and ethanol shown in the table?

(A) Ethanol molecules are more polar than dimethyl ether molecules.

(B) The hydrogen bonds in ethanol are stronger than those in dimethyl ether.

(C) The hydrogen bonding is more extensive in ethanol than in dimethyl ether.

(D) The O-H bonds in ethanol are stronger than the C-O bonds in dimethyl ether.

Questions 14 and 15 refer to the information below.

Spectrophotometry is a technique used to measure the concentration of a chemical in an analyte using the Beer-Lambert law. The equation below summarises that law.

$$A = \varepsilon c l = \log_{10}\frac{I_o}{I} \qquad \text{where:}$$

A = absorbance	c = concentration (mol L^{-1})	I_o = incident light intensity
l = pathlength (cm)	ε = molar absorptivity constant	I = transmitted light intensity

After calibration with samples of known concentration, the unknown sample is tested.

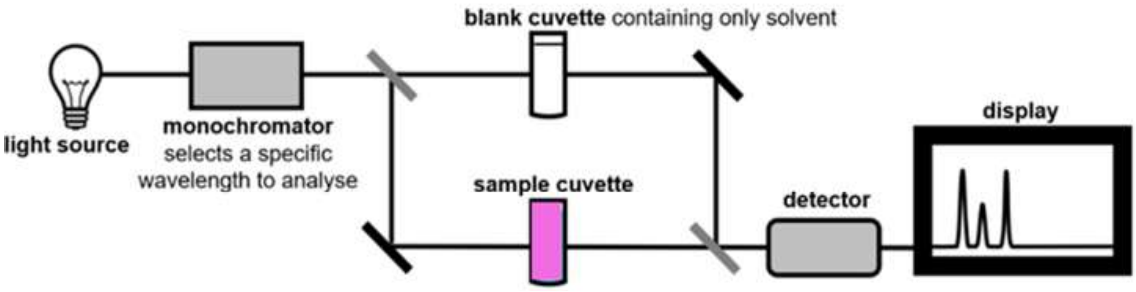
Light from a source is split into two beams, one passing through the cuvette holding the 'blank', the other through the cuvette holding the sample.

Figures 1–3 show various features of this technique.

Fig 1: Spectrophotometer

Fig 2: Glass cuvette

Fig 3: Schematic showing how the components in a spectrophotometer are arranged



Questions 14 and 15 are on page 11.

14. At 524 nm, potassium permanganate ($KMnO_4$) has a molar absorptivity constant of $\varepsilon = 2.33 \times 10^4$ L mol^{-1} cm^{-1}.

What percentage of 524 nm light is transmitted by a 1.0 cm cuvette of 1.5×10^{-5} molL^{-1} potassium permanganate?

(A) 0.35%

(B) 2.2%

(C) 35%

(D) 45%

15. Which error in the technique could result in an estimate for the potassium permanganate solution tested being too *low*?

(A) Consistently rinsing the sample cuvette with the $KMnO_4$ solution to be tested.

(B) Rinsing the 'blank cuvette' with the solvent used to prepare the $KMnO_4$ solution.

(C) Leaving an oily residue on the side of the sample cuvette the light passes through.

(D) Incorrect preparation of the standard solutions used for calibration, such that their labelled concentration was lower than their actual concentration.

16. The mole ratio of sodium ethanoate to ethanoic acid in an equilibrium mixture of the two solutions is found to be 5:2.

Given that the K_a of ethanoic acid is 1.74×10^{-5}, what is the pH of this solution?

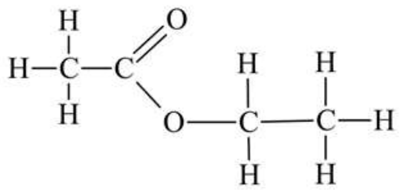
(A) 4.36

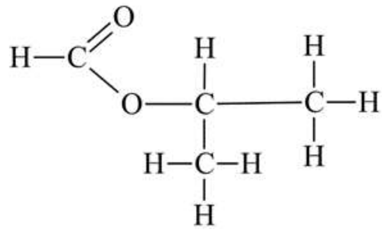
(B) 4.76

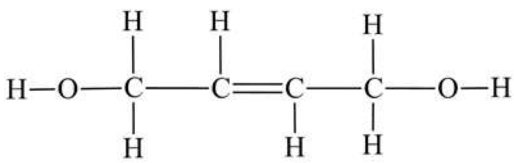
(C) 4.98

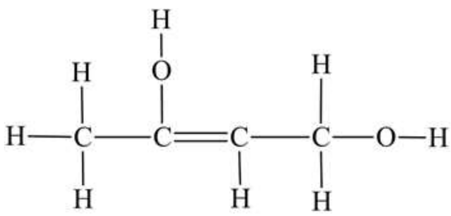
(D) 5.16

17. Which isomer of $C_4O_2H_8$ would show three signals in its ^{13}C NMR spectrum?

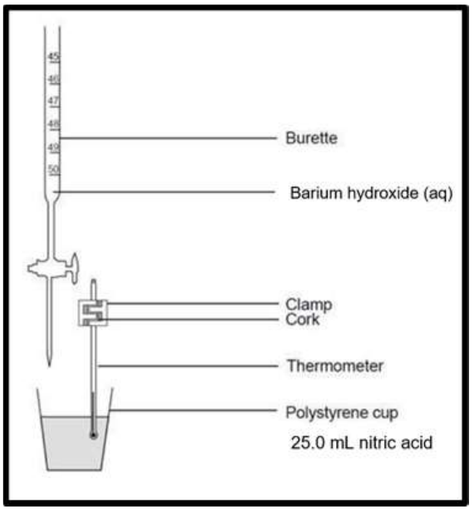
(A) 

(B) 

(C) 

(D) 

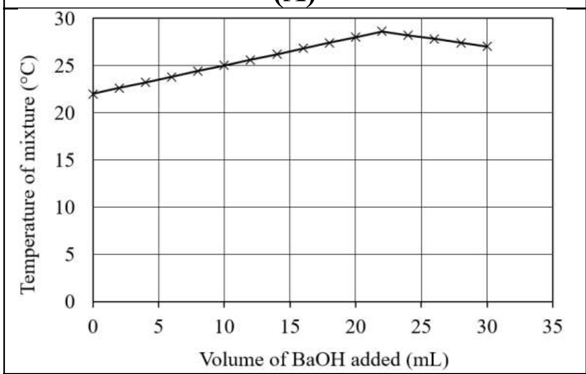
18. A sample of the same barium hydroxide solution was analysed by four students using a thermometric titration against 25.0 mL samples of standardised 0.925 mol L^{-1} nitric acid solution, as shown in the apparatus below.



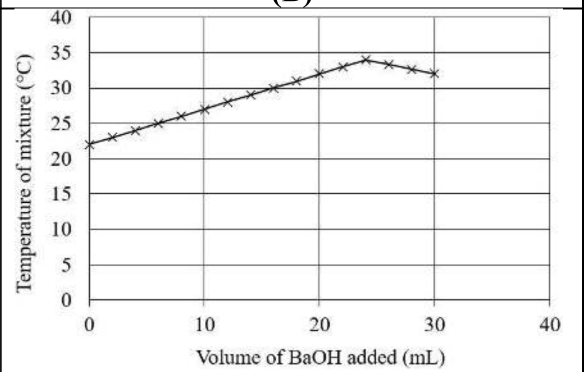
The graphical results of 4 students (A, B, C and D) are shown below.

Assuming the heat of neutralisation for the reaction occurring was -57 kJ mol^{-1}, and knowing that the concentration of the barium hydroxide solution given to the students to analyse was 0.510 mol L^{-1}, which results appear to be the most accurate?

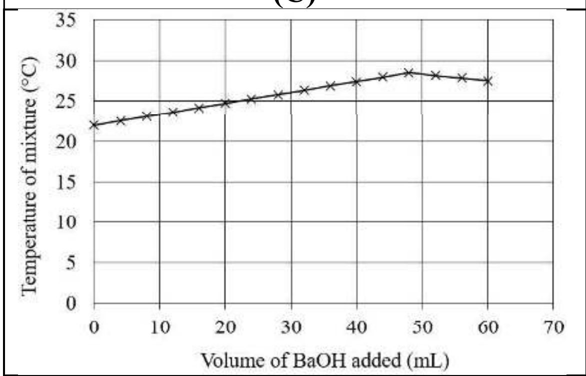
(A)



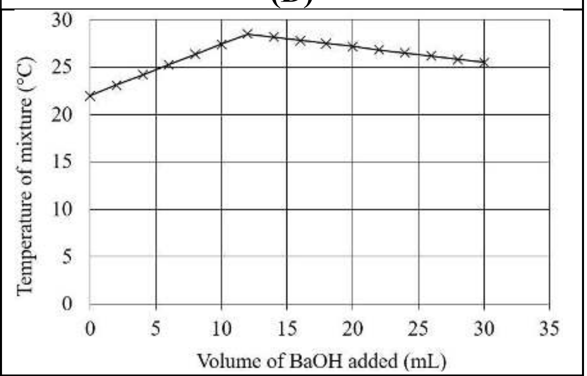
(B)



(C)



(D)



Questions 19 and 20 refer to the information below.

Dicarboxylic acids contain 2 carboxyl groups. Apart from the simplest member of this group, ethanedioic acid (commonly known as oxalic acid), the members of this series can be represented by the general formula *HOOC-R-COOH*, where R represents an alkyl chain between the two carboxyl groups.

In a titration, a solution containing 0.260 g of a dicarboxylic acid dissolved in water, required 25.00 mL of 0.20 mol L^{-1} sodium hydroxide to reach the end-point.

19. According to the result of the titration, and assuming it was accurately carried out, which of following acids must have been analysed in this investigation?

(A) ethanedioic acid

(B) propanedioic acid

(C) butanedioic acid

(D) pentanedoic acid

Question 20 is on page 15.

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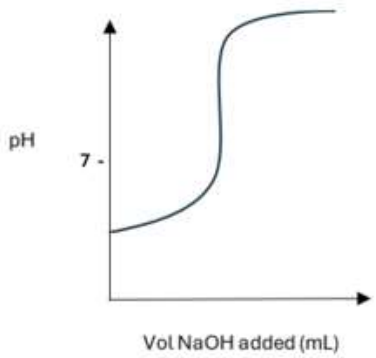
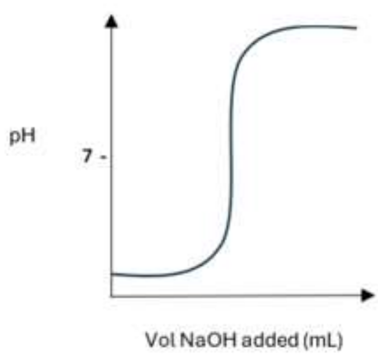
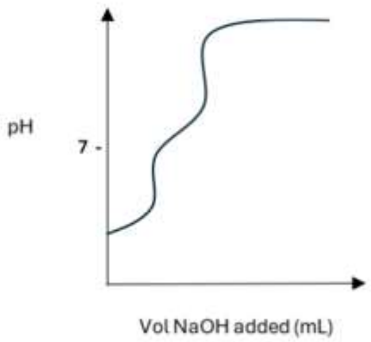
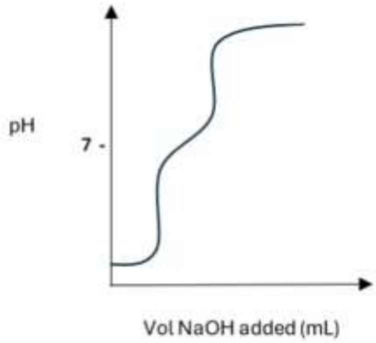
20. Which figure below is the best representation of the pH curve that would be produced by addition of NaOH to the acid analysed?

(A)	**(B)**
	
(C)	**(D)**
	

2024 | TRIAL EXAMINATION

Chemistry

Section II
Answer Booklet

80 marks

Attempt Questions 21 – 30

Allow about 2 hours and 25 minutes for this part

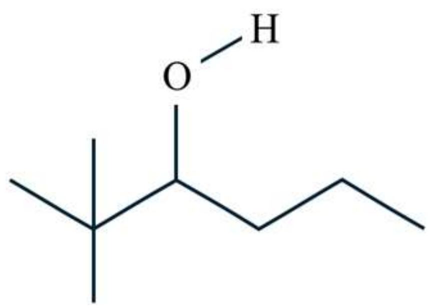
Instructions

- 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 at the back of this booklet. If you use this space, clearly indicate which questions you are answering.

Marks

Question 21 (2 marks)

Draw the structural formula and name the major product of the dehydration of the compound shown below.



Structural formula of product: **1**

Systematic name: **1**

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Marks

Question 22 (11 marks)

During a *Depth Study* related to solubility equilibria, students were asked to demonstrate a reaction system, involving the dissolution of a solid in water, that would be in a state of dynamic equilibrium.

The ideas of two groups, recorded during a planning phase for this task, are shown in the table below.

Group 1	**Group 2**
Collect approximately 20 g of sodium chloride and stir this into100 mL of water in a small beaker. As NaCl has a high solubility, all of the solid will dissolve. Pour the solution into an evaporating basin and heat gently over a Bunsen. As soon as some white solid appears, present this system to the teacher.	Add a small amount of calcium nitrate solution to 10 mL of sodium sulfate solution in a beaker until the mixture appears to be a little opaque. Pour some of the solution into a test tube. Stopper the test tube and place overnight in fridge. Show the refrigerated test tube to the teacher in the following lesson.

(a) Apply your knowledge of solubility equilibria to explain any merits and/or limitations of each plan. **4**

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Question 22 continues on page 19.

Marks

Question 22 (continued)

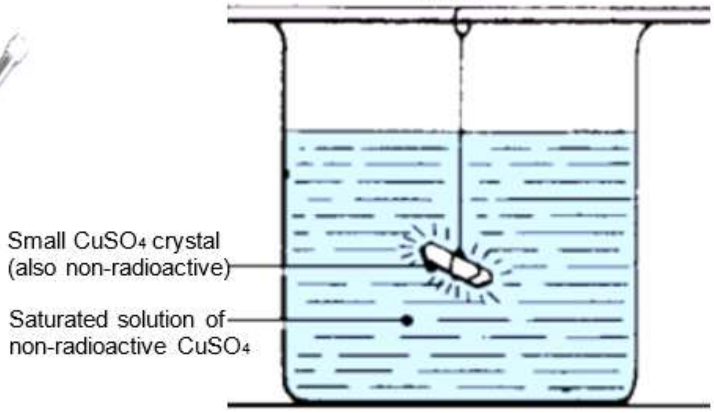
(b) In a subsequent lesson, the teacher discussed the use of radioactive salt samples to provide proof of the dynamic nature of solubility equilibrium.

Using the system shown in Fig b as an example, they explained how a sample of radioactive copper(II) sulfate powder, containing radioactive Cu-67 isotopes instead of stable copper atoms, could be used to trace movement of Cu^{2+} in the system.

Fig a

$CuSO_4$ (s) containing Cu-67, with a half-life of 2.67 days.

Fig b



Outline a method, using the chemicals and equipment shown in Fig a and b, which could provide data to support the hypothesis that the system shown is in a state of dynamic equilibrium. **3**

Provide reasoning to support key steps in your outlined method.

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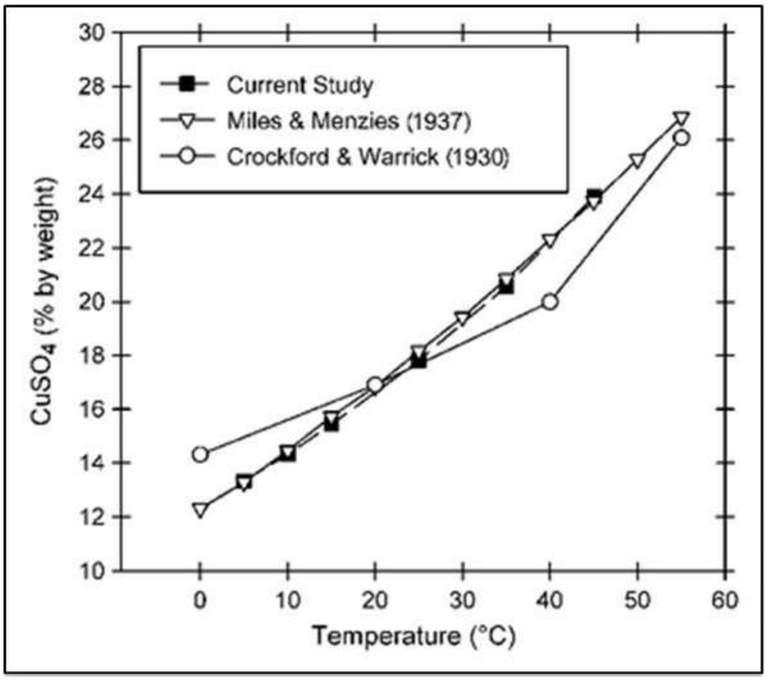
Question 22 continues on page 20.

Marks

Question 22 (continued)

(c) The change in solubility of $CuSO_4$ (s) with increasing water temperature has been studied in several published experiments.

Based on the current study in the data below, estimate a value for the K_{sp} of copper(II) sulfate at 25°C, to an appropriate number of significant figures. **4**



(https://www.researchgate.net/figure/Temperature-dependence-of-the-solubility-of-copper-sulfate-in-water_fig2_251697438)

Show your working, identifying any estimates made from the data above which have been used in your calculation.

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Question 23 (5 marks)

A chemistry student is tasked with identifying the oxidation state of iron in a poorly labelled bottle of '*iron nitrate*' solution.

(a) Identify a suitable reagent that would result in formation of a precipitate when added to a sample of the unknown.

Explain how the colour of the precipitate could aid in the identification of the oxidation state of iron in the sample. **2**

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(b) After adding a reagent to observe the colour of the precipitate formed, the student added a few drops of purple acidified potassium permanganate ($KMnO_4$) to a different sample of the unknown in a test tube, and gently heated the test tube in a Bunsen flame.

They observed a gradual fading in the purple colour of the permanganate.

Describe the nature of the chemical change occurring upon addition of the acidified $KMnO_4$ to the unknown and explain how observation made could help to confirm the oxidation state of the iron present in the solution. **3**

Include relevant ionic equations to support your answer.

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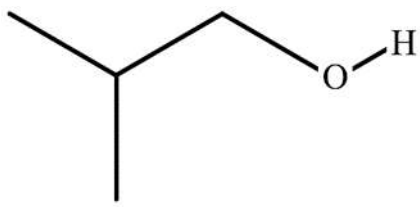
Marks

Question 24 (8 marks)

Isobutanol has been investigated as a possible fuel source for internal combustion engines.



(a) Give the IUPAC name for the structure shown above. **1**

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(b) Outline a procedure which could be used to estimate the heat of combustion of this fuel in a typical school laboratory. **4**

Include a labelled diagram of the apparatus used as well as a justified safety precaution for this type of investigation.

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Question 24 continues on page 23.

Marks

Question 24 (continued)

(c) 2-butanol is an isomer of isobutanol. Data from the mass spectra of the two compounds are shown in the table below.

Compound	**Parent ion peak (m/z)**	**Base peak (m/z)**
Isobutanol	74	43
2-butanol	74	45

Explain a similarity and a difference between the two spectra. **3**

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Marks

Question 25 (9 marks)

Sodium carbonate forms a number of hydrates of general formula $Na_2CO_3.xH_2O$.

A 3.01 g sample of one of these hydrates was dissolved in water and the solution made up to 250.0 mL.

In a titration, a 25.0 mL portion of this solution required 24.3 mL of 0.200 mol L^{-1} of hydrochloric acid to reach the end-point.

The equation for this reaction is shown below.

$$Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$$

(a) Calculate the number of moles of Na_2CO_3 in the 25.0 mL analysed. **2**

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(b) Calculate the molecular weight of the hydrated sodium carbonate and thus the value of x in the general formula of the hydrated compound analysed. **3**

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Question 25 continues on page 25.

Marks

Question 25 (continued)

(c) Of the indicators in the table below, select the most appropriate one to use in this titration.

Provide a thorough justification for your choice, including application of relevant aspects of the Brønsted-Lowry theory of acids and bases. **4**

Indicator	**pH range**	**Colour in acid**	**Colour in alkali**
Tropaeolin G	1.3 – 3.0	red	yellow
Bromocresol green	3.8 – 5.4	yellow	blue
Cresol purple	7.6 – 9.2	yellow	purple
Alizarin yellow	10.1 – 12.0	yellow	orange

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Marks

Question 26 (6 marks)

X and Y are colourless organic liquids known to be isomers.

Analysis of each liquid involved 4 tests, in the sequence described in the table below. Observations made after each test are also identified.

Tests conducted	Observations: X	Observations: Y
1. Unknown liquid tested with Tollen's reagent.	No change	No change
2. Unknown liquid refluxed with NaOH for an hour. Aqueous layer extracted and tested by adding HNO_3 followed by 10 drops of $AgNO_3(aq)$	Yellow precipitate forms. Precipitate does not dissolve in NH_3.	Refluxed mixture forms yellow precipitate which does not dissolve in NH_3.
3. Unknown liquid warmed gently in presence of acidified $K_2Cr_2O_7$.	Colour change from orange to green observed.	No colour change observed.
4. Mixture remaining from Step 3 re-tested tested with Tollen's reagent.	Silver mirror observed on inside of test tube after Tollen's reagent is added.	No change observed.

(a) Which two functional groups can we infer are present in Organic Unknown X? Justify your answer by referring to relevant observations. **3**

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Question 26 continues on page 27.

Marks

Question 26 (continued)

(b) Given the unknown liquids contain 3 carbon atoms, draw a possible structural formula of X and Y which is consistent with the data provided. **3**

Name each structure drawn.

X	Y
Possible structural formula of X	Possible structural formula of Y

Name of X:

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Name of Y:

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Marks

Question 27 (14 marks)

Methanoic acid and ethanol react reversibly to form methyl ethanoate and water. The following procedure was carried out by a chemistry student to estimate the equilibrium constant for this reaction.

- A mixture weighing 8.64 g was made by adding 0.080 mol of ethanoic acid and 0.12 mol of methanol. The mixture was left in a sealed glass syringe with a sliding piston which was placed in a water bath where its temperature was held steady at 60°C for 3 hours. After this time, the temperature of the water bath was reduced to 20°C. The syringe was left for 24 hours in the water bath. At this point, the system was assumed to be at equilibrium.
- 1.0 g of the mixture remaining in the syringe was measured out and titrated with 0.40 mol L^{-1} sodium hydroxide delivered from a burette. A mean volume of 21.20 mL of sodium hydroxide solution was needed to reach the end-point of the titration, when it was assumed all of the ethanoic acid present in the mixture had reacted with the sodium hydroxide

(a) Write a balanced chemical equation, using structural formula, for the reaction between ethanoic acid and methanol which occurred in the first step of the outlined procedure. **2**

(b) Write a balanced chemical equation for the reaction taking place in the titration stage of the procedure. **1**

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(c) Use the data provided to calculate the number of moles of ethanoic acid remaining in the equilibrium mixture formed in the first step. **2**

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Question 27 continues on page 29.

Marks

Question 27 (continued)

(d) Write the expression for the equilibrium constant, *K*, for the system described by your equation in (a). Use molecular formulae for all species in the expression for *K*. **1**

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(e) Use the data provided to estimate the value of *K* for the reaction forming methyl ethanoate at 30°C. Show all working. **2**

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(f) A few drops of concentrated H_2SO_4 are often added to mixtures of an alkanol and alkanoic acid when this type of reaction is carried out in a school laboratory. **1**

What is the primary function of concentrated H_2SO_4 in this reaction?

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(g) Propose a chemical reason for the omission of concentrated H_2SO_4 for this particular investigation. Explain your reasoning. **2**

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(h) Would you expect the omission of concentrated H_2SO_4 in this investigation to affect the accuracy of the estimate for *K*? Explain your reasoning. **3**

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Marks

Question 28 (12 marks)

The hourly energy requirement for an astronaut to function safely in space is equivalent to the energy released when 36.0 g of glucose is fully oxidised to form carbon dioxide and water vapour.

(a) Write a balanced chemical equation to represent the complete oxidation of glucose. **1**

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(b) Using the theoretical value of the heat of combustion of glucose (2800 kJ mol^{-1}), calculate an estimate for the hourly energy requirement of the astronaut. **2**

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(c) Calculate the volume of oxygen (measured at 298.15 K and 100 kPa) required to oxidise 36.0 g of glucose, based on the equation provided in (a) above. **2**

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Question 28 continues on page 31.

Marks

Question 28 (continued)

(d) Explain how a failure to remove much of the exhaled carbon dioxide from a confined space could alter the pH of the astronaut's blood over an extended period.

Refer to the equation: $CO_2(g) \rightleftharpoons CO_2(aq)$ in blood, with at least one other net ionic equation, to support your explanation. **3**

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(e) Certain chemicals in the astronaut's blood would allow for small increases in the gaseous CO_2 composition of the air they inhale without resulting in significant health effects.

Explain the chemical principles which can account for this. Support your answer with relevant ionic equation/s. **4**

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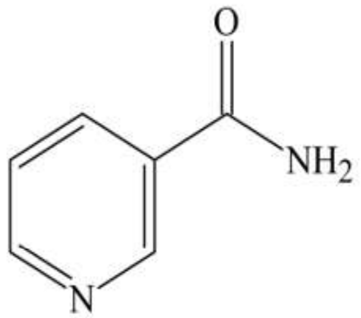
Marks

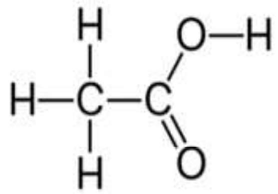
Question 29 (6 marks)

Polyamides are a class of condensation polymer resulting from the reaction of an organic compound with an amide functional group with one containing the carboxyl functional group.

The structures below show the composition of two organic molecules.



Nicotinamide



ethanoic acid

(a) Draw the functional group present in amides. **1**

(b) Could the reaction of the two molecules above result in the formation of a polyamide? Explain your answer. **3**

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Question 29 continues on page 33.

Marks

Question 29 (continued)

(c) An amide with the molecular formula $C_2H_4N_2O_2$ is subjected to reaction conditions which allow for its conversion into a polyamide.

Draw a possible structural formula for this amide and name the molecule formed as a by-product of the condensation polymerisation of the amide drawn. **2**

Name of by-product.

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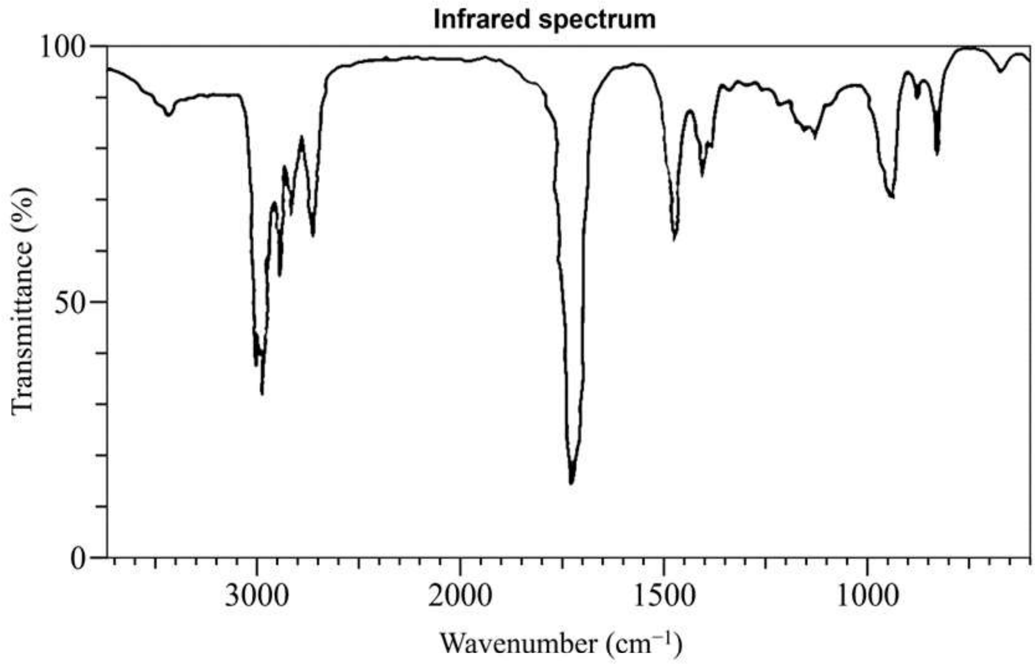
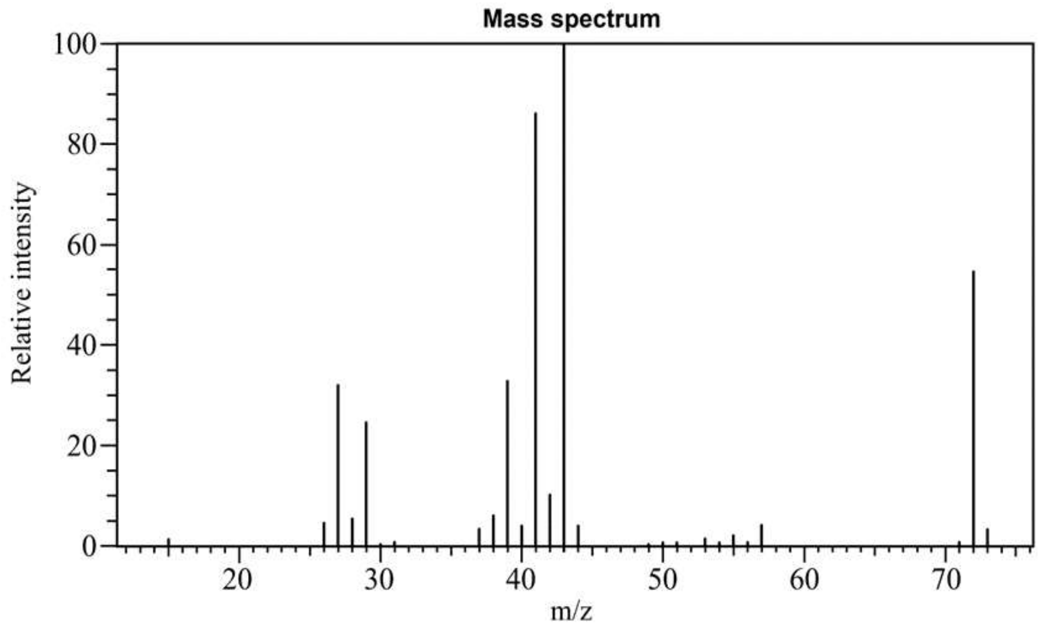
Question 30 (7 marks)

An unknown compound was investigated using several techniques. The results are shown in the spectra below.

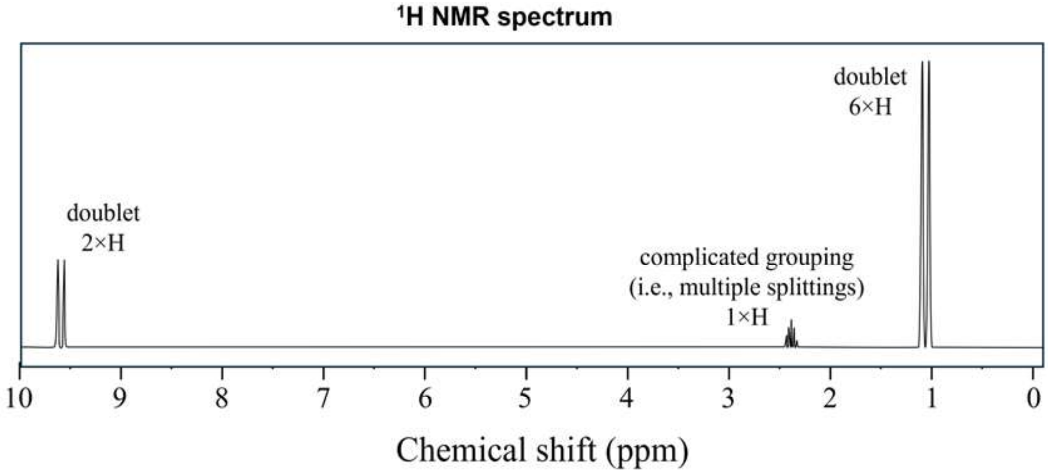


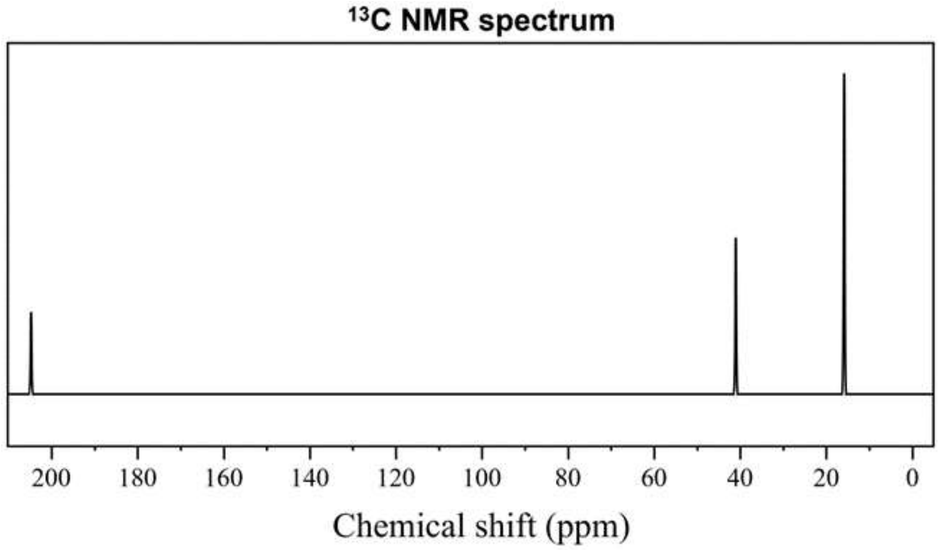


Question 30 continues on page 35.

Marks

Question 30 (continued)





Draw and name the compound that was investigated. **7**

Support your answer with evidence from the spectra.

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Continue your answer to Question 30 on page 36.

Question 30 (continued)

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Section II extra writing space.

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

Exam Choice

2024 Chemistry Trial Examination.

Marking Guidelines and Model Answers.

Section I Multiple Choice

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

Section II

21.

Marking Criteria	Marks
• Draws a correct structure and correctly names compound	**2**
• One of the above	**1**

2,2-dimethyl hex-3-ene

22.a.

Marking Criteria	Marks
• Evaluates both systems on the basis of whether they meet the criteria for being in a state of dynamic equilibrium AND • Demonstrates thorough knowledge of solubility equilibria and conditions required for a system to be at dynamic equilibrium.	**4**
• Evaluates at least one system on the basis of whether they meet the criteria for being in a state of dynamic equilibrium AND • Demonstrates sound knowledge of solubility equilibria and conditions required for a system to be at dynamic equilibrium.	**3**
• Identifies some positive aspects and/or limitations of each system AND • Demonstrates a basic knowledge of solubility equilibria and conditions required for a system to be at dynamic equilibrium.	**2**
• Provides some relevant information.	**1**

To show a system is at dynamic equilibrium you must ensure the reaction or change is reversible and the rate of the forward change is equal to that of the reverse change under a constant set of conditions in a closed system. At this point, no macroscopic changes will be observed. Group A's plan involves a reversible change:

$NaCl(s) \Leftrightarrow Na(aq) + Cl^{-}(aq)$

and the fact they have a saturated solution means both the forward and reverse changes occur. However, the system is not closed or at constant conditions, and the observation of more white solid forming upon heating means the reverse reaction is occurring at a faster rate. Therefore, plan has not met that aim of the investigation.

Group B' s plan also involves solubility equilibria. The reaction between the two solutions produces a solid, as observed by the opaque nature of the mixture.

Ca^{2+} (aq) + SO_4^{2-}(aq) ⇔ $CaSO_4$ (s).

The fact the solution is beyond saturated means both reactions can proceed. The system is also closed and then allowed to come to a constant temperature, by being left in the fridge overnight. As solubility generally decreases with temperature, the mixture remaining will still be opaque and saturated. This better meets the aim of the investigation.

22.b.

Marking Criteria	Marks
• Outlines a procedure that could be followed that uses radioactive $CuSO_4$ to support the inference that the system is in a state of dynamic equilibrium and justifies key aspects of the procedure.	**3**
• Identifies how the use of radioactive $CuSO_4$ make be used to show that the system is in a state of dynamic equilibrium, but procedure is not complete or clear. Provides some justification of steps identified.	**2**
• Provides some relevant information.	**1**

The chemist could use a Geiger counter to measure the radioactivity of the initial solution (and the suspended crystal) as well as that of the background, which is subtracted to determine if the solution or crystal is initially emitting significant radiation.
They should them dissolve some of the $CuSO_4$ marked with radioactivity copper and leave the system closed for several days. They could then retest the solution and the crystal for any changes in radiation emitted. You would expect both the solution and the dried crystal to emit more radiation, from which you could infer both of the following changes were taking place.
$CuSO_4$(s) in radioactive sample added → Cu^{2+} + SO_4^{2-}
Radioactive Cu^{2+} + SO_4^{2-} → $CuSO_4$ (s) -now also radioactive

22.c.

Marking Criteria	Marks
• Uses relevant data from the graph to estimate the solubility of $CuSO_4$ from the current data provided and calculates a value for the K_{sp} based on the estimate from graph. Includes sufficient working.	**4**
• Uses relevant data from the graph to estimate the solubility of $CuSO_4$ from the current data provided and calculates a value for the K_{sp} based on the estimate from graph, with one incorrect step. Includes some working.	**3**
• Completes two steps required to complete the calculation. Mark for follow-on errors.	**2**
• Provides some relevant information e.g. provides a good estimate from the graph.	**1**

At 25°C, the solubility of $CuSO_4$ is approximately 18% (w/w) = 18g / 100 g water.
Converting to molar solubility = 180 g / L = m/MM = 180 / 159.62 =1.128 mol L^{-1}
$CuSO_4$ (s) ⇔ Cu^{2+} (aq) + SO_4^{2-} (aq)
s ⇔ s s
s= 1.128 mol L^{-1}
Thus in a saturated solution at 25°C, the $[Cu^{2+}]$ = 1.128 mol L^{-1} = $[SO_4^{2-}]$
$K_{sp} = [Cu^{2+}] [SO_4^{2-}] = 1.128^2 = 1.27$

23.a.

Marking Criteria	Marks
• Identifies a suitable reagent that precipitates with iron cations in the sample and explains, using identified colours, how this test would help confirm the oxidation state of the iron in the sample.	**2**
• Identifies a suitable reagent that precipitates with iron cations.	**1**

Adding NaOH(aq) to a sample of the unknown would result in a precipitate of either $Fe(OH)_2$ or $Fe(OH)_3$. If the precipitate was green in colour, the iron present in the unknown is Fe^{2+}, whereas if it was orange, it suggests it must be Fe^{3+}.

23.b.

Marking Criteria	Marks
• Provides a sound description of the chemical basis of the test involving addition of acidified MnO_4^- including relevant half-equations or a net ionic equation, and relates the observations and knowledge of the reaction types to the inferred Fe ion present.	**3**
• Provides some features of the chemical basis behind the test including a relevant equation, and relates the observation made to the inferred Fe ion present.	**2**
• Provides some relevant information.	**1**

The addition of acidified $KMnO_4$ (aq) to the unknown results in a redox reaction occurring between the MnO_4^- is a powerful oxidant, and the iron ions in the unknown.
The fact that a colour change occurs in the MnO_4^-, demonstrates a change in the oxidation state of the Mn occurs, hence it is reduced, according to the equation.
$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$
Purple colourless
This reaction demonstrates that the iron in the unknown must be oxidised by the MnO_4^-, i.e., the following reaction occurs.
$Fe^{2+} \rightarrow Fe^{3+} + e^-$
If the Fe in the unknown solution was Fe^{3+}, it would not be oxidised by the MnO_4^-, and no change in colour would be observed. Therefore, results of this test suggest the Fe in the unknown was Fe^{2+}.

24.a.

Marking Criteria	Marks
• Provides IUPAC name	**1**

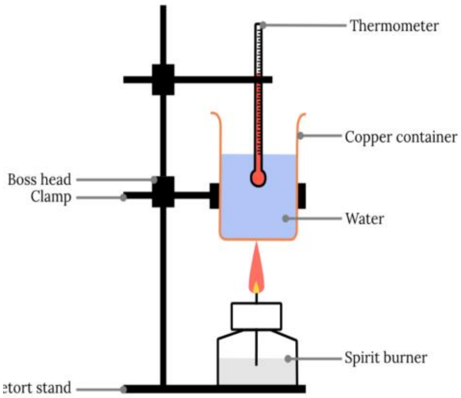
2-methylpropan-1-ol

24.b.

Marking Criteria	Marks
• Describes a procedure with justified safety precaution, labelled diagram of apparatus used, and a step to minimise heat loss to the surroundings.	**4**
• Mostly complete procedure.	**3**
• Some steps taken towards measuring the heat of combustion.	**2**
• A relevant step.	**1**

Measure and record mass of water, m_{water}, in beaker using electronic balance.
Measure and record mass of isobutanol. m_{fuel}, in spirit burner using electronic balance. Ensure no isobutanol has dripped or spilled outside of the spirit burner so that unexpected flames are not produced.

Construct the apparatus as shown in the diagram.



Record temperature of water T_i.
Cover beaker on all sides and top with aluminium foil, leaving only the bottom exposed.
Ignite isobutanol in spirit burner and keep flame as close to beaker as possible.
When isobutanol supply is exhausted, record water temperature, T_f.
Use $Q = m_{water}c(T_f - T_i)$ to find the energy released by the combustion of isobutanol.
Use Heat of combustion $= \frac{\text{energy}}{\text{number of moles}} = \frac{Q}{\left(\frac{m_{fuel}}{MM_{isobutane}}\right)}$ to find the heat of combustion of isobutane in J mol^{-1}.

24.c.

Marking Criteria	Marks
• Explains a similarity and a difference in terms of the properties of the chemical species.	**3**
• Explains a similarity or a difference in terms of the properties of the chemical species.	**2**
• Provides some relevant information.	**1**

The empirical formula for both molecules is $C_4H_{10}O$ therefore they have the same molecular mass and the same parent ion peak in their mass spectra, at m/z = 74.
Isobutanol can break to form the fragment CH_3CHCH_3 which has a mass of 43 amu.
2-butanol can break to form the CH_3CHOH fragment which has a mass of 45 amu.
These fragments give rise to the base peaks in the respective mass spectra.

25.a.

Marking Criteria	Marks
• Correct calculation	**2**
• A correct step	**1**

Moles of HCl used: $n = cV = 0.200 \times 0.0243 = 0.00486$ moles
Mole ratio is 1:2:: Na_2CO_3::HCl, therefore $n(Na_2CO_3)$ is $0.5 \times 0.00486 = 0.00243$ moles.

25.b.

Marking Criteria	Marks
• Calculates the molecular weight and x correctly.	**3**
• As above but with an error or two.	**2**
• A correct step.	**1**

The 250.0 mL solution contained 10× as many moles as the 25.0 mL solution, i.e., 0.0243 moles.

$$M_r = \frac{3.01}{0.0243} = 123.8683 \text{ g mol}^{-1}$$
$$m(\mathrm{Na_2CO_3}) + x \times m(\mathrm{H_2O}) = 123.8683$$
$$x = \frac{123.8683 - m(\mathrm{Na_2CO_3})}{m(\mathrm{H_2O})}$$
$$x = \frac{123.8683 - 105.99}{18.016} = 0.992358$$

So x is 1.

25.c.

Marking Criteria	Marks
• Selects the correct indicator from the table and justifies the selection showing a thorough understanding of the Bronsted-Lowry theory of acids and bases, including salt hydrolysis, as well as a thorough understanding of titration theory (pH at which the indicator changes colour i.e. endpoint) is close to the pH at the equivalence point).	**4**
• Selects the correct indicator from the table and provides some justification, showing a sound understanding of the Bronsted-Lowry theory of acids and bases, as well as some understanding of titration theory (pH at which the indicator changes colour i.e. endpoint) is close to the pH at the equivalence point	**3**
• Selects an indicator from the table and provides some justification, showing limited understanding of the Bronsted-Lowry theory of acids and bases and titration theory.	**2**
• Provides some relevant information.	**1**

At the equivalence point, the moles of HCl are such that the moles of the Na_2CO_3 have been consumed, leaving a solution of salt NaCl and CO_2 (g) and dissolved in water.
Water has a pH of 7, and the salt does not consist of any ion which undergoes hydrolysis to any significant extent. Na^+ ions are stable spectator ions which will be able to remove a proton from water. Cl^- is the conjugate base of a strong acid, which means it is a very weak base, and will not remove a proton from water to an extent that the pH would change.
However, CO_2 (g) dissolves in water to form the weak acid, carbonic acid.
CO_2 (g) + H_2O (l) ⇔ H_2CO_3 (aq)
H_2CO_3 can act as a proton donor, increasing the $[H_3O^+]$ according to the equation:
H_2CO_3 (aq) + H_2O (l) ⇔ HCO_3^- (aq) + H_3O^+ (aq)
The position of this equilibrium lies to the left, so the $[H_3O^+]$ is only moderately increased, and the pH will not fall below 4.
For an indicator to be effective in a titration, it must change colour close to the pH at equivalence. Of the indicators in the table, bromocresol green is the best candidate, as its pH colour range (3.8-5.4) means it will change from yellow to blue when the pH is 4. Thus the endpoint as judged by the colour change of the indicator will occur close to the equivalence point.

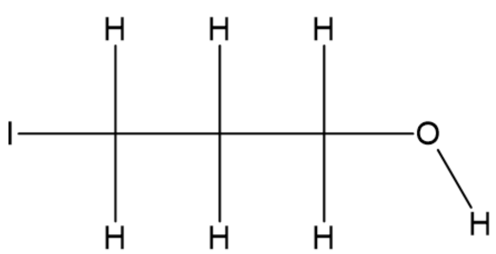
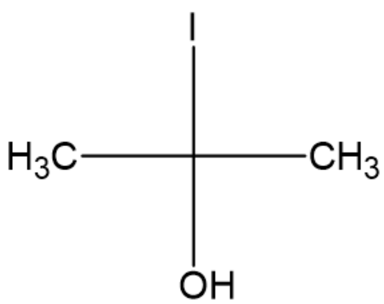
26.a.

Marking Criteria	Marks
• Identifies the two functional groups present in Unknown X and provides coherent and logical justification based on thorough knowledge of the chemical basis of the tests.	**3**
• Identifies the two functional groups present in Unknown X and provides some justification based on a satisfactory knowledge of the chemical basis of the tests. OR • Identifies one of the functional groups present in Unknown X with justification based on sound knowledge of the tests and observations made.	**2**
• Provides some relevant information.	**1**

The two functional groups which appear to be present are an iodine substituent and the hydroxyl (-OH) /alkanol) group.
Step 1: shows X is not an alkanal as no silver mirror is observed upon addition of Tollen's reagent.
Step 2: Involved refluxing X in NaOH. This resulted in a solution which forms a precipitate with Ag^+ ions. The precipitate is yellow and does not dissolve in conc HNO_3. This is consistent with iodide ions. From this, we can infer X underwent substitution when reacted with NaOH (where an I atom from X is removed and replaced by an -OH group.
$X\text{-}I + OH^- \rightarrow X\text{-}OH + I^-$
Step 3: The observation of a colour change in $Cr_2O_7^{2-}$ solution when added to X demonstrates the dichromate is reduced to green Cr^{2+}, hence we can infer X has been able to be oxidised.
This means X could be a primary alkanol or alkanal, but Step 1 shows X was not an alkanal.
Step 4: Shows the mixture for Step 1 now includes an alkanal, as a silver mirror is now observed. This is consistent with X being a primary alkanol, as these can be oxidised under mild conditions to alkanals.

26.b.

Marking Criteria	Marks
• Draws two structural formula for X and Y consistent with observations from tests AND names each correctly.	**3**
• Draws a structural formula for X OR Y consistent with observations from tests AND names at least one of the structures correctly.	**2**
• Provides some relevant information.	**1**

X	Y
	
Other answers are possible but X must be primary alkanol. I atom can be on any C. Name: 3-iodopropan-1-ol	This is the only structure consistent with test observations. Name: 2-iodopropan-2-ol

27.a.

Marking Criteria	Marks
• Uses structural formula to show the balanced chemical equation for the esterification reaction.	**2**
• Uses structural formula to show the balanced chemical equation for the esterification reaction, with a significant error.	**1**

27.b.

Marking Criteria	Marks
• Writes a correctly balanced chemical equation.	**1**

$NaOH(aq) + CH_3COOH(aq) \rightarrow NaCH_3COO\ (aq) + H_2O\ (l)$

27.c.

Marking Criteria	Marks
• Calculates the correct number of moles of CH_3COOH remaining in the sample tested.	**2**
• Calculates the correct number of moles of CH_3COOH in the titrated sample.	**1**

n(NaOH) = cV = 0.4 x 0.0212 = 0.00848 mol
Thus $n(CH_3COOH)_{\text{remaining in equilibrium mixture}}$ = 0.00848 mol (1 : 1 ratio)
This is for 1.0g sample.
Moles remaining in mixture 0.00848 × 8.64 = 0.073 mol in total

27.d.

Marking Criteria	Marks
• Writes the expression for the equilibrium constant.	**1**

$K = [C_3H_6O_2]\ [H_2O]\ /\ [C_2H_4O_2][CH_3OH]$

27.e.

Marking Criteria	Marks
• Calculates K for the reaction from the data provided with sufficient working.	**2**
• Completes one correct step in the calculation.	**1**

From Step (c)

	$C_2H_4O_2$	CH_3OH	$C_3H_6O_2$ +	H_2O
I	0.08	0.12		
C	-0.007	-0.007	+0.007	+0.007
E	0.073	0.113	0.007	0.007

$K = 0.007^{2} / 0.073 \times 0.113 = 0.007^2 / 0.008249 = 0.000049 / 0.008249 = 0.0059$

27.f.

Marking Criteria	Marks
• Identifies the reason for adding [H_2SO_4] is an esterification reaction.	**1**

Addition of concentrated H_2SO_4 is due to the fact it acts a catalyst for the esterification reaction, increasing the reaction rate.
OR
Concentrated H_2SO_4 acts as dehydrating agent and bonds to free water molecules, thus causing a shift to the right, increasing the yield of ester.

27.g.

Marking Criteria	Marks
• Provides a reason for not adding H_2SO_4 with sufficient chemical justification.	**2**
• Identifies a reason for not adding H_2SO_4 without sound justification.	**1**

Since the equilibrium mixture was analysed by titration with NaOH, any H_2SO_4 added would still remain (as a catalyst is not consumed by a reaction), and this would also react with the NaOH, thus not allowing for an accurate estimate for only the CH_3COOH remaining in the equilibrium mixture. Thus any estimate of K based on the investigation would be inaccurate.

27.h.

Marking Criteria	Marks
• Identifies omitting the catalyst will result in a level of inaccuracy in the estimate of K, with an explanation that demonstrates a thorough knowledge of acid-base and equilibrium concepts.	**3**
• Identifies omitting the catalyst will result in a level of inaccuracy in the estimate of K, with an explanation that demonstrates sound knowledge of acid-base and equilibrium concepts.	**2**
• Provides some relevant information.	**1**

The omission of H_2SO_4 in the initial esterification step will result in a level of inaccuracy in the estimate for K. Since the catalyst was not added, it will take the system longer to come to a state of equilibrium, as catalysts speed up both the forward and reverse rate but do not affect the position of equilibrium. The system analysed is approaching equilibrium from the left. If it was not actually at equilibrium, the value for the moles of CH_3COOH remaining may be too high, resulting in an estimate of K lower than the actual accepted value.

28.a.

Marking Criteria	Marks
• Writes balanced equation for complete oxidation of glucose	**1**

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

28.b.

Marking Criteria	Marks
• Correctly calculates the hourly energy requirement.	**2**
• Completes some correct steps.	**1**

$$n = \frac{m}{MM} = \frac{36.0}{(12.01 \times 6) + (1.008 \times 12) + (16.00 \times 6)}$$
$$n = \frac{36.0}{180.156} = 0.199827 \text{ moles}$$
$$\text{Hourly energy requirement} = 0.199827 \times 2800 = 559.5 \text{ kJ}$$

28.c.

Marking Criteria	Marks
• Correctly calculates the volume of oxygen.	**2**
• Completes some correct steps.	**1**

$$n = 6 \times 0.199827 = 1.198961 \text{ moles}$$
$$V = 24.79 \times 1.198961 = 29.7 \text{ L}$$

28.d.

Marking Criteria	Marks
• Provides net ionic equation for the equilibrium between carbon dioxide and carbonic acid. Explains the change in blood pH with reference to the increase in carbonic acid.	**3**
• Explains the change in blood pH with reference to the increase in carbonic acid but explanation may include an error or omission.	**2**
• Provides some relevant information.	**1**

Exhaled CO_2 will increase the concentration of CO_2 in the air. When the astronaut inhales this CO_2-rich air, more CO_2 will get into the bloodstream and dissolve according to:

$$CO_2(g) \rightleftharpoons CO_2(aq)$$

where $CO_2(aq)$ forms $H_2CO_3(aq)$ in combination with the water in blood. The increased carbonic acid concentration reduces the pH of the blood.

$H_2CO_3 + H_2O \rightleftharpoons HCO_3 + H_3O^+$

28.e.

Marking Criteria	Marks
• Demonstrates a thorough knowledge of buffers, their function, composition and how they are able to maintain relatively steady pH levels when additional H^+ or OH^- ions are added to the system. • Supports the answer with two relevant net ionic equations.	**4**
• Demonstrates a sound knowledge of buffers and how they are able to maintain relatively steady pH levels when additional H^+ or OH^- ions are added to the system. • Supports the answer with at least one relevant net ionic equation.	**3**
• Provides some information about the composition, function and/or chemistry involved in buffer systems.	**2**
• Provides some relevant information.	**1**

Blood is a buffered solution. This means it contains chemical species that cause it to resist changes in pH. Buffers are equimolar solutions of a weak acid and its conjugate base, or a weak base and its conjugate acid.

Blood contains carbonic acid (H_2CO_3) and its conjugate base (HCO_3^-).

The relevant equation is:

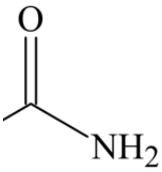
$$H_3O^+(aq) + HCO_3^-(aq) \rightleftharpoons H_2CO_3(aq) + H_2O(l)$$

According to Le Chatelier's Principle, an increase in the acid concentration pushes the equilibrium to the left, increasing the pH. An increase in the conjugate base concentration pushes the equilibrium to the right, decreasing the pH. This way blood can withstand changes to the CO_2 composition in the air, which would otherwise cause a decrease in blood pH. There is a limit, however. Large enough changes in the CO_2 composition in the air would overcome the buffer's ability to resist, and the blood would become acidic, perhaps dangerously so.

29.a.

Marking Criteria	Marks
• Draws the functional group.	**1**

$CONH_2$



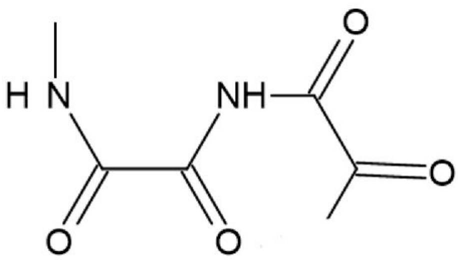
29.b.

Marking Criteria	Marks
• States that the molecules shown could not react to form a condensation polymer with sound justification demonstrating knowledge of condensation polymerisation reactions and the requirements for each reacting molecule.	**3**
• States that the molecules shown could not react to form a condensation polymer with some justification demonstrating a basic knowledge of condensation polymerisation reactions and the requirements for each reacting molecule.	**2**
• Provides some relevant information.	**1**

The molecules could not undergo a condensation polymerisation reaction because they each contain only the 1 functional group. The amide group on nicotinamide could react with the -OH in the carboxyl group on ethanolic acid, but this would only result in formation of a dimer. Since there are no functional groups of either end of the molecules, no further molecules can join to form a long-chained polymer.
For a polyamide to form, one molecule would need to be a diamide (have an amide group on each end of the molecule) and the other a dicarboxylic acid (containing a -COOH group at each end of the molecule).

29.c.

Marking Criteria	Marks
• Draws correct structural formula and names the by-product.	**2**
• Either draws the structural formula or names the by-product.	**1**



By-product: NH_3 (ammonia)

30.

Marking Criteria	Marks
• Specific evidence from all spectra used to justify chosen compound (2-methyl propanal). • Extensive understanding of each spectroscopic method demonstrated. • Correct name given. • Correct structure drawn.	**7**
• Demonstrates thorough understanding of each method to justify a structure.	**6**
• Refers to evidence from spectra that supports a named and drawn structure.	**4-5**
• Some understanding of the evidence from spectra demonstrated.	**2-3**
• Some relevant information.	**1**

Infrared
- Narrow features 2700−3000 cm^{-1} ⇒ C−H
- Large feature ~1725 cm^{-1} ⇒ C=O
- Nothing significant 3300−3500 cm^{-1} ⇒ no N−H
- No broad feature in the 2500−3550 cm^{-1} region: no O−H

Mass spectrum
- Parent ion at m/z = 72
- Base peak at 43
- Together these indicate cleavage to form fragments with masses of 43 and 29.
    - m=29 could be CH=O, which would mean that m=43 is from C_3H_7

Proton NMR
- Doublet caused by 1 hydrogen atom. This is likely CH neighbouring CH.
- Doublet caused by 6 hydrogen atoms. This is likely caused by two CH_3 groups bound to a CH.
- Complicated multiplet caused by one hydrogen atom. This is the CH that is in between a CH_2 and the $(CH_3)_2$.

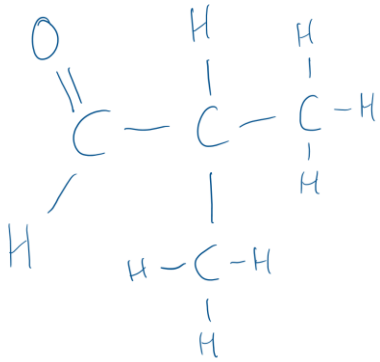
So we have CH—CH—CH_3
|
CH_3

- The terminal CH does not have enough bonds, so it is likely the site of the double-bond to oxygen:

i.e., O=CH—CH—CH_3
|
- CH_3

^{13}C NMR
- Three environments for carbon atoms.
- The peak at ~205 ppm indicates C=O in an aldehyde or ketone.
- The peak at ~41 ppm could be from a carbon atom that neighbours the C=O
- The peak at ~18 ppm could be from a carbon atom with only single bonds.

The structure that satisfies all the evidence from the spectra is that of 2-methyl propanal.



Looking back at the mass spectrum, we see the expected peaks for:
CHO at 29
CH_3 at 15 (small)
Loss of CH_3 at 57
The peak at m/z=41 is probably from C_3H_5 following the loss of the CHO fragment and two H atoms.