2022 **BORED OF STUDIES TRIAL EXAMINATION**

5th October

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A formulae sheet, data sheet and Periodic Table are provided

Total Marks: 100

Section I – 20 marks (pages 2–12)

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

Section II – 80 marks (pages 13–38)

- Attempt Questions 21–38
- 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 for Questions 1–20.

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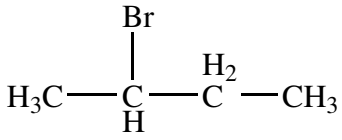
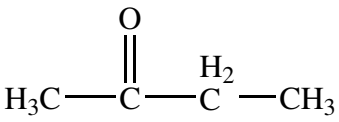
1 Which of the following compounds, when added, would decolourise bromine water?

A.



B.



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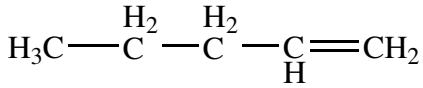

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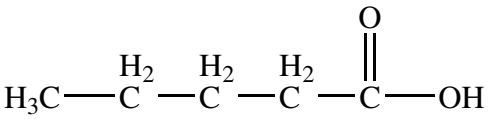


2 The combustion of octane is a non-equilibrium reaction that is commonly used as an energy source to power cars.

Which of the following options correctly describes enthalpy, entropy and Gibbs free energy values of this reaction?

	Enthalpy	*Entropy*	*Gibbs free energy*
A.	$\Delta H > 0$	$\Delta S > 0$	$\Delta G < 0$
B.	$\Delta H > 0$	$\Delta S < 0$	$\Delta G > 0$
C.	$\Delta H < 0$	$\Delta S > 0$	$\Delta G < 0$
D.	$\Delta H < 0$	$\Delta S < 0$	$\Delta G < 0$

3 Which of the following compounds has the greatest molar solubility in water at 25 °C?

A. Lead(II) chloride

B. Lead(II) sulfate

C. Calcium sulfate

D. Barium hydroxide

4 A 0.100 mol L^{-1} solution of ethanoic acid has a pH of 2.960.

What percentage of the total unionised ethanoic acid and ethanoate ion concentration consists of unionised ethanoic acid?

A. 98.9%

B. 1.01%

C. 33.8%

D. 66.2%

5 How many ^{1}H NMR and ^{13}C NMR peaks will appear in 2-hydroxypropane-1,2,3-tricarboxylic acid (citric acid)?

	Number of peaks in ^{1}H NMR	*Number of peaks in ^{13}C NMR*
A.	3	3
B.	4	4
C.	3	4
D.	4	3

6 Calcite is a mineral that is primarily composed of calcium carbonate.

A sample of 12.95 g of calcite containing 95% calcium carbonate was heated to produce calcium oxide and carbon dioxide. No calcium is present in the impurity.

What is the mass of calcium oxide produced after the reaction concludes?

A. 6.89 g

B. 5.21 g

C. 4.78 g

D. 0.689 g

7 Which of the following compounds is an isomer of ethyl propanoate?

A. Butanal

B. Pentan-3-one

C. Butanoic acid

D. 2-methylbutanoic acid

8 A chemist reacts hydrogen chloride with pure oxygen to form chlorine gas and water vapour in an equilibrium reaction.

If the chemist replaces pure oxygen with air from the atmosphere, whilst keeping the total pressure constant, how will it likely affect the equilibrium?

A. Decreases forward rate of reaction and increases the yield of chlorine gas

B. Increases forward rate of reaction and increases the yield of chlorine gas

C. Decreases forward rate of reaction and decreases the yield of chlorine gas

D. Increases forward rate of reaction and decreases the yield of chlorine gas

9 A 450 mL solution of $0.15\,\text{mol}\,\text{L}^{-1}$ nitric acid was mixed with 250 mL of $0.10\,\text{mol}\,\text{L}^{-1}$ barium hydroxide in a beaker. What is the pOH of the solution in the beaker?

A. 1.60

B. 12.40

C. 12.39

D. 1.61

10 Soaps and detergents are vital materials used in everyday life to clean and wash clothing and glassware. What are their roles in removing grease from surfaces?

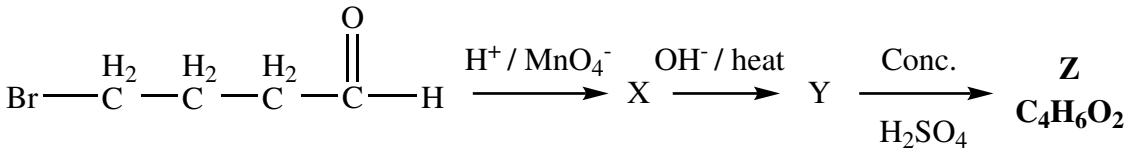
A. They are emulsifiers and will increase cohesive forces.

B. They are emulsifiers and will decrease cohesive forces.

C. They are stabilisers and will increase cohesive forces.

D. They are stabilisers and will decrease cohesive forces.

11 The following chemical pathway was used to produce a compound Z with chemical formula $C_4H_6O_2$. Compound Z then underwent polymerisation to produce a polymer that had a molar mass of 1.03×10^5 g mol^{-1}.



What is the approximate number of carbon atoms that make up this polymer?

A. 1200

B. 946

C. 3782

D. 4800

The following information applies to both question 12 and 13.

A student attempts to determine the enthalpy of neutralisation for the reaction between hydroioidic acid (HI) and sodium hydroxide (NaOH). The student mixes 90.0 mL of equimolar 1.00 mol L^{-1} solutions of HI and NaOH into a copper calorimeter and records a temperature increase of 4.43 K.

12 What is the empirical molar enthalpy of neutralisation?

A. -37.0 kJ mol^{-1}

B. -18.5 kJ mol^{-1}

C. -37.0×10^3 kJ mol^{-1}

D. -18.5×10^3 kJ mol^{-1}

13 The student repeated the same experiment with the same volume, concentrations and equipment, but with hydrobromic acid (HBr) and potassium hydroxide (KOH) instead.

The empirical molar enthalpy of neutralisation would be

A. more negative than the original experiment.

B. less negative than the original experiment.

C. approximately the same as the original experiment.

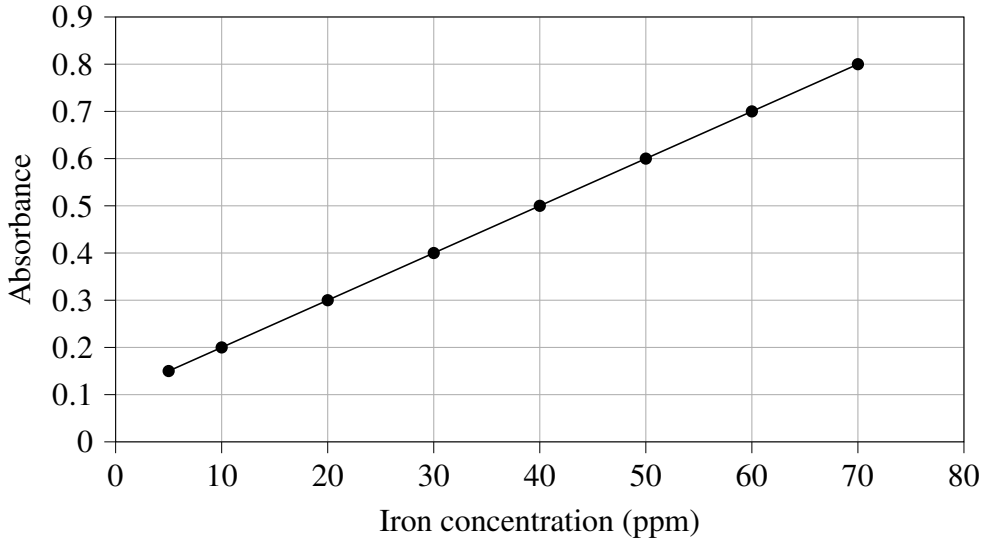
D. different from the original experiment, but more or less negative cannot be predicted.

The following information applies to both question 14 and 15.

Atomic absorption spectroscopy was used to analyse a set of standard solutions of iron. The results are presented in the table and its corresponding calibration curve below.

Concentration of iron (ppm)	5	10	20	30	40	50	60	70
Absorbance	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80

This calibration curve was used by a student to determine the iron concentration in nearby lakes at two separate sites. The results of this analysis and the concentrations found are given below.



This calibration curve was used by a student to determine the iron concentration in nearby lakes at two separate sites. The results of this analysis and the concentrations found are given below.

Sample location	*Absorbance*	*Concentration* (ppm)
Site A	0.35	25
Site B	0.90	80

14 Which of the following statements correctly describes the validity and reliability of the data collected at Site A and B?

A. The data at Site A is valid and reliable, while the Site B data is invalid and unreliable.

B. The data at Site A is valid and unreliable, while the Site B data is invalid and unreliable.

C. The data at both Site A and B is invalid and unreliable.

D. The data at both Site A and B is valid and reliable.

15 The student was also asked to use the same calibration curve to analyse the iron content of a 200 mg iron supplement tablet using the following process.

The tablet was crushed, dissolved and made up to a volume of 200 mL. 10.0 mL of this solution was further diluted to 100.0 mL. The absorbance of this resulting solution was 0.45.

What is the percentage by mass of iron in the tablet?

A. 3.5%

B. 0.18%

C. 35%

D. 18%

16 Hypochlorous acid (HOCl) is a weak acid which ionises to form the hypochlorite and hydronium ions in water in an equilibrium reaction:

$$HOCl(aq) + H_2O(l) \rightleftharpoons OCl^-(aq) + H_3O^+(aq)$$

Which of the following salts can increase the degree of ionisation of hypochlorous acid, when added into reaction?

A. Sodium chloride

B. Sodium nitrate

C. Ammonium nitrate

D. Sodium acetate

17 Throughout history, the definition of an 'acid' and a 'base' has constantly evolved to holistically encompass the properties of certain substances with each other.

Which of the following contains an acid and a base, one of which cannot be explained by Arrhenius theory, yet both of which can be explained by Bronsted-Lowry theory?

A. Na_2O and $Ba(OH)_2$

B. C_3H_9N and NaOH

C. $C_{17}H_{35}COONa$ and $C_6H_8O_7$ (citric acid)

D. $C_6H_{12}O_6$ (glucose) and CH_3CONH_2

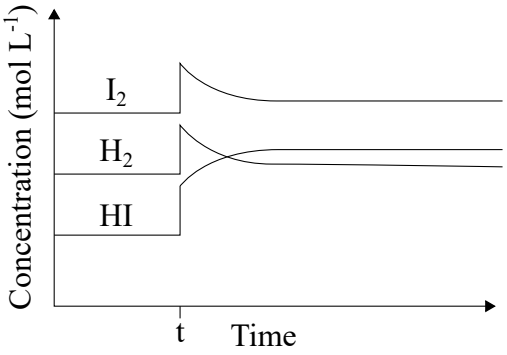
18 Hydrogen iodide (HI) can be formed from the reversible reaction of iodine and hydrogen gas:

$$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$$

A system of HI, H_2 and I_2 was initially at equilibrium. At time t, the pressure of the system was increased by compressing the system.

Which of the following graphs best represents the changes in concentration of the equilibrium mixture?

A.



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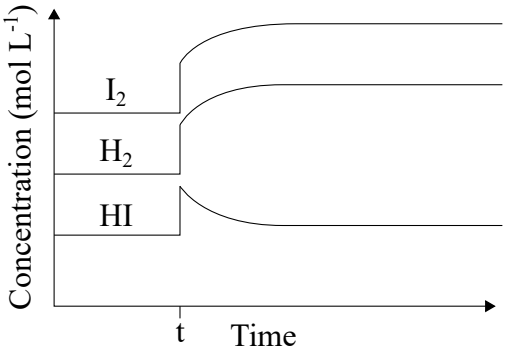

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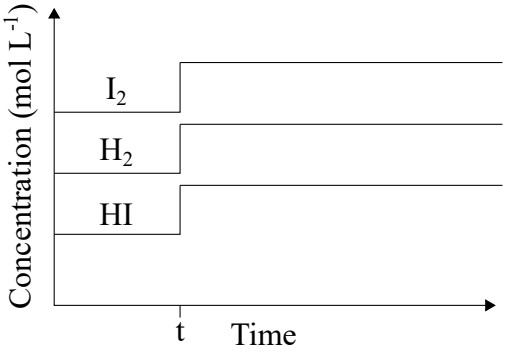
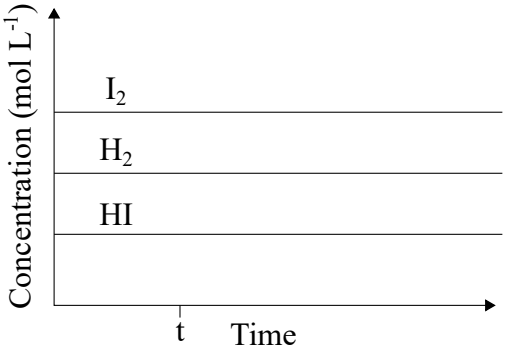


D.



19 A student prepared two solutions in separate beakers by mixing different chemicals.

In Beaker A, 50 mL of 0.01 mol L^{-1} HNO_3 was mixed with 50 mL of 0.01 mol L^{-1} $NaNO_3$.

In Beaker B, 50 mL of 0.01 mol L^{-1} KH_2PO_4 was mixed with 50 mL of 0.01 mol L^{-1} K_2HPO_4.

5 mL of 0.01 mol L^{-1} NaOH was added to each beaker.

Which of the following correctly describes the effect on the pH after adding the NaOH to each beaker?

	pH in beaker A	*pH in beaker B*
A.	Increases	Remains relatively stable
B.	Remains relatively stable	Increases
C.	Decreases	Remains relatively stable
D.	Decreases	Decreases

20 In a titration of standardised sodium hydroxide with hydrochloric acid, the following procedure was used:

1. A burette was first rinsed three times with distilled water, then three times with sodium hydroxide. The burette was then filled with the sodium hydroxide.
2. A conical flask was rinsed three times with distilled water.
3. A pipette was rinsed three times with distilled water. Hydrochloric acid was pipetted into the conical flask immediately after rinsing.
4. Three drops of phenolphthalein were added to the conical flask and titrated with the sodium hydroxide.

Based on the above procedure, the calculated concentration of hydrochloric acid from the titration is most likely to be

A. approximately the same as the actual concentration.

B. below the actual concentration.

C. above the actual concentration.

D. different from the actual concentration, but above or below cannot be predicted.

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Chemistry

Section II Answer Booklet 1

80 marks
Attempt Questions 21–38
Allow about 2 hours and 25 minutes for this section

Booklet 1 – Attempt Questions 21–31 (40 marks)
Booklet 2 – Attempt Questions 32–38 (40 marks)

Instructions

- Write your student number, username and name on the top right of this page.
- 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.
- If you require extra writing space, please ask for a writing booklet. If you use a writing booklet, clearly indicate which questions you are answering.

Please turn over

Question 21 (5 marks)

An ester is produced from a 10.0 g sample of propan-1-ol.

During its production from propan-1-ol, only inorganic reactants were used but there were no carbon-carbon bonds broken.

(a) The ester was produced using reflux. Outline the purpose of refluxing. **2**

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(b) Calculate the maximum possible mass of the ester produced. Show the relevant reaction scheme. **3**

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Question 22 (3 marks)

The table below shows the boiling points of straight chain alcohols and esters of similar carbon atom numbers. **3**

Alcohol	*Boiling point* (°C)	*Ester*	*Boiling point* (°C)
CH_3CH_2OH	78	$CHCOOCH_3$	32
$CH_3(CH_2)_2OH$	97	CH_3COOCH_3	57
$CH_3(CH_2)_3OH$	118	$CH_3CH_2COOCH_3$	80
$CH_3(CH_2)_4OH$	138	$CH_3(CH_2)_2COOCH_3$	102
$CH_3(CH_2)_5OH$	157	$CH_3(CH_2)_3COOCH_3$	126

Explain the trends in boiling point in the table with reference to intermolecular forces.

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Question 23 (3 marks)

The solubility of radium sulfate ($RaSO_4$) in water at 25 °C is 2.1×10^{-3} g L^{-1}. Find the value of K_{sp}, given the molar mass of $RaSO_4$ is 322.06 g mol^{-1}. **3**

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Question 24 (3 marks)

A student mixed 20 mL of 0.0100 mol L^{-1} barium chloride with 20 mL of 0.0200 mol L^{-1} silver nitrate. **3**

Determine whether a precipitate will form. Justify your answer.

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Question 25 (5 marks)

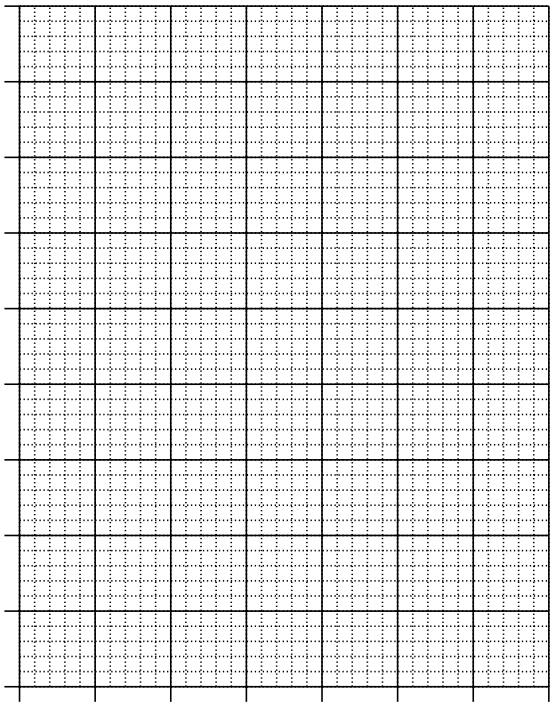
A student was provided with a spirit burner containing an unknown alcohol and was asked to determine the identity of this alcohol.

The student performed an experiment to determine the heat of combustion of this alcohol using 250.0 mL of water in a calorimeter. The spirit burner initially weighed 120.00 g. After the experiment, it weighed 119.06 g.

The following temperature data was collected.

Time (min)	0	0.5	1	2	3	4	5	6
Temperature of water (°C)	20.0	22.0	24.0	28.0	32.0	36.0	32.0	28.0

(a) By graphing the temperature over time, calculate the experimental heat of combustion in kJ g^{-1} for this unknown alcohol. **3**



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Question 25 continues on page 18

(b) The heat of combustion experiment the student performed is prone to heat loss. Assume that 40% of the heat was lost to the surroundings. **2**

Given that the molar heat of combustion of this unknown alcohol is $-1370\ \text{kJ mol}^{-1}$, determine the identity of the unknown alcohol. Justify your answer using a calculation.

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End of Question 25

Question 26 (3 marks)

The pK_a for nitrous acid (HNO_2) is 3.16 at 25 °C. **3**

Calculate the pH of a solution of 0.200 mol L^{-1} of sodium nitrite.

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Question 27 (5 marks)

Hydrocyanic acid (HCN) is a weak acid with $K_a = 6.2 \times 10^{-10}$ at temperature 298 K.

A student prepared a solution in a laboratory mixing 100 mL of 0.10 mol L^{-1} HCN with 100 mL of 0.10 mol L^{-1} KCN.

(a) Calculate the pH of the solution. **3**

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(b) Explain how the solution can be considered appropriate as a buffer. **2**

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Question 28 (4 marks)

A 1.0 L vessel at temperature of 300 K is filled with 0.10 mol of nitrogen monoxide gas, 0.050 mol of hydrogen gas and 0.10 mol of water vapour. The reaction of the gases reaches an equilibrium.

(a) Write down the chemical equation of the equilibrium reaction in the vessel. **1**

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(b) At equilibrium, the concentration of the nitrogen monoxide is 0.062 mol L^{-1}. Calculate the value of the equilibrium constant of the reaction based on your chemical equation written in part (a). **3**

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Question 29 (3 marks)

Explain why a titration between ammonia and butanoic acid is better monitored using a pH probe rather than chemical indicators. **3**

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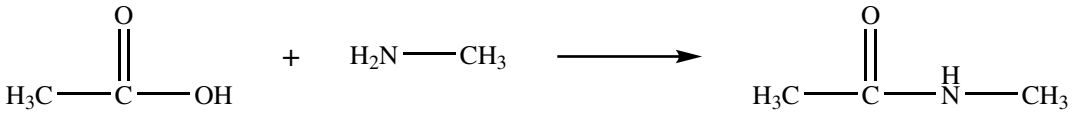
Question 30 (3 marks)

The pK_b of methanamine is 3.34 and the pK_a of acetic acid is 4.76. **3**

Explain why the following reaction cannot be conducted directly with good yield. Show all calculations.



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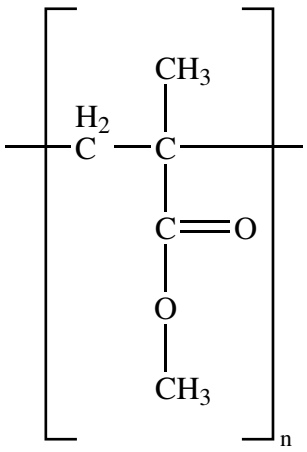
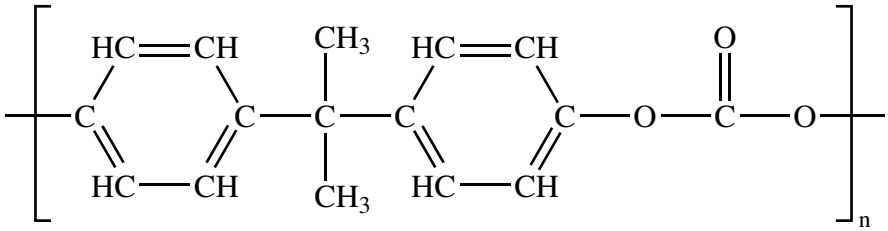
Question 31 (3 marks)

The chemical structures of two polymers are provided below. **3**



polymethyl methacrylate



polycarbonate

Which polymer is more brittle than the other? Justify your answer.

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Chemistry

Section II Answer Booklet 2

Booklet 2 – Attempt Questions 32–38 (40 marks)

Instructions

- Write your student number, username and name on the top right of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
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Please turn over

Question 32 (5 marks)

The fermentation of compound A ($C_6H_{12}O_6$) produces a main target product compound B (C_2H_6O). This process also produces several by-products with the following chemical formulae, where *a* and *b* are unknown integers: **5**

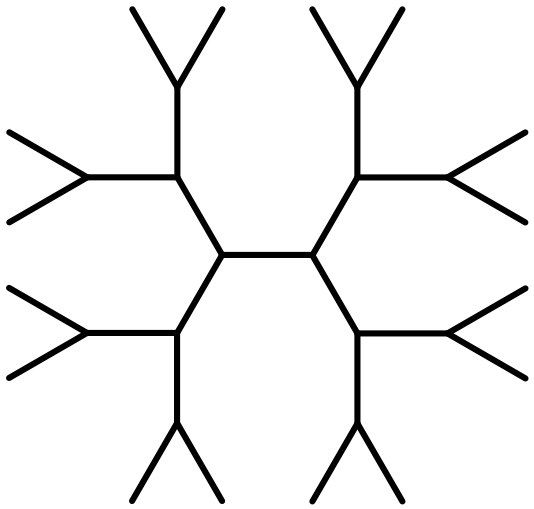
- Compound C ($C_2H_aO_2$)
- Compound D ($C_3H_bO_3$)
- Compound E ($C_4H_6O_4$)

Compound C, D and E underwent chemical tests with acidified $KMnO_4$ and aqueous $NaHCO_3$.

The results are shown in the following table.

Compound	*Colour after addition of acidified $KMnO_4$ solution*	*Observation after addition of aqueous $NaHCO_3$ solution*
C	Purple	Bubbles produced
D	Colourless	No change
E	Purple	Bubbles produced

Compound D and compound E each have two peaks in their ^{13}C NMR spectra. Also, they react with each other to form a two-dimensional polymer with the following geometric structure.



Question 32 continues on page 25

Question 32 (continued)

Draw the following chemical structures. Justify your answers.

Compound B	Compound C
Compound D	Compound E

Polymer formed from reaction of D and E

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End of Question 32

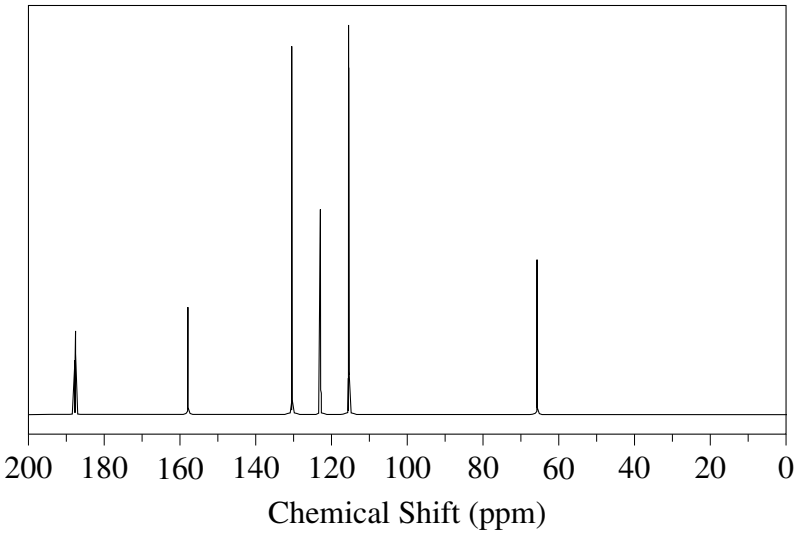
Please turn over

Question 33 (5 marks)

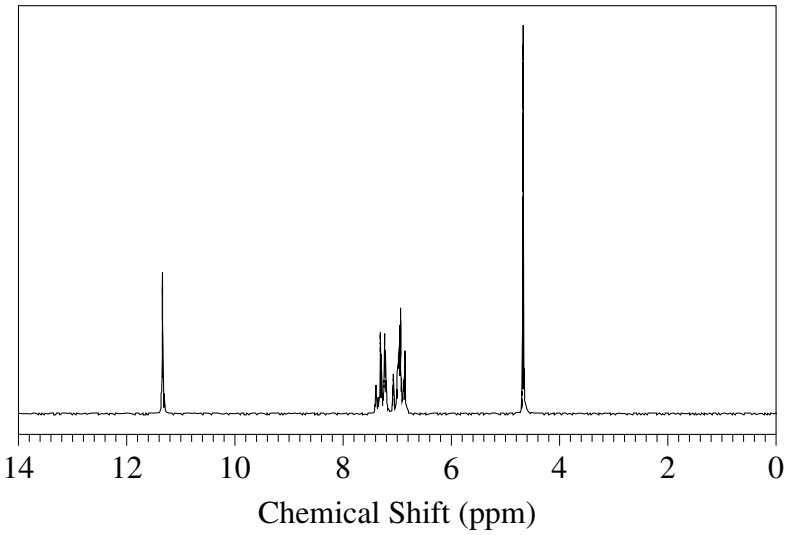
A chemist obtained ^{13}C NMR and proton NMR spectral data of an unknown compound as shown below. **5**

The chemist is aware that the compound has the molecular formula $C_8H_8O_3$.

Carbon-13 NMR



Proton NMR



Question 33 continues on page 27

Question 33 (continued)

For the proton NMR spectrum, the following additional information is provided.

Chemical shift (ppm)	*Multiplicity*	*Number of hydrogens*
4.67	Singlet	2
6.91	Doublet	2
7.01	Triplet	1
7.28	Triplet	2
11.34	Singlet	1

With reference to the data provided, draw the structure of the compound. Justify your answer.

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End of Question 33

Please turn over

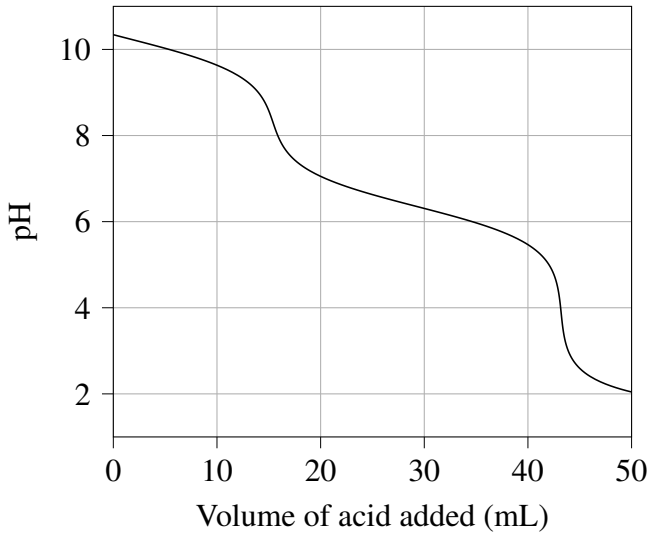
Question 34 (5 marks)

A student has a 1500 mL sample of freshly prepared sodium hydroxide solution. They titrate 25.00 mL of the solution against 0.1006 mol L^{-1} hydrochloric acid using phenolphthalein indicator. The titres are recorded as below. **5**

Titre	*Volume of HCl(aq) added* (mL)
1	27.02
2	26.62
3	26.65
4	26.59

After the titrations, 1351 mL of the sample remains in the bottle.

The student then accidentally left the bottle of sodium hydroxide open to the air for a long period of time. The student then takes 25.00 mL from this bottle and titrates it against 0.0998 mol L^{-1} hydrochloric acid. The solution was monitored by a pH meter, which showed the following graph.



Question 34 continues on page 29

Question 34 (continued)

Explain how the bottle of sodium hydroxide being left open affected the results of the subsequent titration. Include relevant calculations in your answer.

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End of Question 34

Please turn over

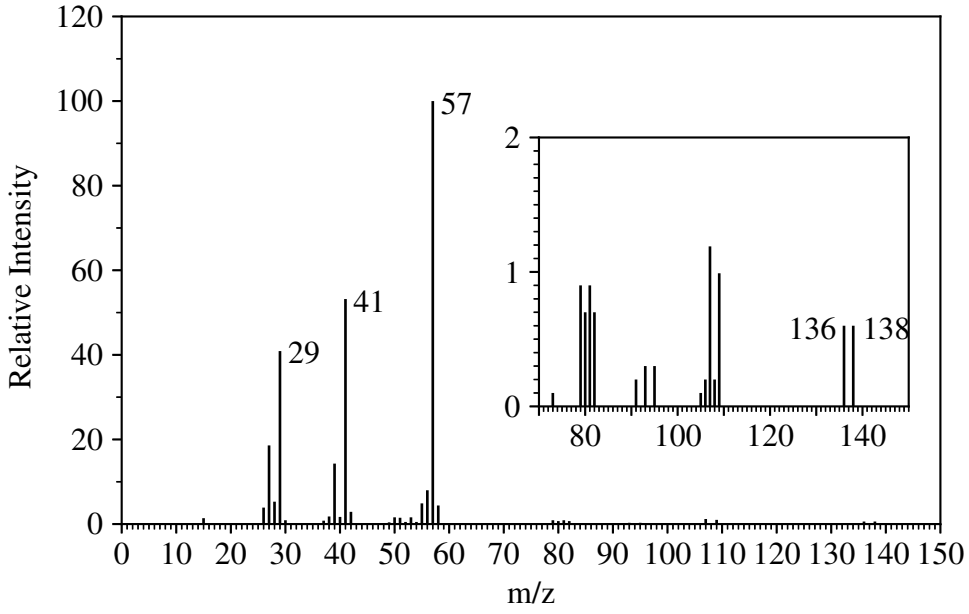
Question 35 (5 marks)

The flowchart shown on the next page shows seven distinct chemical compounds A, B, C, D, E, F and G. Each arrow represents one of the following reagents and conditions: **5**

- Reaction with concentrated H_2SO_4
- Reaction with ethanolic KOH
- Reaction with H_2 through a palladium on carbon catalyst
- Reaction with an elemental halogen under UV light

The boiling point of compound G is higher than the boiling point of compound B.

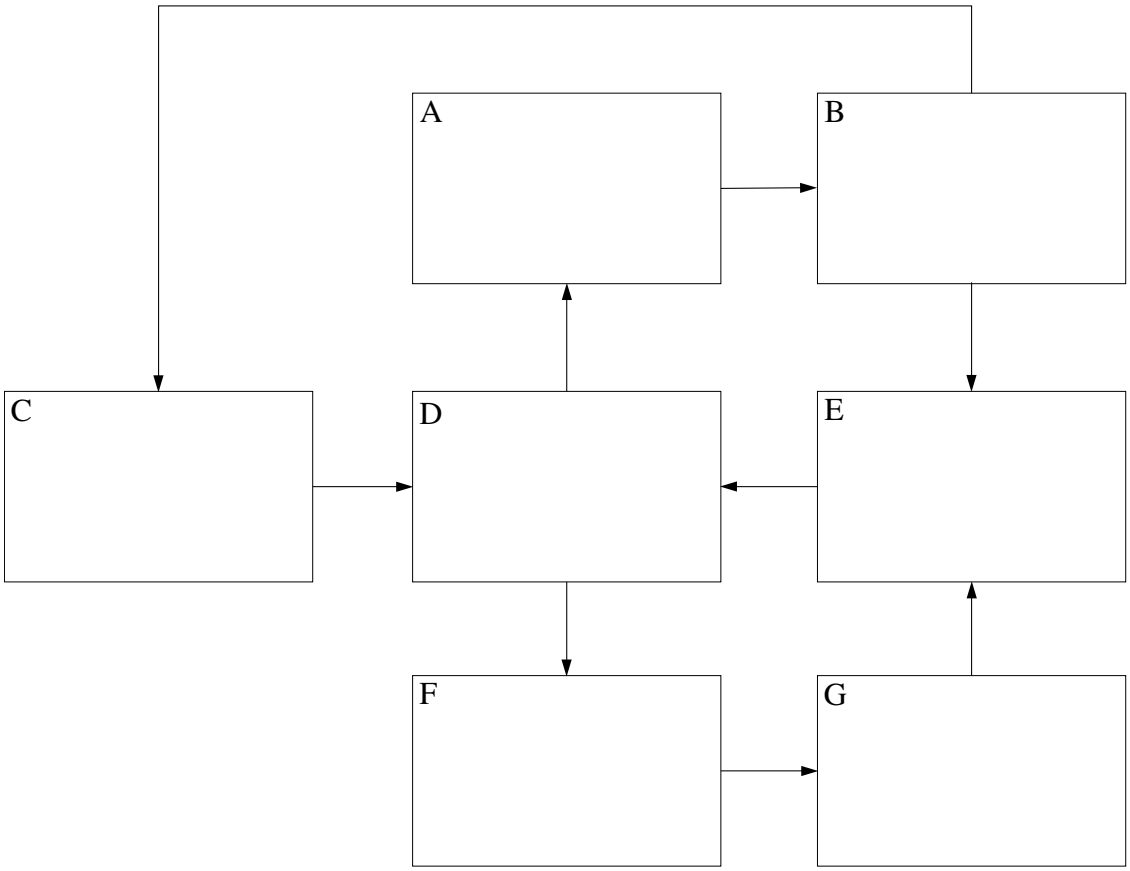
The mass spectrum of one of the seven compounds is shown below.



Question 35 continues on page 31

Question 35 (continued)

Complete the flow chart by drawing the structural formulae for the compounds A, B, C, D, E, F and G.



End of Question 35

Please turn over

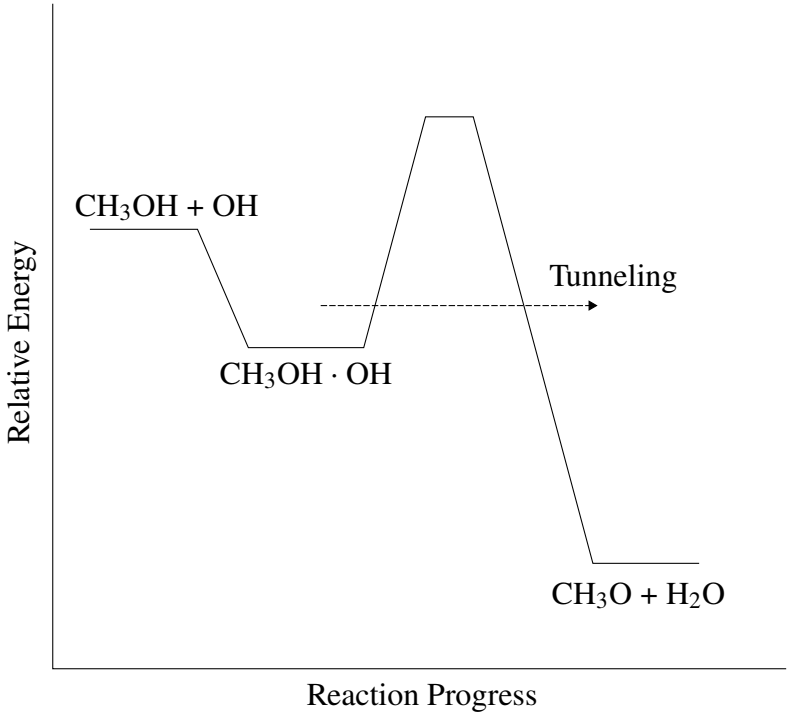
Question 36 (5 marks)

A reaction sequence between methanol and a hydroxy species (OH) is shown in the chemical equations below.

$$CH_3OH(g) + OH(g) \rightleftharpoons CH_3OH \cdot OH(g)$$

$$CH_3OH \cdot OH(g) \longrightarrow CH_3O(g) + H_2O(g)$$

The following diagram shows the relative energy of the different species on the pathway to the formation of products.



The arrow in the diagram represents "tunelling effects", which enable reactants that do not have sufficient activation energy to cross the barrier at a low rate.

The reaction is carried out in an inert atmosphere of helium gas.

Assume the concentration of each mentioned species, except the helium gas, is low.

Question 36 continues on page 33

Question 36 (continued)

(a) Explain why the formation of the final products can be seen as irreversible but the formation of the $CH_3OH \cdot OH$ gas must be considered as reversible. **1**

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(b) By considering collision theory and other effects, explain how the rate of formation of CH_3O gas is affected by the temperature of the reactants and the pressure of helium gas. **4**

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End of Question 36

Please turn over

Question 37 (7 marks)

A student is given unknown compounds A, B and C. The following information is known about the compounds: **7**

- There are exactly four distinct elements amongst the three compounds
- Compound A contains two ions in a 1:1 molar ratio
- Compound B contains an element that compound C does not
- Addition of aqueous ammonia to 1.000 g of compound A dissolved in water leads to the formation of 0.7794 g of compound B as a precipitate, which is then converted to compound C as a solid after heating.

The student performs two different sets of titrations on:

- 1.000 g of compound A dissolved in neutral aqueous buffer
- 0.7794 g of compound B dissolved in neutral aqueous buffer

Each of the precipitation titrations used a barium nitrate solution which reacts with various neutral buffered solutions to form a precipitate with $K_{sp} = 1.08 \times 10^{-10}$. The buffer acts only as a proton donor or acceptor.

The average volume of $0.1000\,\text{mol}\,\text{L}^{-1}$ barium nitrate solution that must be added to reach the equivalence point in the titration is given by V_{eq} in the table below.

Compound which titration was performed on	V_{eq} (mL)
Compound A	46.56
Compound B	15.52

Assume all reactions give a 100% yield.

Question 37 continues on page 35

Question 37 (continued)

Identify the chemical formulas for compounds A, B and C. Justify your answer.

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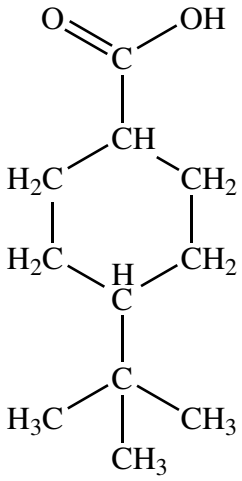
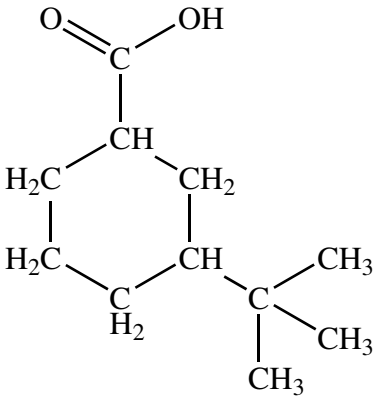
End of Question 37

Please turn over

Question 38 (8 marks)

A HSC student has samples of two structurally similar carboxylic acids shown below. **8**





The student has access to chemicals, laboratory equipment and instruments encountered or discussed in the HSC course (this includes the relevant spectrometers, any chemical reagents and any glassware), with the exception of pH meters and pH indicators.

Question 38 continues on page 37

Question 38 (continued)

Propose a method the student could use to determine the difference in pK_a between the two acids as accurately as possible. Include qualitative descriptions of how calculations may be carried out by hand and calculator to find the difference in pK_a.

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Section II extra writing space

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

Do NOT write in this area.