2019

JAMES RUSE AGRICULTURAL HIGH SCHOOL

TRIAL HSC EXAMINATION

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- NESA approved calculators may be used
- A formula sheet, data sheet and Periodic Table are provided at the back of this paper
- For questions in Section II, show all relevant working in questions involving calculations

Total Marks – 100

Section I – 20 marks (pages 3-10)

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

Section II – 80 marks (pages 12-25)

- Attempt questions 21-33
- 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
Mark your answers on the ANSWER grid in the Answer booklet on page 11.

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

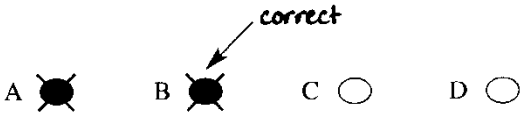
Sample: $2 + 4 =$ (A) 2 (B) 6 (C) 8 (D) 9

A ○ B ● C ○ D ○

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

A ● B ⊗ C ○ D ○

If you 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. What is the conjugate acid of the hydrogen sulfate ion?

   A. HSO_3^-

   B. H_2SO_4

   C. H_3O^+

   D. SO_4^{2-}

2. Which catalyst is used in the production of an ester?

   A. Concentrated sulfuric acid

   B. Iron oxide

   C. Palladium

   D. Dilute phosphoric acid

3. The table below gives the colour and pH range for some acid/base indicators.

Indicator	*Colour in low pH*	*Colour in high pH*	*pH range*
Cresol red	red	yellow	0.2 – 1.8
Methyl orange	red	yellow	3.1 – 4.4
Bromocresol green	yellow	blue	3.8 – 5.4
Bromothymol blue	yellow	blue	6.0 – 7.6

   Which indicators could be used to identify rainwater with a pH of 5.6?

   A. Methyl orange and bromocresol green

   B. Bromothymol blue and cresol red

   C. Methyl orange and bromothymol blue

   D. Bromocresol green and bromothymol blue

4. Which of the following metal ions would exhibit a green colour during a flame test?

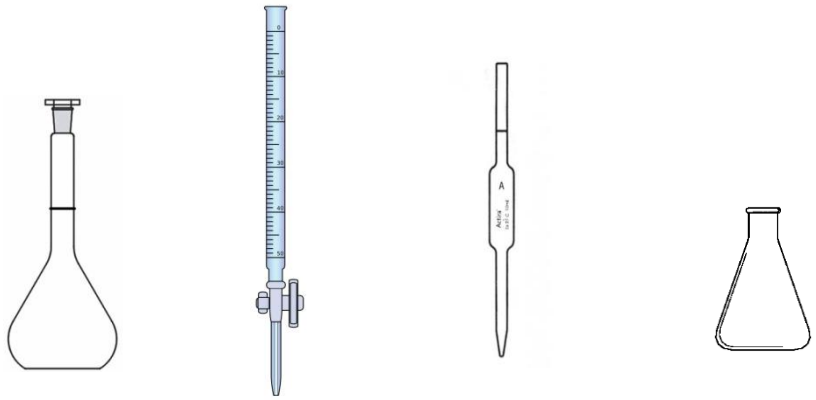
A. Iron

B. Copper

C. Calcium

D. Magnesium

5. Which type of glassware is used to prepare a primary standard solution for titration?



W X Y Z

A. W

B. X

C. Y

D. Z

6. Which equation shows water acting as a Brönsted/Lowry acid?

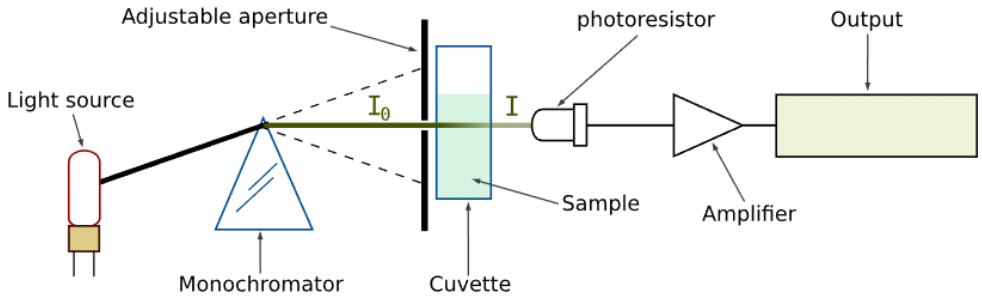
A. $H_2O\ (l) + HCl\ (aq) \rightleftharpoons H_3O^+\ (aq) + Cl^-\ (aq)$

B. $H_2O\ (l) + NH_3\ (aq) \rightleftharpoons NH_4^+\ (aq) + OH^-\ (aq)$

C. $H_2O\ (l) + NaCl\ (s) \rightleftharpoons Na^+\ (aq) + Cl^-\ (aq) + H_2O\ (l)$

D. $H_2O\ (l) + HCO_3^-\ (aq) \rightleftharpoons H_3O^+\ (aq) + CO_3^{2-}\ (aq)$

7. A pale blue copper sulfate solution was analysed using the setup below.



Which analysis technique is being used?

A. Colourimetry

B Gravimetric analysis

C. Infrared spectroscopy

D. Atomic absorption spectroscopy

8. How many chain isomers does hexane have?

A. 2

B. 3

C. 4

D. 5

9. Which of the following is an organic base?

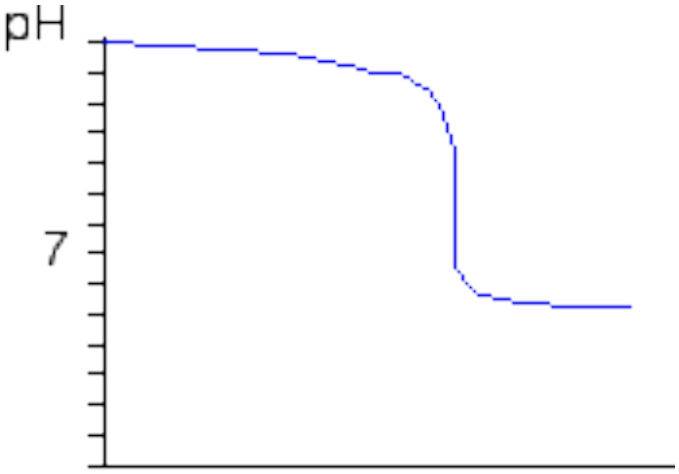
A. $CH_3CH_2CH_3$

B. C_2H_5OH

C. CH_3COOCH_3

D. CH_3NH_2

10. Consider the following titration curve below.



Which of the following solutions is most likely to be in the burette?

A. NaOH

B. $NaHCO_3$

C. CH_3COOH

D. HCl

11. The shape of ethane is best described as

A. linear.

B. trigonal planar.

C. overlapping tetrahedrons.

D. trigonal linear.

12. Which of the following conditions is least likely to enable equilibrium to be established earlier?

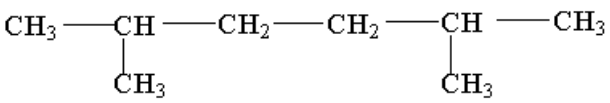
A. Higher temperatures

B. Addition of a catalyst

C. Larger reaction vessel

D. Higher concentrations of reactants

13. How many peak signals would you expect to see in the carbon NMR spectrum of the compound below?



A. 3

B. 4

C. 6

D. 8

14. Which option best accounts for the cleaning action of soap?

A. The polar alkyl tail forms dispersion forces with the oil and the carboxylate head forms dipole-dipole forces with water.

B. The non-polar alkyl tail forms dispersion forces with water and dipole-dipole forces with oil.

C. The non-polar carboxylate head forms dispersion forces with water and dipole-dipole forces with oil.

D. The polar carboxylate head forms dipole-dipole forces with water and the non-polar alkyl tail forms dispersion forces with oil.

15. Gravimetric analysis was performed on a sample of hydrated magnesium sulfate in order to determine the number of water of crystallization molecules present. It was found that after heating, the sample lost 51.2 % of its mass.

What is the value of n in this formula for hydrated magnesium sulfate ($MgSO_4 \cdot nH_2O$)?

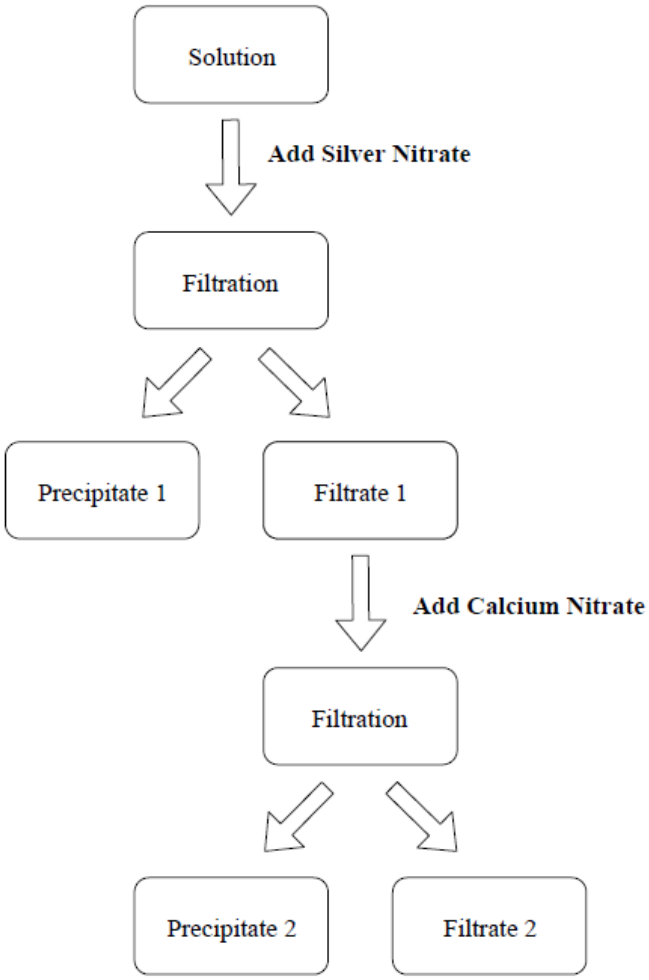
A. 5

B. 6

C. 7

D. 8

16. A solution containing hydroxide, chloride, and sulfate anions was separated using the procedure outlined in the flowchart below.



Which of the following options correctly identifies the products?

	Precipitate 1	*Precipitate 2*	*Filtrate 2*
A.	silver hydroxide	calcium chloride	sulfate solution
B.	silver sulfate	calcium chloride	hydroxide solution
C.	silver chloride	calcium sulfate	hydroxide solution
D.	silver chloride	calcium hydroxide	sulfate solution

17. Which of the following is a possible molecular ion fragment produced in the mass spectrum of pent-2-ene.

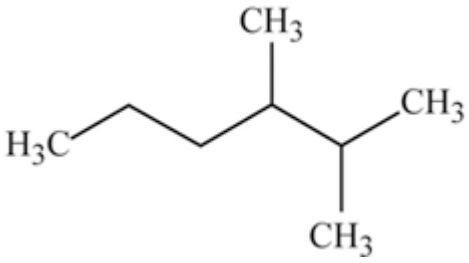
A. 28 *m / z*

B. 30 *m / z*

C. 43 *m / z*

D. 56 *m /z*

18. What is the name of this compound?



A. 1,1,2-trimethyl pentane

B. 2,3-dimethyl hexane

C. 1,1,2,4-tetramethyl butane

D. 1-ethyl-2-methyl pentane

19. What is the pOH of the final solution when 0.37 g of calcium hydroxide is reacted with 100 mL of 0.20 mol L^{-1} hydrochloric acid solution?

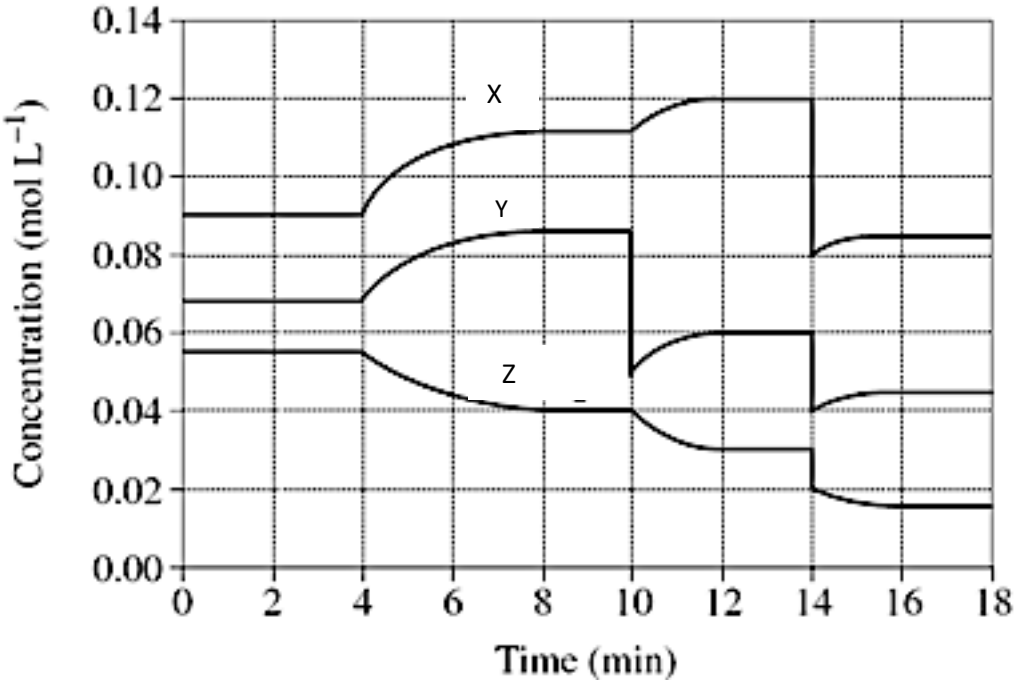
A. 0.82

B. 1.0

C. 13

D. 13.2

20. Three gases X, Y and Z were mixed in a closed container and allowed to reach equilibrium. The temperature was decreased at 4 minutes and equilibrium was re-established. Two other changes were made to the system.



Which reaction is represented by the graph?

A. $2Z(g) \rightleftharpoons X(g) + Y(g) \quad \Delta H > 0$

B. $2Z(g) \rightleftharpoons X(g) + Y(g) \quad \Delta H < 0$

C. $X(g) + Y(g) \rightleftharpoons Z(g) \quad \Delta H > 0$

D. $X(g) + Y(g) \rightleftharpoons Z(g) \quad \Delta H < 0$

JRAHS Chemistry Trial 2019 **Student Number** …….

Mark.....

Section I

Multiple Choice Answer Sheet

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

Section II

80 marks

Attempt Questions 21 – 33

Allow about 2 hours and 25 minutes for this section

Instructions

- Answer all 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 question you are answering and direct the examiner to your answer.

Question 21 (4 marks)

Polymers can be made synthetically by polymerisation processes.

(a) Outline the difference between addition and condensation polymerisation. **2**

……..

……..

……..

……..

(b) Draw the structures of an addition polymer and a condensation polymer in the boxes below. **2**

Addition polymer
Condensation polymer

Question 22 (7 marks)

The pH of 0.010 mol L^{-1} solutions of four monoprotic acids are given below.

Acid	L	M	N	P
pH	4.2	6.1	2.0	2.7

(a) Arrange these acids in order of increasing acid strength from weakest to strongest. **1**

……..

(b) Determine if any of these acids are completely ionised. Justify your answer. **2**

……..

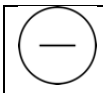
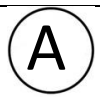
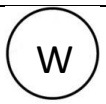
……..

……..

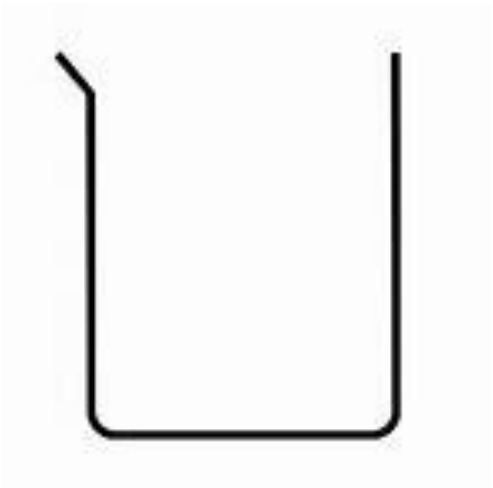
……..

……..

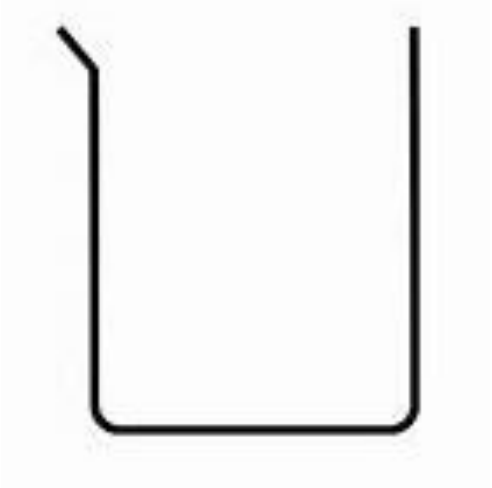
(c) Use up to 12 symbols in each beaker to model solutions of acids N and L. **4**

			
Anion	Proton	Acid molecule	Water molecule

A dilute solution of acid N



A concentrated solution of acid L



Question 23 (6 marks)

A student studied the carbon dioxide/carbonic acid equilibrium in a can of soft drink.

The chemical equilibrium can be represented as

$$H_2CO_3\ (aq) \rightleftharpoons CO_2\ (g) + H_2O\ (l) \qquad \Delta H > 0$$

(a) Use Le Chatelier's Principle to explain any change in the pH of the solution after the can was opened. **4**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

(b) Predict and explain any temperature change in the solution after the can was opened. **2**

……..

……..

……..

……..

……..

……..

Question 24 (4 marks)

5.0 mL of a 0.050 mol L^{-1} lead (II) nitrate solution is mixed with 5.0 mL of a 0.10 mol L^{-1} sodium chloride solution.

Using K_{sp} values provided on the data sheet, predict if a precipitate will form. Show all relevant working in your answer. **4**

……..

……..

……..

……..

……..

……..

……..

……..

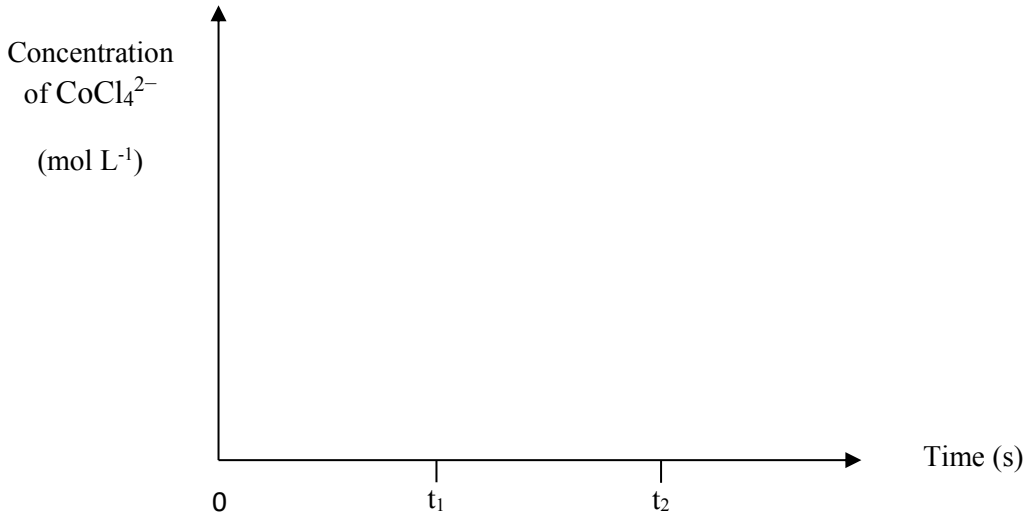
Question 25 (9 marks)

The following chemical equation describes a cobalt chloride equilibrium.

$$Co(H_2O)_6^{2+}\ (aq)\ +\ 4Cl^-\ (aq)\ \rightleftharpoons\ CoCl_4^{2-}\ (aq)\ +\ 6H_2O\ (l)$$

Pink Blue

(a) Sketch a line on the graph below from 0 to time t_2, showing the system achieving equilibrium at time t_1 when $Co(H_2O)_6^{2+}$ is added to chloride ions.
(no values are required) **1**



(b) At time t_1, and 298 K, the following equilibrium concentrations were established.

$[Co(H_2O)_6^{2+}] = 0.05$ mol L^{-1} , $[Cl^-] = 0.20$ mol L^{-1} and $[CoCl_4^{2-}] = 6.97 \times 10^{-14}$ mol L^{-1}

Calculate the equilibrium constant. **2**

……..

……..

……..

……..

……..

……..

……..

……..

Question 25 continues on page 17

(c) The equilibrium constant for this reaction decreases as temperature decreases.

(i) Determine whether the forward reaction is exothermic or endothermic and explain your answer. **3**

……..

……..

……..

……..

……..

……..

……..

……..

……..

(ii) *Sketch* on the graph on the previous page, any change to the concentration of $CoCl_4^{2-}$ when the temperature is changed to 313K at time t_2. **2**

(iii) Outline ONE qualitative change to the system at 313 K. **1**

……..

……..

……..

Question 26 (5 marks)

In human cells the pH must remain close to 7.4 to maintain cellular function. The dihydrogen phosphate ion is a weak acid present in cells which maintains pH with the following equilibrium:

$$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$$

(a) Give TWO equations to show how the buffer maintains the constant pH in cells. **2**

……..

……..

(b) Write the K_a expression for this equilibrium reaction. **1**

.....

.....

(c) If 0.50 mol $H_2PO_4^-$ and 0.50 mol HPO_4^{2-} are in equilibrium in 1.0 L of aqueous solution, calculate the pH of the solution. (K_a for $H_2PO_4^-$ = 6.4 x 10^{-8}) **2**

……..

……..

……..

……..

……..

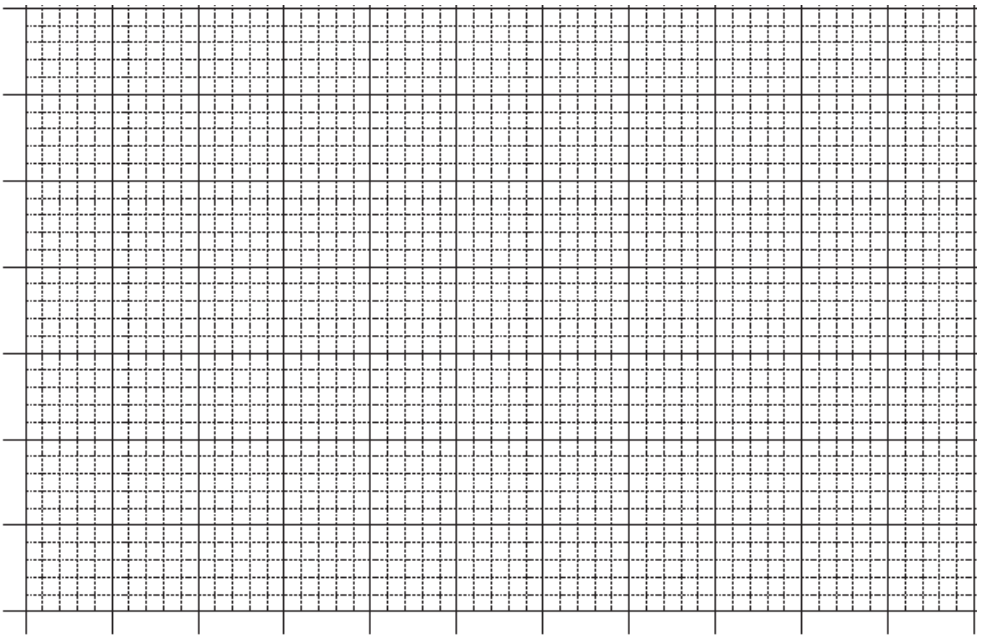
Question 27 (4 marks)

A water sample has been collected from a stream located near a textile and manufacturing company. This body of water is believed to have been contaminated with chromium (VI) compounds, which are recognised human carcinogens.

Scientists have decided to use Atomic Absorption Spectroscopy to analyse the water sample to account for the extremely low concentrations. A series of chromium (VI) standard solutions was created and their absorbance values were recorded in a results table.

Parts Per Million (ppm)	*Absorbance (at 358 nm)*
2	0.12
4	0.24
6	0.37
8	0.49
10	0.61

(a) Plot the data on the graph and draw a line of best fit. **3**



(b) The water sample collected provided an absorbance reading of 0.54. **1**

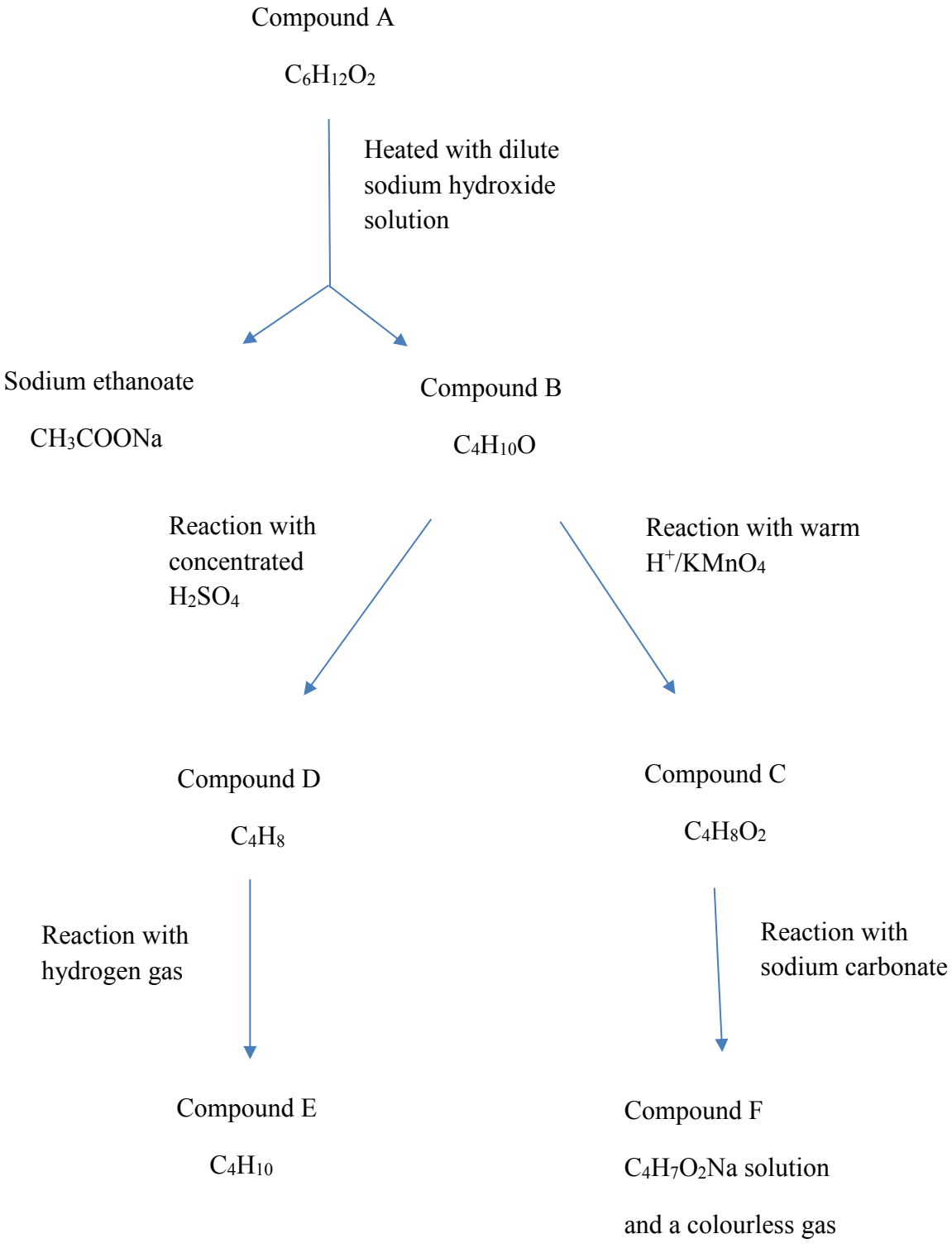
The Australian Drinking Water guidelines state that the safe limit for chromium (VI) is 5mg/L. Use a value from your graph to determine whether the water sample tested is fit for consumption.

……..

……..

Question 28 (7 marks)

This flowchart shows reactions involving six different organic compounds A to F.



Question 28 continues on page 21

Draw the structures of compounds A to F, and use the information provided to justify your identifications. **7**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

Question 29 (6 marks)

Explain the trends in boiling points and solubility in water of primary alcohols as they increase in molar mass. Support your answer with a labelled diagram showing intermolecular forces. **6**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

Question 30 (8 marks)

Hydrocarbons from the Earth can be used as fuels, and in the manufacture of petrochemicals.

Describe environmental impacts of these uses of hydrocarbons from the Earth. **8**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

Question 31 (7 marks)

An investigation was conducted to determine the amount of chloride ions in canned tomatoes as a means of determining the salt (sodium chloride) content. A precipitation titration experiment was carried out using the following method.

The contents of a tin of canned tomatoes was blended using a food processor and then filtered. Bulb pipettes were used to add 25.0 mL of 0.10 mol L^{-1} silver nitrate solution to 25.0 mL of the filtrate. Any chloride ions reacted to form a silver chloride precipitate as shown below.

$$Ag^{+}\ (aq) + Cl^{-}\ (aq) \rightarrow AgCl\ (s)$$

After the silver chloride precipitate was removed via filtration, the remaining silver ions were titrated against a 0.10 mol L^{-1} potassium thiocyanate solution with 3 drops of a saturated ferric ammonium sulfate indicator. This reaction is shown in the following equation.

$$Ag^{+}\ (aq) + SCN^{-}\ (aq) \rightleftharpoons AgSCN\ (s)$$

The procedure was repeated several times and the titration results are given in the table.

Trial number	Volume of titre of potassium thiocyanate added (mL)
1	10.90
2	10.80
3	10.70
4	10.75

(a) Discuss the validity of this procedure in determining the chloride ion content of canned tomatoes. **3**

……..

……..

……..

……..

……..

……..

……..

……..

……..

Question 31 continues on page 25

(b) Outline the accuracy and reliability of the data obtained. **4**

……..

……..

……..

……..

……..

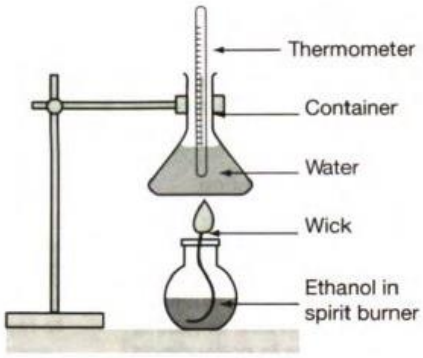
……..

……..

……..

Question 32 (4 marks)

The following experiment was set up to measure temperature change for a heat of combustion reaction.



100.0 mL of water at 298 K was heated by the burning of 1.20 g of ethanol in the spirit burner. Only 45.0% of the energy produced was used to heat the water. The molar heat of combustion of ethanol is 1368 kJ mol^{-1}. Calculate the final temperature of the water. **4**

……..

……..

……..

……..

……..

……..

……..

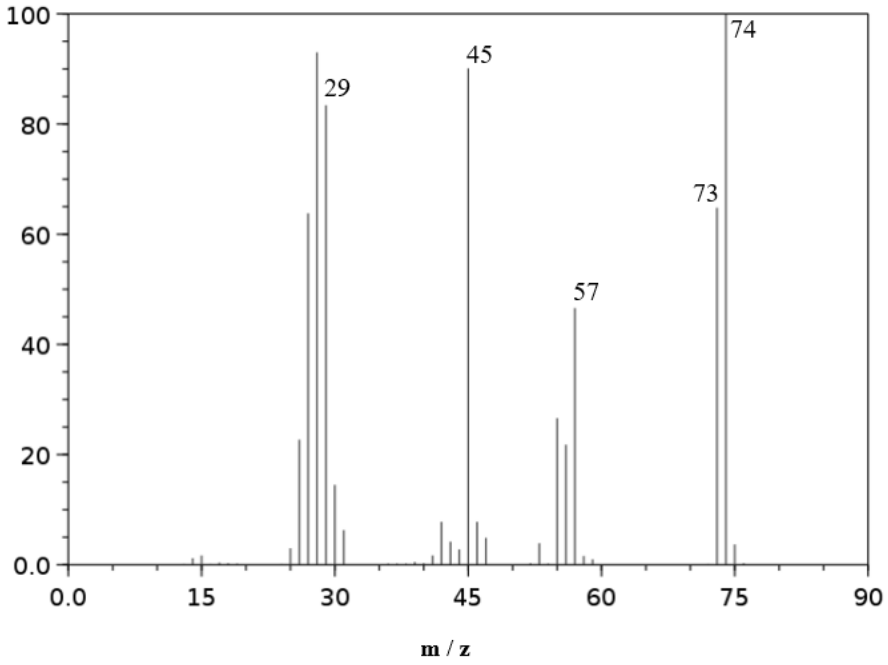
……..

Question 33 (9 marks)

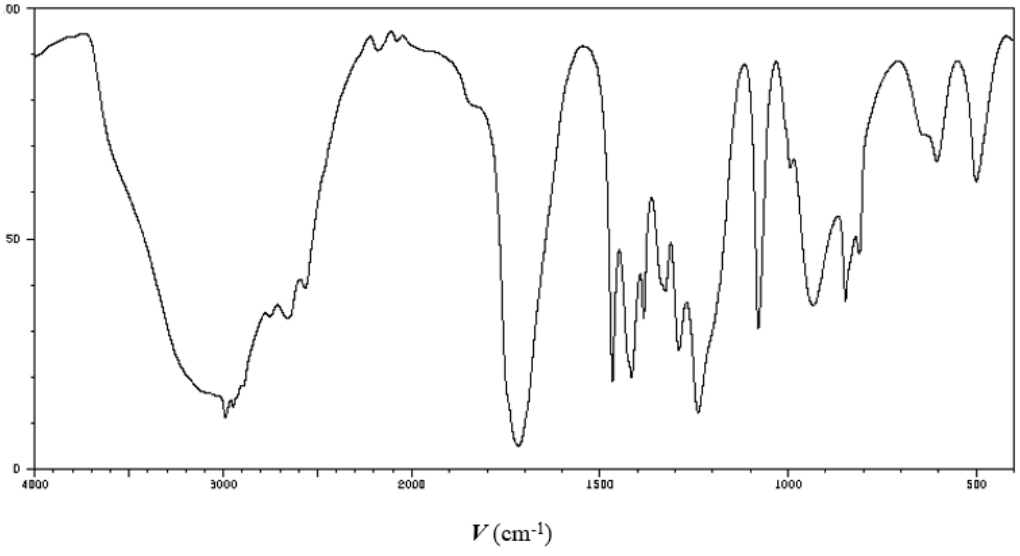
A student performed a series of reactions to synthesise a compound with a molecular formula of $C_3H_6O_2$. In order to determine the molecular structure, they performed a series of spectral analysis techniques to obtain the given spectra.

Analyse each spectra provided in order to deduce the molecular structure of this compound and justify your reasoning. (Proton NMR data is included on page 32) **9**

Mass Spectrum



Infrared spectrum



……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

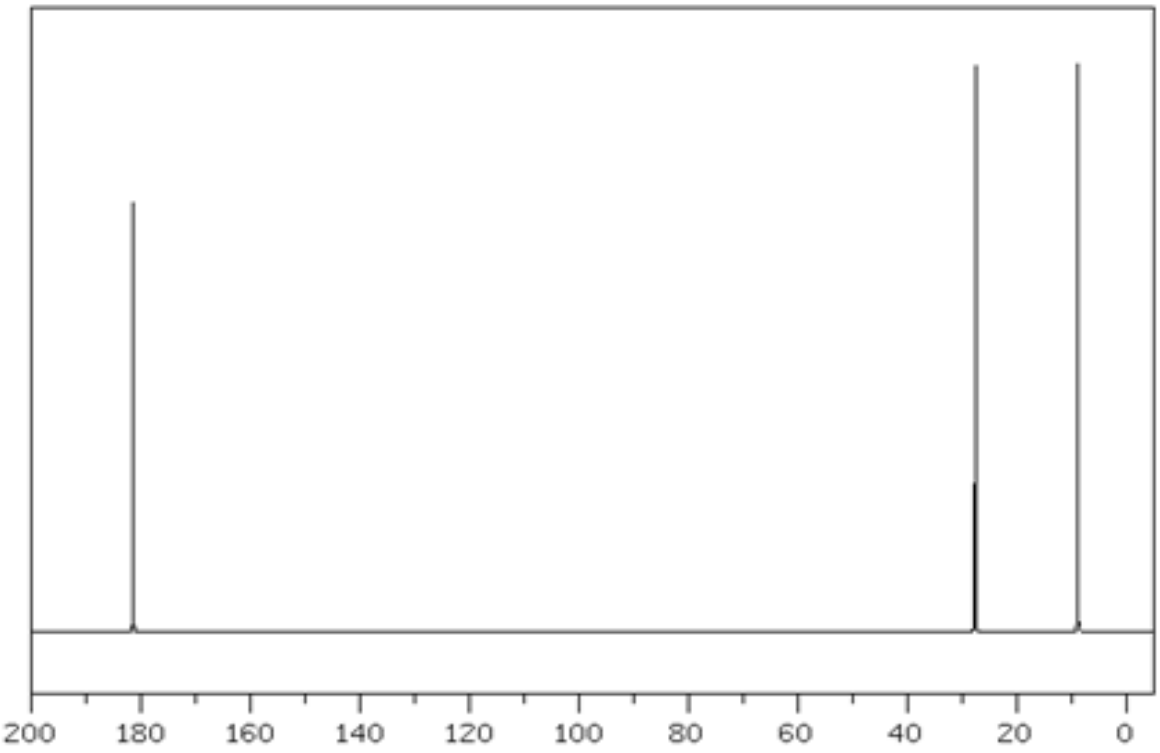
……..

……..

……..

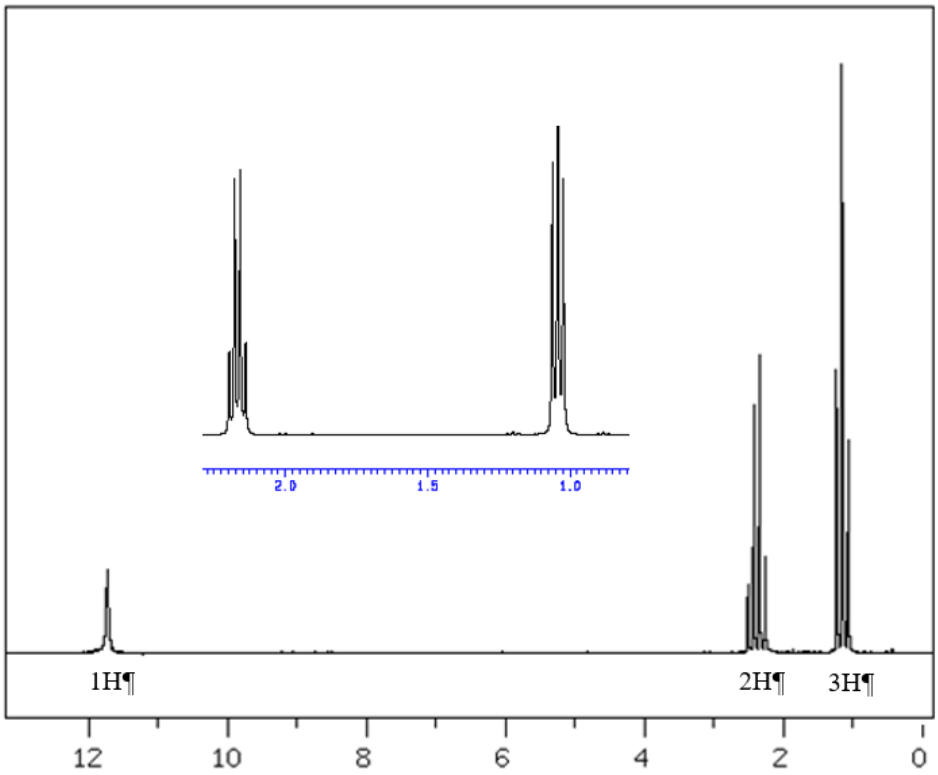
Question 33 continues on page 28

^{13}C NMR Spectrum



δ (ppm)

^{1}H NMR Spectrum



δ (ppm)

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

Part B extra writing space

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

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

Part B extra writing space

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

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

2019 Trial Chemistry Answers and Marking Criteria

1. What is the conjugate acid of the hydrogen sulfate ion?
   A. HSO_3^-
   B. H_2SO_4
   C. H_3O^+
   D. SO_4^{2-}

2. Which catalyst is used in the production of an ester?
   A. concentrated sulfuric acid
   B. iron oxide
   C. palladium
   D. dilute phosphoric acid

3. The table below gives the colour and pH range for some acid/base indicators.

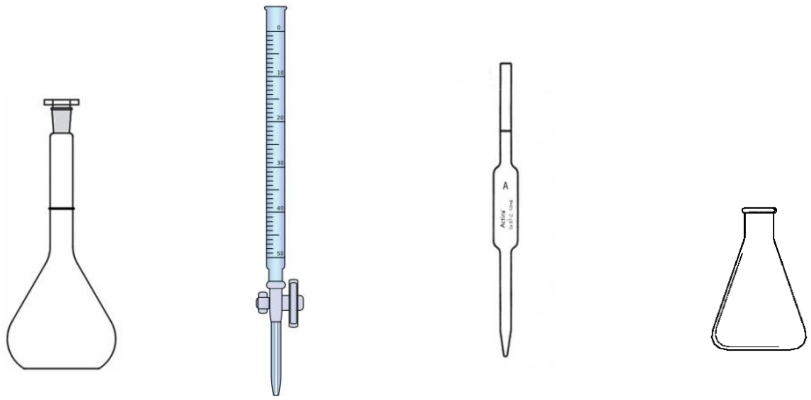
Indicator	*Colour in low pH*	*Colour in high pH*	*pH range*
Cresol red	red	yellow	0.2 – 1.8
Methyl orange	red	yellow	3.1 – 4.4
Bromocresol green	yellow	blue	3.8 – 5.4
Bromothymol blue	yellow	blue	6.0 – 7.6

   Which indicators could be used to identify rainwater with a pH of 5.6?
   A. Methyl orange and bromocresol green
   B. Bromothymol blue and cresol red
   C. Methyl orange and bromothymol blue
   D. Bromocresol green and bromothymol blue

4. Which of the following metal ions would exhibit a green colour during a flame test?

   A. Iron
   B. Copper
   C. Calcium
   D. Magnesium

5. Which type of glassware is used to prepare a primary standard solution for titration?

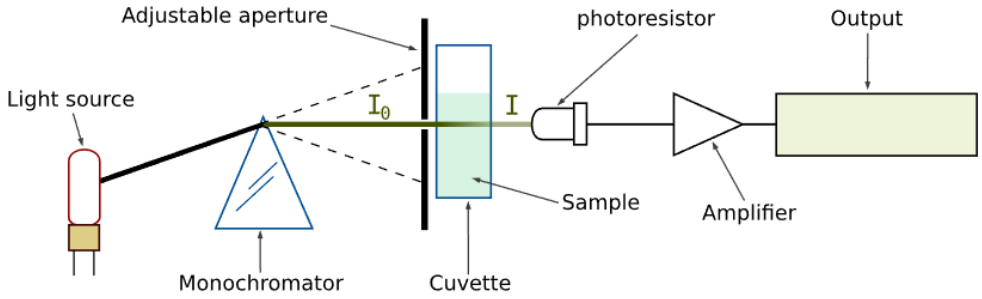


W X Y Z

A. **W**
B. X
C. Y
D. Z

6. Which equation shows water acting as a Brönsted/Lowry acid?
A. $H_2O\ (l) + HCl\ (aq) \rightleftharpoons H_3O^+\ (aq) + Cl^-\ (aq)$
B. $\mathbf{H_2O\ (l) + NH_3\ (aq) \rightleftharpoons NH_4^+\ (aq) + OH^-\ (aq)}$
C. $H_2O\ (l) + NaCl\ (s) \rightleftharpoons Na^+\ (aq) + Cl^-\ (aq) + H_2O\ (l)$
D. $H_2O\ (l) + HCO_3^-\ (aq) \rightleftharpoons H_3O^+\ (aq) + CO_3^{2-}\ (aq)$

7. A pale blue copper sulfate solution was analysed using the setup below.



Which analysis technique is being used?

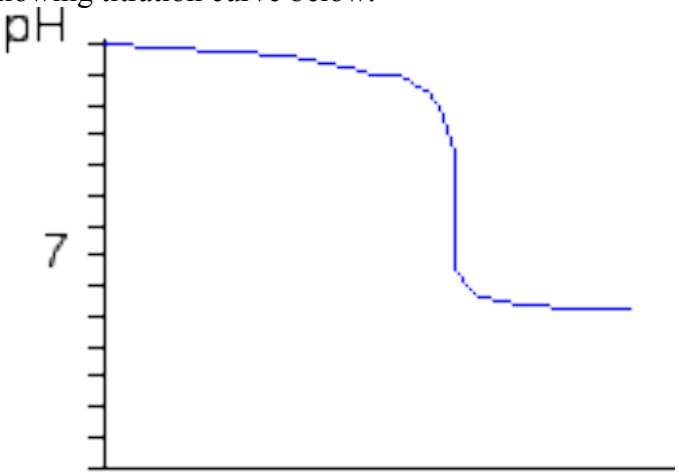
A. **Colourimetry**
B Gravimetric analysis
C. Infrared spectroscopy
D. Atomic absorption spectroscopy

8. How many chain isomers does hexane have?
A. 2
B. 3
C. 4
D. **5**

9. Which of the following is an organic base?

A. $CH_3CH_2CH_3$
B. C_2H_5OH
C. CH_3COOCH_3
D. CH_3NH_2

10. Consider the following titration curve below.



Solution added (mL)

Which of the following solutions is most likely to be in the burette?

A. NaOH
B. $NaHCO_3$
C. CH_3COOH
D. HCl

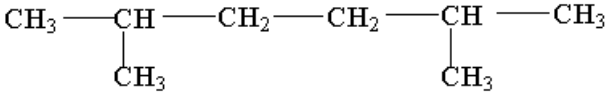
11. The shape of ethane is best described as

A. linear.
B. trigonal planar.
C. overlapping tetrahedrons.
D. trigonal linear.

12. Which of the following conditions is LEAST LIKELY to enable equilibrium to be established earlier?

A. Higher temperatures
B. Addition of a catalyst
C. Larger reaction vessel
D. Higher concentrations of reactants

13. How many peak signals would you expect to see in the carbon NMR spectrum of 2, 5-dimethylhexane?



A. **3**
B. 4
C. 6
D. 8

14. Which option best accounts for the cleaning action of soap?
    A. The polar alkyl tail forms dispersion forces with the oil and the carboxylate head forms dipole-dipole forces with water.
    B. The non-polar alkyl tail forms dispersion forces with water and dipole-dipole forces with oil.
    C. The non-polar carboxylate head forms dispersion forces with water and dipole-dipole forces with oil.
    D. The polar carboxylate head forms dipole-dipole forces with water and the non-polar alkyl tail forms dispersion forces with oil.

15. Gravimetric analysis was performed on a sample of hydrated magnesium sulfate in order to determine the number of water of crystallization molecules present. It was found that after heating, the sample lost 51.2 % of its mass.

    What is the value of *n* in this formula for hydrated magnesium sulfate($MgSO_4 \cdot nH_2O$)?

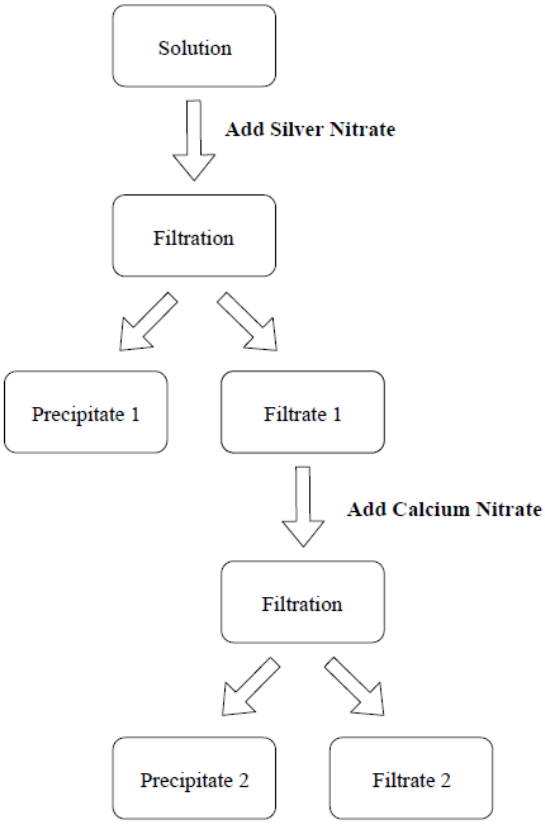
    A. 5

    B. 6

    C. 7

    D. 8

16. A solution containing hydroxide, chloride, and sulfate anions was separated using the procedure outlined in the flowchart below.



Which of the following options correctly identifies the products?

	Precipitate 1	*Precipitate 2*	*Filtrate 2*
A.	silver hydroxide	calcium chloride	sulfate
B.	silver sulfate	calcium chloride	hydroxide
C.	silver chloride	calcium sulfate	hydroxide
D.	**silver chloride**	**calcium hydroxide**	**sulfate**

17. Which of the following is a possible molecular ion fragment produced in the mass spectrum of pent-2-ene.

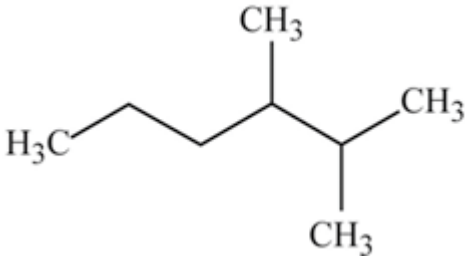
A. **28 *m / z***

B. 30 *m / z*

C. 43 *m / z*

D. 56 *m / z*

18. What is the name of this compound?

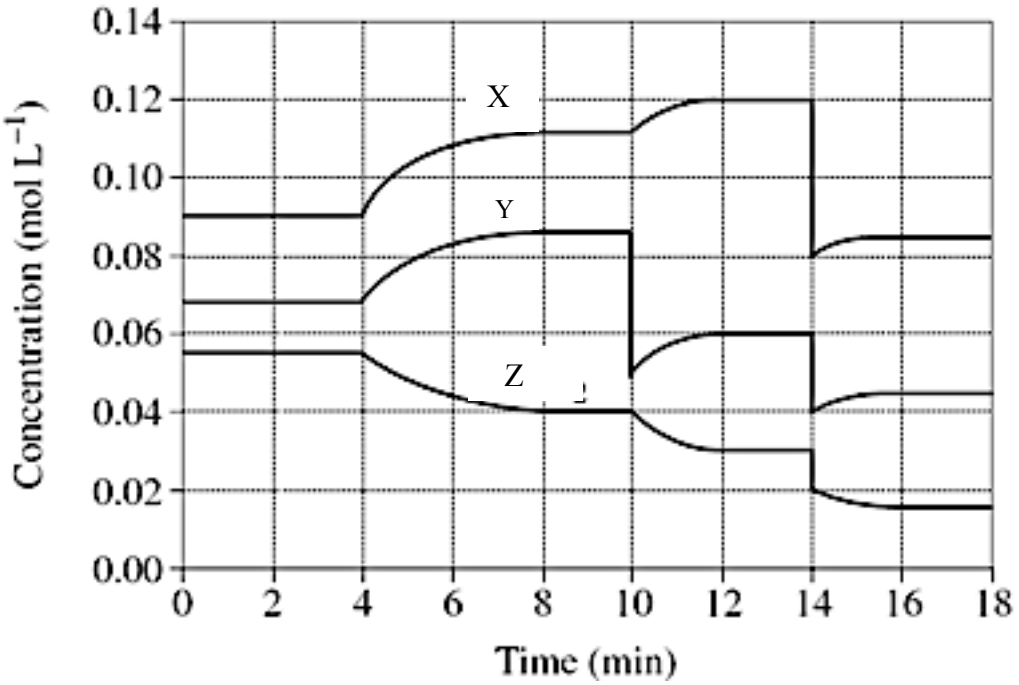


A. 1,1,2-trimethyl pentane
B. 2,3-dimethyl hexane
C. 1,1,2,4-tetramethyl butane
D. 1-ethyl-2-methyl pentane

19. What is the pOH of the final solution when 0.37 g of calcium hydroxide is reacted with 100 mL of 0.2 $molL^{-1}$ hydrochloric acid solution.

A. 0.82
B. 1.0
C. 13
D. 13.2

20. Three gases X, Y and Z were mixed in a closed container and allowed to reach equilibrium. The temperature was decreased at 4 minutes and equilibrium was re-established. Two other changes were made to the system.



Which reaction is represented by the graph?

A. $2Z(g) \rightleftharpoons X(g) + Y(g)$ $\Delta H > 0$
B. $2Z(g) \rightleftharpoons X(g) + Y(g)$ $\Delta H < 0$
C. $X(g) + Y(g) \rightleftharpoons Z(g)$ $\Delta H > 0$
D. $X(g) + Y(g) \rightleftharpoons Z(g)$ $\Delta H < 0$

JRAHS Chemistry Trial 2019 **Student Number** .....

Mark.....

Section I

Multiple Choice Answer Sheet

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

Section II

Question 21 (4 marks)

Polymers can be made synthetically by polymerisation processes.

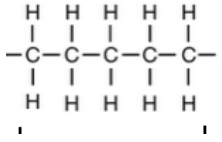
(a) Outline the difference between addition and condensation polymerisation. **2**

Sample answer

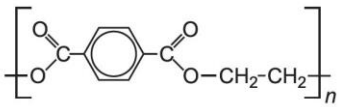
Polyethylene forms from the addition polymerisation of ethene molecules. Only one product is formed in the polymerisation as the monomers add together across a double bond.
A polyester is formed by condensation polymerisation. The polymer is formed by the combination of two monomers, usually a dicarboxylic acid and a diol, forming the polymer and eliminating a small molecule, in this case, water. In condensation polymerisation two products are formed.

Marking Criteria	*Mark(s)*
• Outlines the difference between addition and condensation polymerisation	2
• Outlines one form of polymerisation	1

(b) Draw the structures of an addition polymer and a condensation polymer in the boxes below. **2**



polythene (addition)



polyester (condensation)

Marking Criteria	*Mark(s)*
• Gives structures for the two types of polymers	2
• Gives some relevant information about polymers	1

Question 22 (7 marks)

The pH of 0.010 $molL^{-1}$ solutions of four monoprotic acids are given below.

Acid	L	M	N	P
pH	4.2	6.1	2.0	2.7

(a) Arrange these acids in order of increasing acid strength from weakest to strongest. **1**

The order of increasing $[H_3O^+]$ is pH 6.1, 4.2, 2.7 and 2.0
Hence the order of increasing strength of the acids is M, L, P, N.

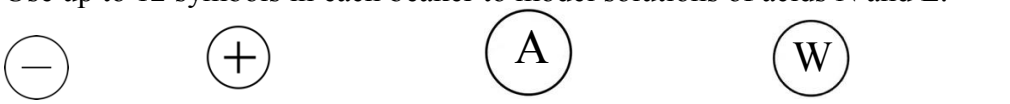
Criteria	*Mark*
• Complete correct order of acid strength from weakest to strongest	1

(b) Determine if any of these acids are completely ionised. Justify your answer. **2**

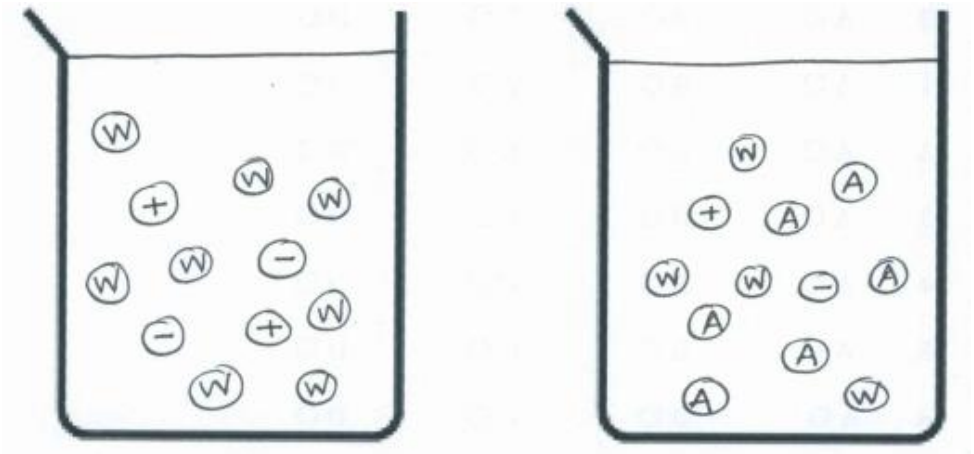
Sample Answer :
Stronger acids ionise to a greater extent then weaker acids, thus stronger acids produce the higher concentration of $[H_3O^+]$ and the lower pH.
For a 0.010 mol L^{-1} acid solution complete ionisation would be 0.010 mol L^{-1}
Thus pH = $-\log_{10}$ [0.010] = 2.0 , hence N is completely ionised.

Criteria	*Mark*
• Correct identification and justification	2
• Correct identification	1

(c) Use up to 12 symbols in each beaker to model solutions of acids N and L. **4**



A dilute solution of and N *A concentrated solution of acid L*



Marking Criteria	*Mark(s)*
• Draws two different solutions in the beakers with fewer than 13 symbols. • Correctly models a dilute solution of a strong acid in the first beaker • Correctly models a concentrated solution of a weak acid in the second beaker	4

• Correctly models a dilute solution of a strong acid in the first beaker • Correctly models a concentrated solution of a weak acid in the second beaker • Uses more than 12 symbols OR • Correctly models a dilute solution of a strong acid in the first beaker OR • Correctly models a concentrated solution of a weak acid in the second beaker	3
• Shows complete ionisation in one beaker and some intact molecules in the second	2
• Uses some symbols correctly	1

Question 23 (6 marks)
A student studied the carbon dioxide/carbonic acid equilibrium in a can of soft drink.
The chemical equilibrium can be represented as

$$H_2CO_3\ (aq) \rightleftharpoons CO_2\ (g) + H_2O\ (l) \qquad \Delta H > 0$$

(a) Use Le Chatelier's Principle to explain any change in the pH of the solution after the can was opened. **4**

Sample answer
As the can is opened the undissolved carbon dioxide is immediately released since the gas inside the can was at higher pressure than atmospheric pressure. Due to the decrease in concentration of carbon dioxide gas in the system, the amount of dissolved carbon dioxide will also decrease.

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

The equilibrium above will shift to favour the forward reaction, according to Le Chatelier's Principle (LCP) which states that a system at equilibrium will shift to favour either side to minimise changes made to the system.
As there is fewer molecules of carbon dioxide in the solution to react with water molecules to produce carbonic acid.
Thus forward reaction rate will be greater than the reverse reaction rate in the equilibrium equation shown below.

$$H_2CO_3\ (aq) \rightleftharpoons CO_2\ (aq) + H_2O\ (l)$$

The concentration of carbonic acid will decrease, and the equilibrium below will shift to favour the reverse reaction, according to LCP.

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

The concentration of hydronium ion will decrease, hence pH will increase.

Marking Criteria	*Mark(s)*
• States Le Chatelier's Principle OR implements the principle correctly. • Identifies that the pressure decreases AND that the equilibrium will shift to favour the right side because there is greater number of moles of gas on that side (molar gas ratio 0:1). • Identifies that there is a decrease of hydronium ion concentration. • Identifies that the pH increases due to the decrease in hydronium ions.	4

• States Le Chatelier's Principle OR implements the principle correctly. • Identifies that there is a decrease of hydronium ion concentration. • Identifies that the pH increases due to the decrease in hydronium ions.	3
• States Le Chatelier's Principle OR implements the principle correctly. • Identifies that there is a decrease of hydronium ions.	2
• States Le Chatelier's Principle OR implements the principle correctly.	1

(b) Predict and explain any temperature change in the solution after the can was opened. **2**

Sample answer
The forward reaction is favoured which is endothermic where thermal energy is absorbed. Hence there will be a small decrease in temperature at the instant the can is opened.

Marking Criteria	*Mark(s)*
• Explains why the temperature decreases when the can is opened.	2
• Identifies that the temperature decreases when the can is opened.	1

Question 24 (4 marks)
5.0 mL of a 0.050 molL^{-1} lead nitrate solution is mixed with 5.0 mL of a 0.10 molL^{-1} sodium chloride solution.
Using K_{sp} values provided on the data sheet, predict the formation of a precipitate. Show all relevant working in your answer.

Sample answer
$Pb(NO_3)_2$ *(aq)* + 2NaCl *(aq)* → $PbCl_2$ *(s)* + 2$NaNO_3$ *(aq)*

$n(Pb^{2+}) = c \times V = 0.05 \times 0.005$
$= 2.5 \times 10^{-4}$ *mol*
$n(Cl^-) = 0.1 \times 0.005$
$= 5.0 \times 10^{-4}$ *mol*

$[Pb^{2+}] = n/V = 2.5 \times 10^{-4} / 0.01 = 2.5 \times 10^{-2}$

$[Cl^-] = 5.0 \times 10^{-4} / 0.01 = 5.0 \times 10^{-2}$

$Q_{sp} = [Pb^{2+}] \times [Cl^-]^2$
$= (2.5 \times 10^{-2}) \times (5.0 \times 10^{-2})^2$
$= 6.25 \times 10^{-5}$

As the calculated solubility product is greater than K_{sp} lead (II) chloride precipitate will form.

Marking Criteria	*Mark(s)*
• Converts the units for volume from mL to L. • Calculates the concentration of BOTH lead and chloride ions. • Calculates Q_{sp}. • Concludes that precipitate will form. • *Did NOT use the concentration of lead (II) chloride as part of their working.	4
• Gives most of the calculations.	3
• Gives some calculations.	2
• Gives some relevant information.	1

Question 25 (9 marks)

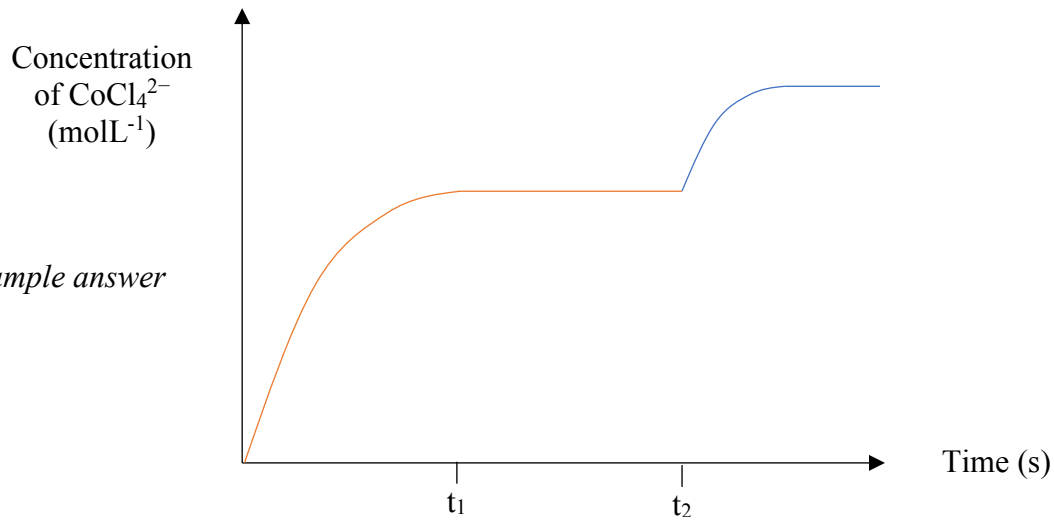
The following chemical equation describes a cobalt chloride equilibrium.

$$\underset{\text{Pink}}{Co(H_2O)_6^{2+}\ (aq)} + 4Cl^-\ (aq) \rightleftharpoons \underset{\text{Blue}}{CoCl_4^{2-}\ (aq)} + 6H_2O\ (l)$$

(a) Sketch a line on the graph below from 0 to t_2 to show the system achieving equilibrium at time t_1 when $Co(H_2O)_6^{2+}$ is added to chloride ions. (no values are required)

1

Sample answer



Marking Criteria	*Mark(s)*
• The initial concentration is zero. • The concentration at first increased until time t_1 and then remains constant until t_2.	1

(b) At time t_1, and 298 K, the following equilibrium concentrations were established. $[Co(H_2O)_6^{2+}] = 0.05$ molL^{-1}, $[Cl^-] = 0.20$ molL^{-1} and $[CoCl_4^{2-}] = 6.97 \times 10^{-14}$ molL^{-1}. Calculate the equilibrium constant. **2**

Sample answer

$$K_c = \frac{[CoCl_4^{2-}]}{[Co(H_2O)_6^{2+}] \times [Cl^-]^4}$$
$$= \frac{(6.97 \times 10^{-14})}{(0.05) \times (0.20)^4}$$
$$= 8.7 \times 10^{-10}$$

Marking Criteria	*Mark(s)*
• Provides the equilibrium expression. • Calculates the equilibrium constant.	2
• Addresses ONE of the points above.	1

(c) The equilibrium constant for this reaction decreases as temperature decreases.

(i) Determine whether the forward reaction is exothermic or endothermic and explain your answer. **3**

Sample answer

As the temperature decreases, the equilibrium constant decreases thus the concentration of products decreases while the concentration of the reactants increases, hence the reverse reaction is favoured.
According to Le Chatelier's Principle, the equilibrium shifted to the left where heat is released to minimise the decrease in temperature, thus the reverse reaction is exothermic.
Hence the forward reaction is endothermic.

Marking Criteria	*Mark(s)*
• Identifies that the concentration of products decrease thus the reverse reaction is favoured when the temperature is decreases. • Justifies that the reverse reaction is exothermic. • Identifies that the forward reaction is endothermic.	3
• Identifies that the concentration of products decrease thus the reverse reaction is favoured when the temperature is decreases. • Identifies that the forward and reverse reaction have opposite changes to enthalpy.	2
• Identifies that the concentration of products decrease thus the reverse reaction is favoured when the temperature is decreases.	1

(ii) Draw on the graph any change to the concentration of $CoCl_4^{2-}$ if the temperature is changed to 313K at time t_2. **2**

Marking Criteria	*Mark(s)*
• The concentration increases. • The concentration at first increased at a decreasing rate from time t_2 and then remains constant.	2
• Shows ONE correct feature of the curve.	1

(iii) Outline ONE qualitative change to the system at 313 K. **1**

Sample answer
As the concentration of $CoCl_4^{2-}$ *is higher at the new equilibrium position, the colour of the solution at 313 K will be more blue (changed from pink-purple).*

Marking Criteria	*Mark(s)*
• Identifies the correct qualitative change.	1

Question 26 (5 marks)
In human cells the pH must remain close to 7.4 to maintain cellular function. The dihydrogen phosphate ion is a weak acid present in cells which maintains pH with the following equilibrium.

$$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$$

(a) Give TWO equations to show how the buffer maintains the constant pH in blood. **2**

$$H_2PO_4^-(aq) + OH^-(aq) \rightleftharpoons HPO_4^{2-}(aq) + H_2O(aq)$$

$$HPO_4^{2-}(aq) + H_3O^+(aq) \rightleftharpoons H_2PO_4^-(aq) + H_2O(aq)$$

Marking Criteria	*Mark(s)*
• Correct equations showing $H_2PO_4^-$ reacting with both base and acid • Equilibrium arrows in the equations	2
• One correct equation	1

(b) Write the K_a expression for this equilibrium reaction. **1**

Sample Answer : $K_a = [H_3O^+][HPO_4^{2-}] / [H_2PO_4^-]$

Criteria	*Mark*
• Correct K_a expresssion	1

(c) If 0.50 mol $H_2PO_4^-$ and 0.5 mol HPO_4^{2-} are in equilibrium in 1.0 L of aqueous solution, calculate the pH of the solution. (K_a for $H_2PO_4^- = 6.4 \times 10^{-8}$) **2**

$[H_3O^+] = K_a \times [HPO_4^-] / [H_2PO_4^{2-}] = 6.4 \times 10^{-8} \times 0.5 / 0.5 = 6.4 \times 10^{-8}$

$pH = -\log_{10} [H_3O^+] = -\log_{10} (6.4 \times 10^{-8}) = 7.2$

Criteria	*Mark*
• Correct expression for $[H_3O^+]$, calculation and pH calculation	2
• One correct calculation	1

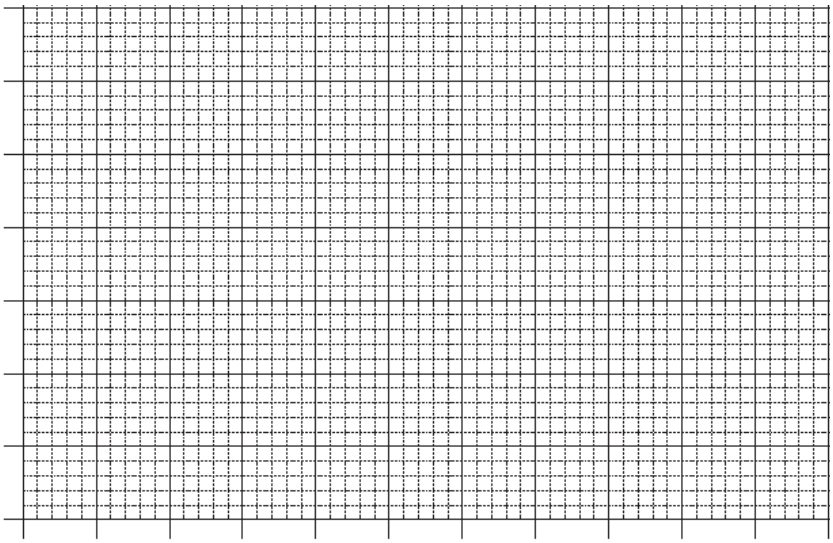
Question 27 (4 marks)

A water sample has been collected from a stream located near a textile and manufacturing company. This body of water is believed to have been contaminated with chromium (VI), which is a recognised human carcinogen.

Scientists have decided to use Atomic Absorption Spectroscopy to analyse the water sample to account for the extremely low concentrations. A series of chromium (VI) standard solutions were created and their absorbance values were recorded in a results table.

Parts Per Million (ppm)	*Absorbance (at 358 nm)*
2	0.12
4	0.24
6	0.37
8	0.49
10	0.61

(a) Draw a line graph of these data. **3**



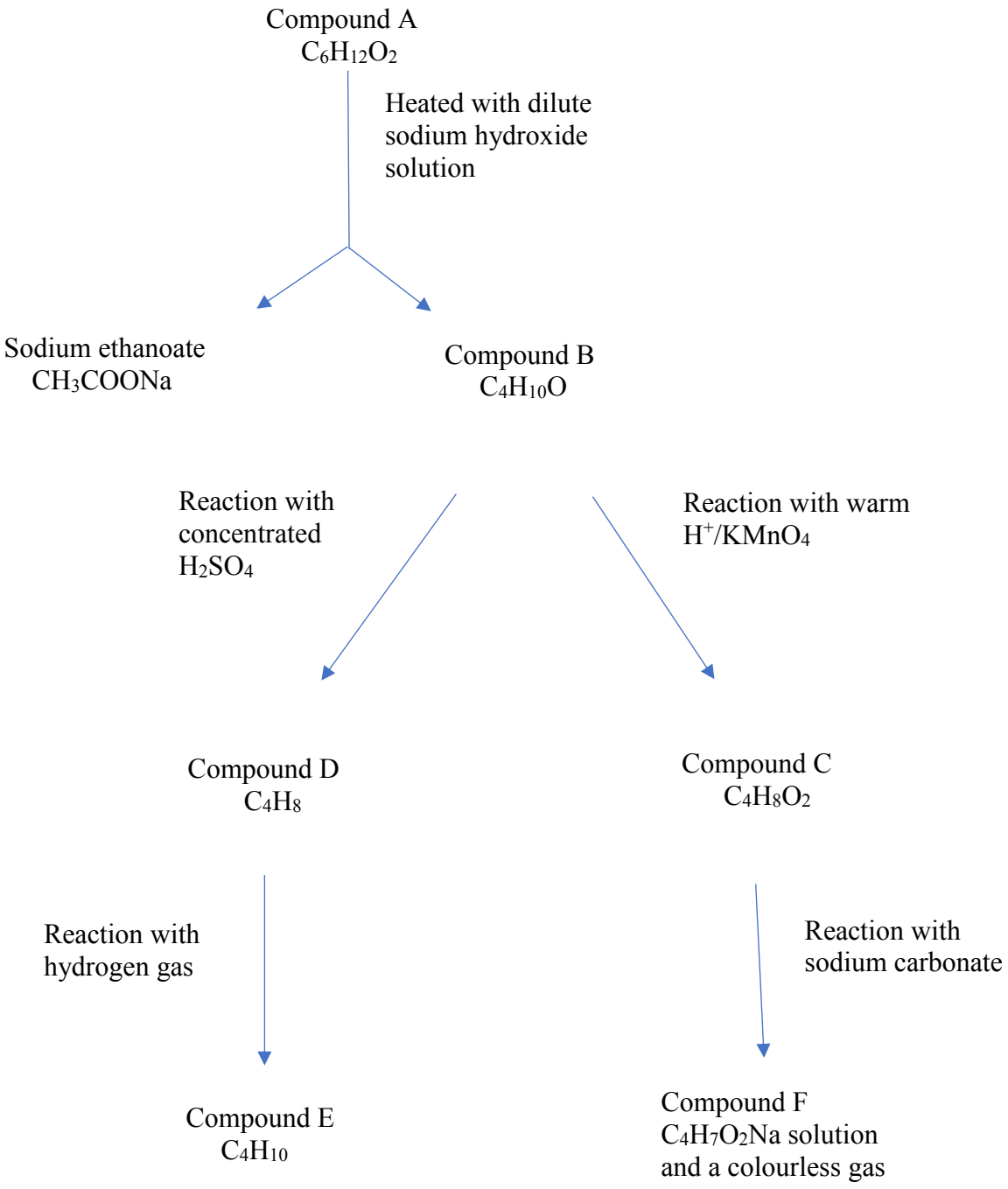
Marking Criteria	*Mark(s)*
• Correctly graphs results (uses an appropriate scale, labels axes correctly with units, accurately plots points, and draws a line of best fit).	3
• Provides a substantially correct graph	2
• Provides some basic features of the graph	1

(b) The water sample collected provided an absorbance reading of 0.54. **1**
The Australian Drinking Water guidelines state that the safe limit for chromium(VI) is 5mg/L.
Use your graph to determine whether the water sample tested was fit for consumption.

Sample answer An absorbance reading of 0.54 corresponds to 9ppm, which is well above the guidelines safe limit of 5 ppm. Hence, the water is not fit for consumption.

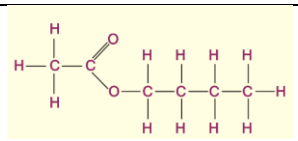
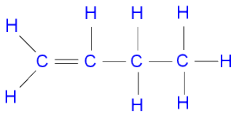
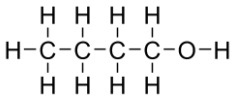
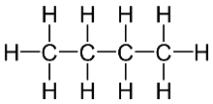
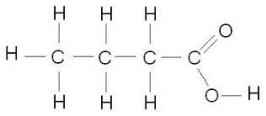
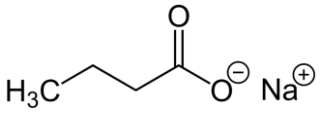
Marking Criteria	*Mark(s)*
• Correctly determines chromium concentration and viability.	1

Question 28 (7 marks)
This flowchart shows reactions involving six different organic compounds A to F.



Draw the structures of compounds A to F, and use the information provided to justify your identifications. **7**

The reaction from compound B to D is dehydration of an alkanol to an alkene.
The reaction from compound B to C is oxidation of a primary alkanol to an alkanoic acid therefore B is 1-butanol, D is 1-butene and C is butanoic acid.
C reacts with a carbonate to form a salt, sodium butanoate (F)solution and carbon dioxide gas.
Compound D, 1-butene is hydrogenated through addition to form butane C_4H_{10}, compound E.
Compound A is butyl ethanoate, an ester. Through basic hydrolysis it forms the salt of the acid, sodium ethanoate and the alkanol which is 1- butanol, compound B.

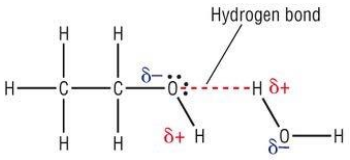
A		D	
B		E	
C		F	

Marking Criteria	*Mark(s)*
• Identifies and correctly draws all six compounds and provides a justification for each compound	7
• Correctly draws most of the structures with relevant justifications	6
• Correctly draws some of the structures with relevant justifications • Correctly draws all 6 structures with no justifications (4)	4-5
• Identifies some of the compounds or processes	2-3
• Provides some relevant information	1

Structures correct	Marks	Justifications	Marks
6	4	6	3
4 or,5	3	4 or5	2
2 or 3	2	1,2 or 3	1
1	1		

Question 29 (6 marks)
Explain the trends in boiling points and solubility in water of primary alcohols as they increase in molar mass. Support your answer with a labelled diagram showing intermolecular forces.

Sample answer



$CH_3(CH_2)_4CH_2OH$

↑

Dispersion forces

↓

$CH_3(CH_2)_4CH_2OH$

As molar mass increases, for example ethanol (46) to hexan-1-ol (102), the dispersion forces between the molecules also increase so the boiling points increase. Also, small chain alkanols, methanol, ethanol, also have hydrogen bonding between the molecules making their boiling points quite high compared to corresponding molecules of similar mass.
Small chain alkanols are soluble in water as the polar hydroxyl group (-OH) on the chain allows the molecule to hydrogen bond with water which is also polar (see diagram). As the carbon chain gets longer, the hydroxyl group has less influence over the larger molecule that is now a long non-polar alkyl chain with a small hydroxyl group on the end. The longer the non-polar chain the less soluble the alkanol will be. There are dispersion forces between the long non-polar alkyl chains. (see diagram).

Marking Criteria	*Mark(s)*
• Explains the differences in boiling points and solubility in water of primary alcohols as they increase in molar mass. • Identifies short and long chain alcohols • Uses a labelled diagram to show hydrogen bonding and/or dispersion forces.	6
• Explains the differences in boiling points and solubility in water of primary alcohols as they increase in molar mass. • Uses a diagram to show some polarity or intermolecular forces	5
• Outlines the differences in boiling points and solubility in water of primary alcohols as they increase in molar mass. AND • Uses a diagram to show some intermolecular forces or polarityOR. • Explains the differences in boiling points and solubility in water of primary alcohols as they increase in molar mass. (no diagram)	4
• Outlines the differences in boiling points and solubility in water of primary alcohols as they increase in molar mass.	3
• Outlines the differences in boiling points OR solubility in water of primary alcohols as they increase in molar mass.	2
• Gives some relevant information on a difference or shows a structure	1

EB – explains boiling ES – explains solubility D2 – correct diagram
I short and long chain primary alcohols

EB	EB	EB	EB	B	12 x combinations	S	B	EB	B	EB		B	S
ES	ES	ES	S	ES		D	S	S	ES	D		*	*
D2	D	D2	D2	D2		I							
I	I		I	I									
6	5	5	5	5	4	3	3	3	3	3		2	2

*Shows some structure

Question 30 (8 marks)
Hydrocarbons from the Earth can be used as fuels, and in the manufacture of petrochemicals. Describe environmental impacts of these uses of hydrocarbons from the Earth. **8**

Hydrocarbons we use from the Earth come from crude oil and natural gas.
We burn natural gas and components of crude oil as fuels.
Natural gas $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O\ (l)$
Octane (Petrol) $C_8H_{18}(g) + 25/2\ O_2\ (g) \rightarrow 8CO_2\ (g) + 9H_2O(l)$
The environmental impacts of using these hydrocarbons as fuels is an increase in global atmospheric carbon dioxide concentrations that are causing global climate change. The added carbon dioxide has had a greenhouse effect on the Earth, causing temperatures of the air and sea to rise. The consequences have been increased damaging weather systems eg cylclones, record breaking high temperatures and rising sea level. Warmer oceans are causing coral deaths and changes to reef ecosystems.
(These hydrocarbons are non-renewable so alternatives to energy production are essential to allay climate change and also to find a productive alternative when hydrocarbon reserves run out. Biofuels go some way to alleviate the amounts of non-renewables used.)
Hydrocarbons from crude oil are also used to make plastics like polythene.
Long chain alkanes are cracked to form shorter chain alkenes like ethene which is polymerised to make polythene.

$C_{10}H_{22} \rightarrow C_8H_{18} + C_2H_4$
$n\ (C_2H_4) \rightarrow -(C_2H_4)-n$

These single use petrochemicals, like polythene, are not biodegradable and are building up in land fill and polluting the oceans. Sea creatures and birds consume these plastics and die as a consequence. Microplastics are also throughout the food chain. The consequences of our consumption of all these microplastics is not yet known. (Bioplastics from renewable sources that are biodegradable are better options as they do not build up in land fill and do degrade in the environment.)

Marking Criteria (H H E TF TP)	*Mark(s)*
• A thorough description of the environmental impacts of using two identified hydrocarbons from the Earth, one as a fuel and one for petrochemicals. • One relevant balanced equation • Articulates a concise, coherent and logical progression with relevant information (L)	8

• A thorough description of the environmental impacts of using two identified hydrocarbons from the Earth as fuels and petrochemicals. • Some chemistry shown	7
• A description of the environmental impacts of using identified hydrocarbons from the Earth as fuels and petrochemicals. • Some chemistry shown	6
• An outline of the environmental impacts of using from the Earth as fuels and petrochemicals.	5
• An outline of the environmental impacts of using one identified hydrocarbon from the Earth as a fuel or a petrochemical.	3-4
• Shows some understanding of an environmental impact of a hydrocarbon	2
• Some relevant information	1

H – identified hydrocarbon TF – thorough description of impact using a hydrocarbon fuel
TP – thorough description of impact using a hydrocarbon as a petrochemical
L – logical progression with no irrelevant information (eg extraction of HC from the Earth)
E balanced relevant chemical equation C some chemistry
(M* , P* special cases)

H	H	H	H	H	H	H	H	H	H		H	H	H	H		H			H
H	H	H				H	H												
TF	TF	TF	TF	TF	F	F	F	TF	FF	TF	FF	TF	F	TF	TF	FF	F	FF	F
TP	TP	TP	TP	P	TP	P			P	TP							P		
E	E	C	E	E	E	C	E	E		C	E	C	E		C				
L																			
8	7	7	7	6	6	6	5	5	5	5	5	4	4	3	3	3	2	2	2

Question 31 (7 marks)
An investigation was conducted to determine the amount of chloride ions in canned tomatoes as a means to determine the salt (sodium chloride) content. A precipitation titration experiment was carried out following the Volhard method.

The contents of a tin of canned tomatoes was blended using a food processor and then filtered. Bulb pipettes were used to add 25 mL of 0.1 $molL^{-1}$ silver nitrate solution to 25 mL of the filtrate to react with the chloride ions to form a silver chloride precipitate as shown below.

$$Ag^{+}\ (aq) + Cl^{-}\ (aq) \rightarrow AgCl\ (s)$$

After the silver chloride precipitate was removed via filtration, the remaining silver ions were titrated against a 0.10 $molL^{-1}$ potassium thiocyanate solution with 3 drops of a saturated ferric ammonium sulfate indicator. This reaction is shown in the following equation.

$$Ag^{+}\ (aq) + SCN^{-}\ (aq) \rightleftharpoons AgSCN\ (s)$$

The procedure was repeated several times and the titration results are given in the table.

Trial number	Volume of titre of potassium thiocyanate added (mL)
1	10.90
2	10.80
3	10.70
4	10.75

(a) Discuss the validity of this procedure in determining the chloride ion content of canned tomatoes. **3**

The procedure stated within this experiment is valid. It is clear that within the method all variables have been controlled, such as the use of a food processor on the canned tomatoes, followed by filtration to ensure a homogenous solution was used for each test. In addition to this, the volumes and concentrations of all the reagents were kept constant for each trial. The back titration technique provides a valid means to measure the sodium chloride content in canned tomatoes. The tomato filtrate was reacted with excess silver nitrate solution to precipitate all the chloride ions present in solution, followed by the removal of the precipitate. After this, the excess silver ions present in solution were titrated against a potassium thiocyanate solution which was used to determine the amount of silver ions remaining and in turn the amount of silver that reacted with chloride ions to measure the original salt content of the canned tomatoes.

Marking Criteria	*Mark(s)*
• Discusses the validity of the experimental procedure provided. • Supports conclusion with TWO appropriate reasons.	3
• Discusses the validity of the experimental procedure provided. • Supports conclusion with ONE appropriate reason.	2
• Provides some relevant information	1

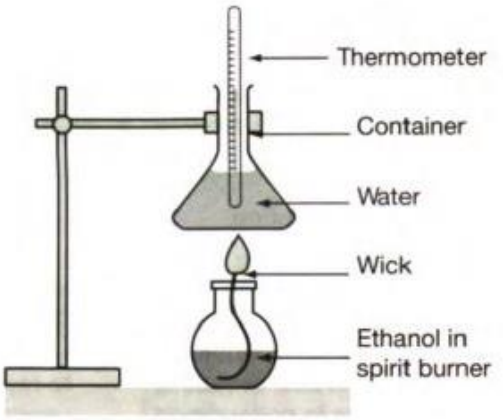
(b) Outline the accuracy and reliability of the data obtained. **4**

The data obtained from this precipitation titration is reliable. From the method it is clear that the experimental procedure has been repeated for each of the 4 trials, with a range of 0.2 mL. There is very little variation between the results obtained from each trial, so the experimental results have been replicated and in turn confirmed that the data is reliable.

The data collected from the experiment is accurate. The use of highly accurate equipment, such as bulb pipettes and burettes as stated in the method have allowed for the reporting of experimental values to two decimal places, however it is noteworthy to mention that the second decimal place is only accurate up to half the smallest increment on the burette.

Marking Criteria	*Mark(s)*
• Identifies the data obtained is accurate and reliable with appropriate reasoning for BOTH.	4
• Identifies the data obtained is accurate and reliable with appropriate reasoning for ONE.	3
• Identifies the data obtained is accurate with appropriate reasoning. **OR** • Identifies the data obtained is reliable with appropriate reasoning.	2
• Provides some relevant information.	1

Question 32 (4 marks)
The following experiment was set up to measure temperature change for a heat of combustion reaction.



100.0 mL of water at 298 K was heated by the burning of 1.20 g of ethanol in the spirit burner. Only 45.0% of the energy produced is used to heat the water. The molar heat of combustion of ethanol is 1368 $kJmol^{-1}$. Calculate the final temperature of the water.

M C_2H_5OH = 2(12.01) + 6(1.008) + 16 = 46.068 g

Mol C_2H_5OH = m/M = 1.20/46.068 = 0.026 mol

1 mol releases 1368 kJ therefore
0.026 mol releases x kJ

x = 1368 x 0.026 = 35.63 kJ

45% x 35.63 = 16.035 kJ = 16035 J

$\Delta H = mc\Delta T$

16035J = 100 x 4.18 x ΔT

$\Delta T = 38.36^o$
Final temperature = 25 + 38.36 = 63.4^{o}C

Marking Criteria	*Mark(s)*
• Provides ALL correct steps ***(no. of moles of ethanol, heat of combustion per mole, efficiency of combustion, change in temperature, and the final temperature)*** in the calculation of the final temperature to 3 significant figures.	4
• Provides most correct steps in the calculation of the final temperature.	3
• Provides some relevant calculation steps.	2
• Provides some relevant information.	1

Question 33 (9 marks)

A student performed a series of reactions to synthesise a compound with a molecular formula of $C_3H_6O_2$. In order to determine the molecular structure, they performed a series of spectral analysis techniques to obtain the given spectra.
Analyse the spectra provided in order to deduce the molecular structure of this compound and justify your reasoning. (Proton NMR data is included on page 32) **9**

Sample answer*Infrared Spectrum*

The Infrared Spectrum is a useful starting point as this provides us with information regarding the particular functional groups that are present in this compound. There are three characteristic peaks present in this compounds spectra. A very broad peak present from 2300 – 3700 cm^{-1} is characteristic for a hydroxyl (O–H) group belonging to a carboxylic acid. The presence of a carboxylic acid is also further confirmed by the presence of a carbonyl (C=O) peak at ~1700 cm^{-1}. There is also a narrow C–H stretch present at ~3000 cm^{-1}.

Mass Spectrum

The Mass Spectrum provides insightful information concerning the connectivity of functional groups through the fragmentation patterns. The peak signal at 74 corresponds to the molecular mass of the compound, whereas the peak signal at 73 is the deprotonated form of the carboxylic acid (M^+). The peak signal at 29 could be an aldehyde (^+CHO) fragment, but is more likely to represent a ethyl fragment ($CH_3CH_2^+$), which could be further supported by a minor peak signal at 15 corresponding to a methyl fragment (CH_3^+). The peak signal at 45 has a difference of 16 when compared to the peak signal at 29, which suggests the loss of an O atom, thus this signal at 45 could represent an alcohol fragment ($CH_3CH_2O^+$). However, since the IR spectrum above indicated the presence of a carboxylic acid, it is more than likely that the peak signal at 45 represents the fragmentation of the carboxylic acid group (^+COOH). There is only one possibility for the peak signal at 57 which confers to the following fragment ($CH_3CH_2C{=}O^+$).

^{13}C NMR Spectrum

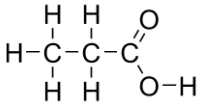
The Carbon NMR Spectrum is used to obtain information regarding the nature of each individual carbon environment. As the molecular formula contains three carbon atoms, and we see there are three distinct peaks in the spectrum, we can conclude that each carbon environment is unique, and that there is no symmetry in this molecule. There are two upfield peaks at 9 ppm and 18 ppm which should correspond to the respective carbons in an ethyl group. The carbon signal at 18 ppm represents that CH_2 of the ethyl group, that is slightly downfield shifted due to its proximity to the carboxylic acid, whereas the signal at 9 ppm represents the CH_3 of the ethyl group, which is at a lower chemical shift / less downfield shifted due to being further away.. There is one carbon environment that is heavily shifted downfield at 182 ppm, which indicates the presence of a carbonyl (C=O) carbon, from either an aldehyde, ketone, but most likely a carboxylic acid in light of the previous observations.

^{1}H NMR Spectrum

The Proton NMR Spectrum is arguably the most useful analytical resource as this provides information on the nature of each hydrogen environment as well as those adjacent, thus allowing us to determine the connectivity. The intensities / integration of each peak signal tells us the number of hydrogen atoms present in each environment. The signal at 1.1 ppm contains 3 protons and the signal at 2.2 ppm contains 2 protons, of which both are likely to confer to the CH_3 and CH_2 sections of an ethyl fragment respectively. We can further conclude this by the splitting patterns observed in these peaks, were the peak signal at 1.1 ppm is a triplet that

is split twice indicating the presence of an adjacent 2 proton environment and the 2.2 ppm is a quartet split thrice indicating the presence of an adjacent 3 proton environment. Thus, we can conclude that we indeed have an ethyl fragment. The peak signal at 11.8 ppm is a singlet which is not adjacent to any proton environments due to the lack of splitting. Since this peak is heavily downfield shifted, it suggests that this proton is attached to a large electron withdrawing group and is most likely a proton attached to a carboxylic acid.

Using the information provided by each spectrum, we can conclude that the structure of the isomer is propanoic acid, CH_3CH_2COOH.



Marking Criteria	*Mark(s)*
• Identifies **ALL** important features of the mass, infrared, carbon NMR, and proton NMR spectra provided. • Thoroughly analyses features of the mass (***confirmation***), infrared (***functionality***), carbon NMR (***chemical shift***), and proton NMR (***splitting pattern***) spectra provided. • Thoroughly justifies the deduced molecular structure using the analyses of the spectra provided.	9
• Identifies important features from the mass, infrared, carbon NMR, and proton NMR spectra provided. • Thoroughly analyses features from at least THREE of the mass, infrared, carbon NMR, and proton NMR spectra provided. • Justifies the deduced molecular structure using the analyses of the spectra provided.	8
• Identifies important features from the mass, infrared, carbon NMR, and proton NMR spectra provided. • Analyses features from at least TWO of the mass, infrared, carbon NMR, and proton NMR spectra provided. • Justifies the deduced molecular structure using the analyses of the spectra provided.	7
• Identifies important features from the mass, infrared, carbon NMR, and proton NMR spectra provided. • Analyses features from at least ONE of the mass, infrared, carbon NMR, and proton NMR spectra provided. • Correctly deduces the molecular structure.	6
• Identifies relevant features from the mass, infrared, carbon NMR, and proton NMR spectra provided. • Correctly deduces the molecular structure.	5
• Identifies relevant features from the mass, infrared, carbon NMR, and proton NMR spectra provided.	4
• Identifies relevant features from at least THREE of the mass, infrared, carbon NMR, and proton NMR spectra provided.	3
• Identifies relevant features from at least TWO of the mass, infrared, carbon NMR, and proton NMR spectra provided.	2
• Provides some relevant information.	1