2022
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
- For questions in Section II, show all relevant working in questions involving calculations

Total Marks – 100

Section I – 20 marks (pages 3-12)

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

Section II – 80 marks (pages 13-36)

- Attempt questions 21-34
- 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 13.

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

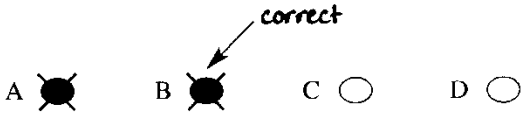
Sample: $2 + 4 =$ (A) 2 (B) 6 (C) 8 (D) 9

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. How many straight chain esters have the formula $C_6H_{12}O_2$?

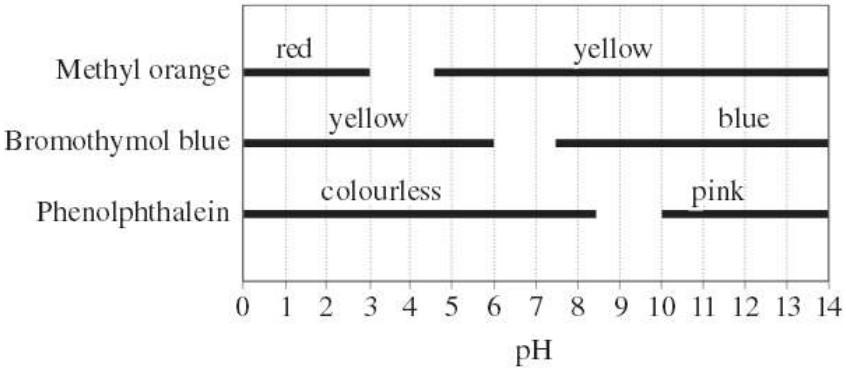
A. 3

B. 4

C. 5

D. 6

2. The chart below shows the colour ranges for three common indicators.



Equal volumes of a particular solution are poured into three separate beakers and a few drops of one indicator only, is added to one of each beaker.

The resulting colours are shown below:

Indicator	*Colour*
Bromothymol blue	Yellow
Methyl Orange	Yellow
Phenolpthalein	Colourless

What is the pH range of the solution?

A. 3.0 – 4.5

B. 4.5 – 6.0

C. 6.0 – 7.5

D. 6.0 -8.5

3. Which of the following statements about equilibrium systems is true?

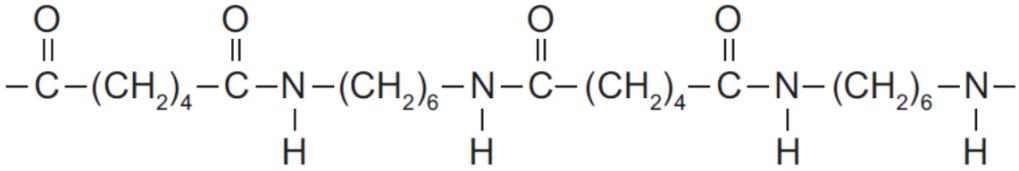
A. Increasing the temperature of an equilibrium system causes a greater increase in number of collisions in the endothermic direction than in the exothermic direction.

B. Increasing the pressure of an equilibrium system causes a greater increase in number of collisions in the endothermic direction than in the exothermic direction.

C. Increasing the volume of an equilibrium system causes a greater increase in the number of collisions in the side with more moles of gas than the side with fewer moles of gas.

D. Increasing the concentration of an equilibrium system causes a greater increase in the number of collisions in the side with more moles of gas than the side with the fewer moles of gas.

4. Nylon 6,6 is a polymer with the following structure.



Which combination gives the correct monomers used and the type of polymerisation undergone to form nylon 6,6?

	monomer	*monomer*	*Type of polymerization*
A.	$HOOC(CH_2)_4COOH$	$H_2N(CH_2)_6NH_2$	addition
B.	$HOOC(CH_2)_4COOH$	$H_2N(CH_2)_6NH_2$	condensation
C.	$HOOC(CH_2)_4\,NH_2$	$H_2N(CH_2)_6COOH$	addition
D.	$HOOC(CH_2)_4\,NH_2$	$H_2N(CH_2)_6COOH$	condensation

5. A sample liquid of compound Q did not decolourise when acidified potassium permanganate was added to it.

Which of the following is a possible identity for compound Q?

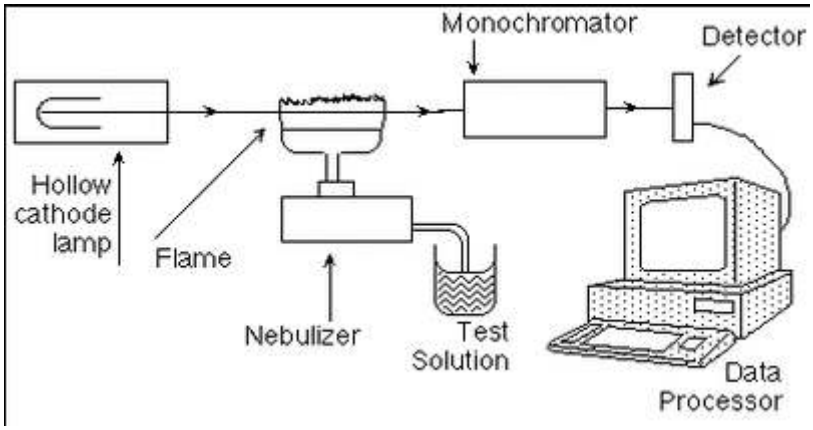
A. Pentan-1-ol

B. Pentan-2-ol

C. Cyclopentene

D. 2-methylpentan-2-ol

6. The diagram shows the components of an atomic absorption spectrophotometer.



Which component allows for a valid experiment to be carried out when testing for the concentration of a particular metal ion in a solution that contains other metal ions?

A. Flame

B. Detector

C. Monochromator

D. Hollow cathode lamp

7. Bitter yams contain high levels of toxic oxalates. In the Tiwi Islands, bitter yam plants are placed in streams for several days as part of a ritual to make the plants safe to eat.

Which concept does this best demonstrate?

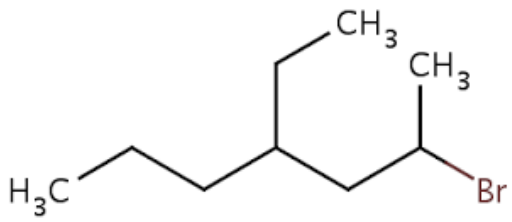
A. Static equilibrium

B. Dynamic equilibrium

C. Open system

D. Closed system

8. What is the name of the compound drawn below?



A. 2-bromo-4-ethylheptane

B. 1-bromo-3-ethyl-1-methylhexane

C. 4-ethyl-2-bromoheptane

D. 4-ethyl-6-bromohexane

9. The mass of magnesium carbonate that will dissolve in 1 L of water is closest to

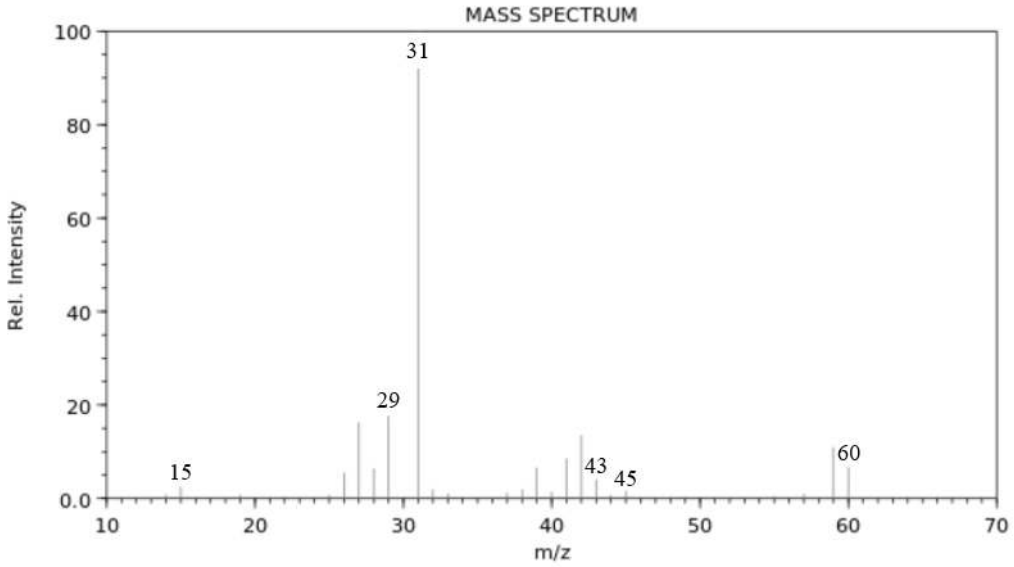
A. 2.6 mg

B. 22 mg

C. 0.22 g

D. 0.26 g

10. The mass spectrum for a position isomer of propanol is shown.



Which isomer of propanol was analysed and what fragment could confirm this?

	Isomer	*Fragment*
A.	Propan-1-ol	43
B.	Propan-1-ol	29
C.	Propan-2-ol	31
D.	Propan-2-ol	45

11. A solution contained a mixture of ions comprised of magnesium, calcium and lead.

Which of the following correctly lists the reagents in an order whereby the metals could be individually isolated via selective precipitation?

A. $NaBr$, Na_2CO_3, $NaOH$

B. $NaCl$, Na_2SO_4, Na_3PO_4

C. $NaSO_4$, NaI, Na_3PO_4

D. $NaNO_3$, $NaOH$, $NaCO_3$

12. When pure ammonium chloride is dissolved in pure water at a temperature of 25° C, the pH of the final solution is less than 7.

Which statement best explains that the pH < 7 for the resultant solution?

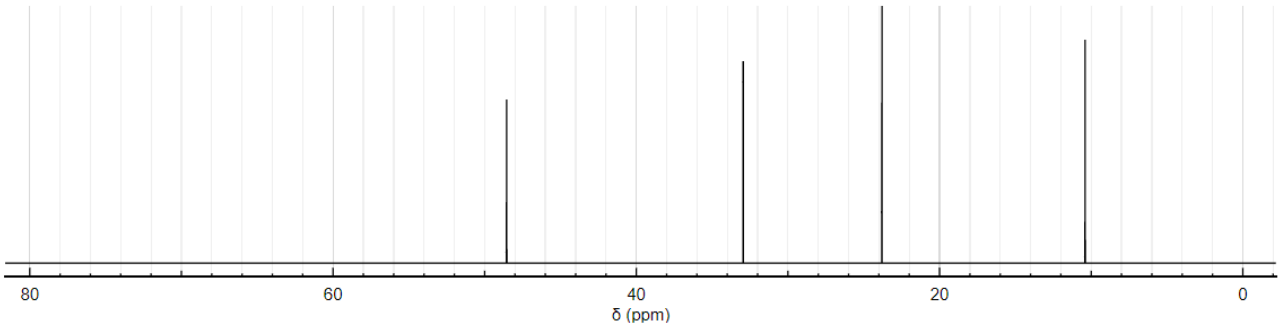
A. Ammonium ions accept protons from water, leaving hydroxide ions in solution.

B. Chloride ions make the solution acidic.

C. Ammonium ions combine with water molecules to give ammonium hydroxide.

D. Water molecules accept protons from ammonium ions forming hydronium ions in solution.

13. The carbon-13 NMR spectrum for butan-2-amine is shown.



Which signal corresponds to the carbon atom directly attached to the amine group?

A. 10.4 ppm

B. 23.8 ppm

C. 33.0 ppm

D. 48.6 ppm

14. Iodine, a silver solid, sublimes to produce a purple gas. A crystal of iodine was placed into a sealed container. When equilibrium was reached at t=20 minutes, a purple gas could be seen.

A change was made to the system and a new equilibrium was established which had a more intense purple colour to the gas, compared to the colour at t=20 minutes.

Which change could account for a more intense purple colour, as outlined above?

A. The pressure of the system was reduced.

B. The volume of the container was halved.

C. The temperature of the container was increased.

D. More crystal was added to the container.

15. The molar heat of neutralisation is -55kJ $molL^{-1}$.

What is the heat released when 40 mL of 0.40 $molL^{-1}$ sodium hydroxide reacts with 100 mL of 0.10 $molL^{-1}$ sulfuric acid?

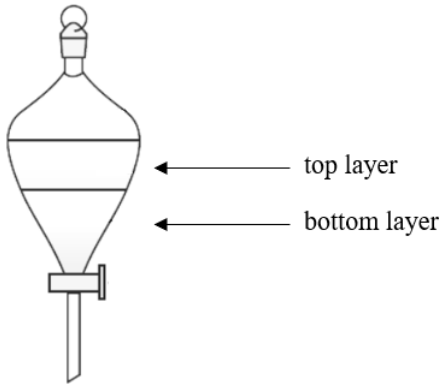
A. 0.55 kJ

B. 0.88 kJ

C. 1.1 kJ

D. 1.8 kJ

16. An experiment was carried out to synthesise butylethanoate. The resultant mixture was transferred to a separating funnel as illustrated in the diagram.



Which of the following tests could be used to determine the presence of unreacted carboxylic acid molecules?

A. Treating the bottom layer with $NaHCO_3$.

B. Addition of sodium metal to the bottom layer.

C. Isolating the top layer and checking for a fruity smell.

D. Reacting the top layer with $K_2Cr_2O_7$ and a few drops of H_2SO_4.

17. 12 mL of a gaseous hydrocarbon was reacted with 90 mL of oxygen at 25°C. On cooling to 25°C, the residual mixture of gases had a volume of 72 mL. This was shaken with potassium hydroxide solution to remove the carbon dioxide and, as a consequence, the volume of gas dropped to 36 mL consisting of oxygen only.

What was the gaseous hydrocarbon?

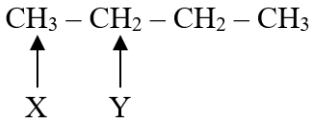
A. propane

B. propene

C. butane

D. butene

18. A molecule of butane is shown.



What is the multiplicity of signals X and Y in the ^{1}H spectrum of butane?

	X	*Y*
A.	Triplet	Quartet
B.	Quartet	Triplet
C.	Triplet	Quintet
D.	Quartet	Quintet

19. In the fermentation of a glucose ($C_6H_{12}O_6$) sample, 5.6 L of gas was produced at 35°C and 95 kPa of pressure.

What mass of ethanol was produced in this fermentation reaction?

A. 4.2 g

B. 4.8 g

C. 9.2 g

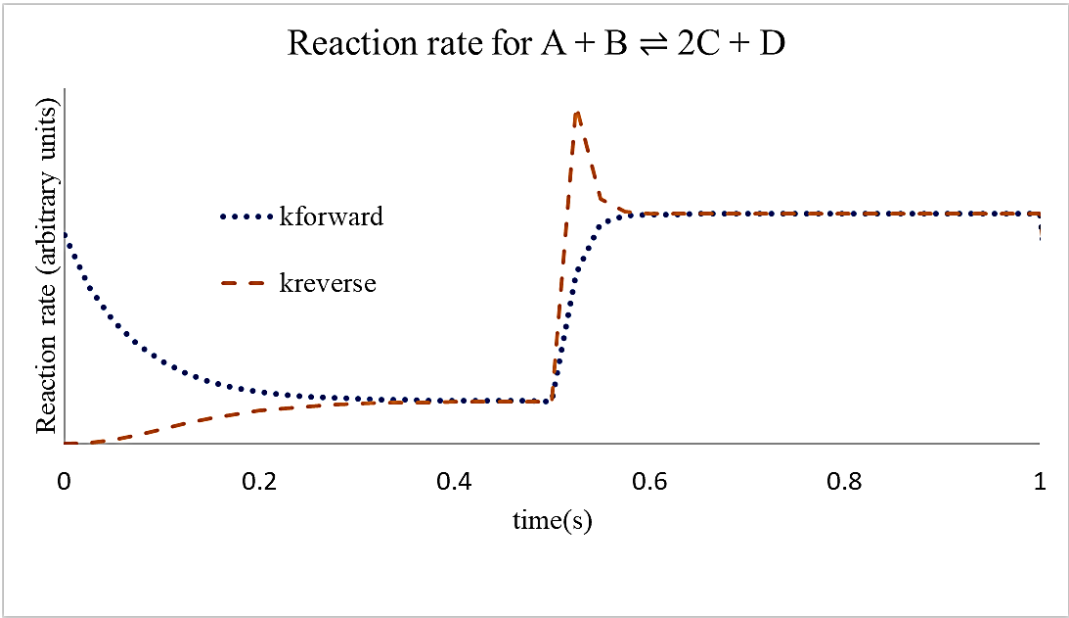
D. 9.6 g

20. A gaseous reaction between molecules A and B occurs as follows:

$$A(g) + B(g) \rightleftharpoons 2C(g) + D(g) \quad \Delta H = 12 \text{ kJ mol}^{-1}.$$

A and B are introduced into a sealed reaction vessel, and the system comes to equilibrium by t=0.4 s. At t=0.5 s a change is made to the system and the system re-establishes a new equilibrium.

A graph of reaction rate as a function of time is shown below.



Which of the following changes to the system is consistent with the reaction rate graphs?

	Change occurring at t=0.5 s
A.	Doubling of reaction volume
B.	Increase of reaction temperature
C.	Halving of reaction volume
D.	Decrease of reaction temperature

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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 – 34

Allow about 2 hours and 25 minutes for this section

- 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)

Discuss the changes in the development of theories of acids and bases with reference to Arrhenius and Bronsted-Lowry theories using the chemical reaction below. **4**

$$HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)$$

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Question 22 (5 marks)

Ammonia is a weak base with a Kb value of 1.8×10^{-5}.

Determine the pH of a 0.500 $molL^{-1}$ ammonia solution? **5**

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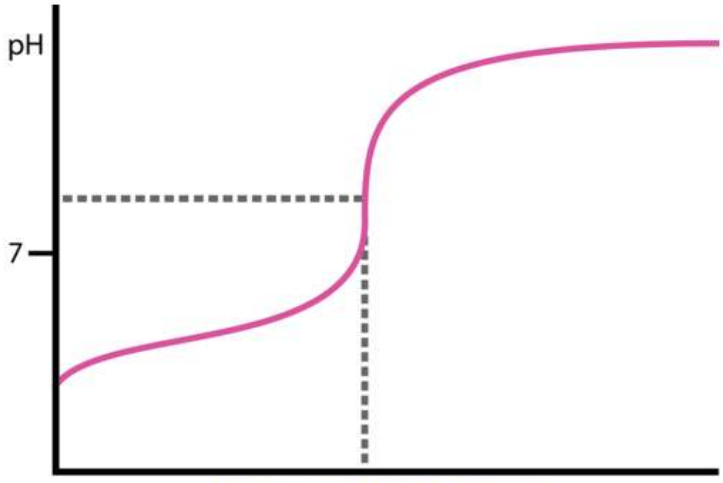
Question 23 (4 marks)

The graph below shows a titration with ethanoic acid and sodium hydroxide.



Titration curve of a weak acid (CH_3COOH) with a strong base (NaOH)

(a) Indicate on the graph the point which shows the buffering zone with an "X". **1**

(b) Explain the chemical reactions in the buffering zone. **3**

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Question 24 (4 marks)

A diesel engine vehicle can use either petrodiesel or biodiesel as a fuel.

Some properties of the two fuels are given below.

Fuel	*Major component*	*Energy content (MJ/kg)*	*Density (kg/L)*
Petrodiesel	$C_{12}H_{26}$	43	0.89
Biodiesel	$C_{19}H_{32}O_2$	38	0.89

(a) Assume that combustion occurs in an unlimited supply of oxygen and use the data from the table to calculate the number of litres of biodiesel that are required to be burnt to produce the same amount of energy as 2.5 kg of petrodiesel. **3**

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(b) Suggest ONE advantage of using biodiesel instead of petrodiesel. **1**

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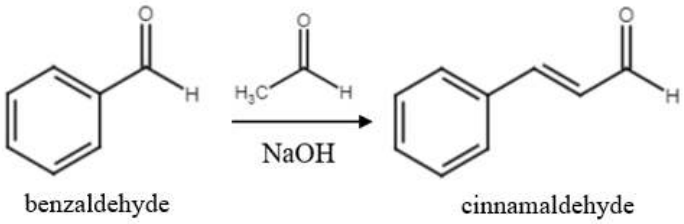
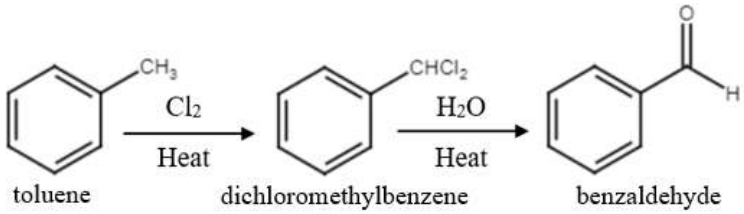
Question 25 (4 marks)

Cinnamaldehyde is an organic molecule responsible for the cinnamon flavour and odour in food products. It is commonly synthesised from benzaldehyde using the following reaction:

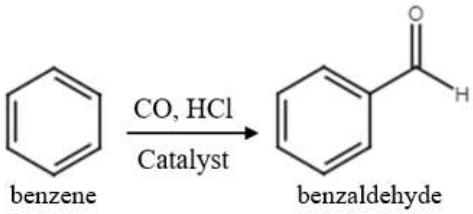


The benzaldehyde precursor can be derived from one of two reaction pathways:

Pathway 1



Pathway 2



Discuss the design considerations made for these reaction pathways. **4**

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Question 25 is continued on page 19

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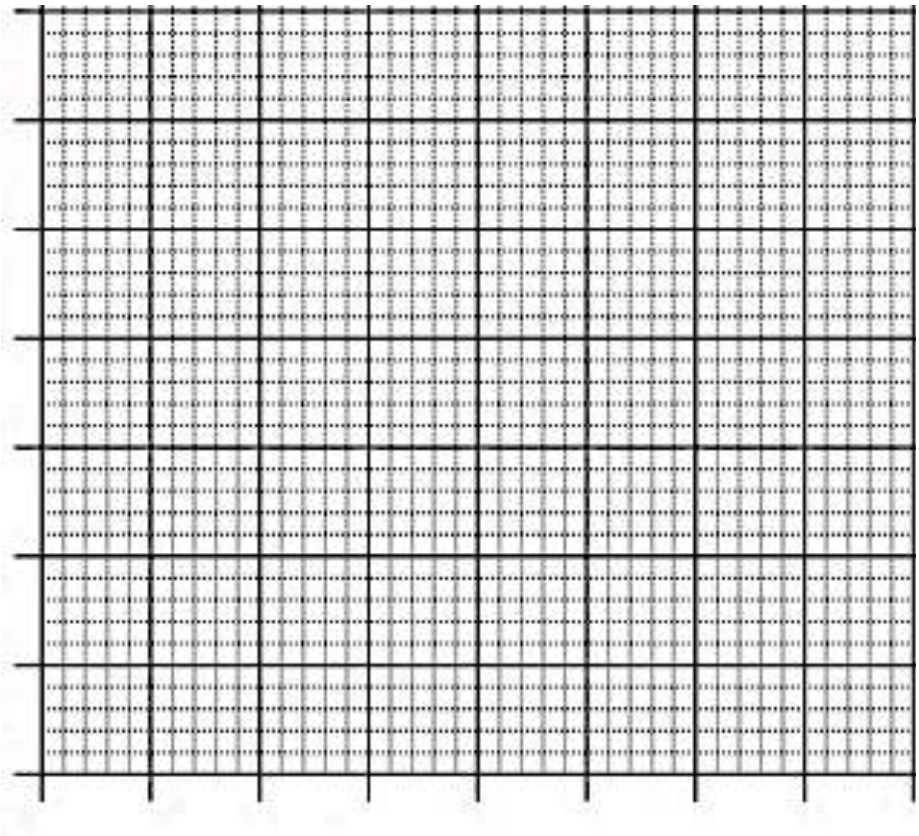
Question 26 (5 marks)

The endpoint of a titration may be determined using a conductivity meter.

(a) Draw the conductivity curve for the titration of 0.01 $molL^{-1}$ potassium hydroxide with 10.00 mL of hydrochloric acid using the data provided. **4**

Potassium hydroxide added (mL)	0	1	2	3	4	5	6	7
Conductivity (Sm^{-1})	130	116	103	89	76	73	87	103



(b) Account for the conductivity value not being zero at the end point. **1**

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Question 27 (6 marks)

The difference in the electronegativity of atoms can be used to determine the polarity of a bond. The electronegativity values for a range of elements are presented in the following table.

Element	*Electronegativity*
Hydrogen	2.1
Carbon	2.5
Nitrogen	3.0
Oxygen	3.5
Fluorine	4.0

(a) Using the information provided, compare the intramolecular bonds present in the molecules of separate pure samples of tetrafluoromethane and ammonia. **3**

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(b) Explain the intermolecular forces present in pure samples of tetrafluoromethane and ammonia. **3**

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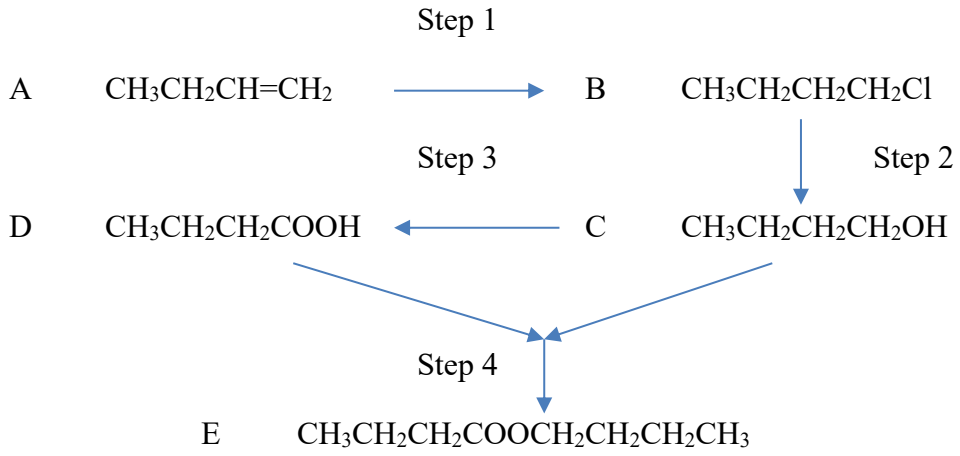
Question 28 (9 marks)

The following scheme can be used to prepare an ester.



(a) Identify compounds A, B, C, D and E. **3**

Compound	*Name*
A	
B	
C	
D	
E	

(b) Identify the reagents/conditions for steps 1, 2, 3 and 4 and the type of reaction e.g oxidation **4**

Step	*Reagents/conditions*	*Type of reaction*
1		
2		
3		
4		

Question 28 is continued on page 23

(c) Outline two reasons for preparing an ester in the school laboratory under reflux. **2**

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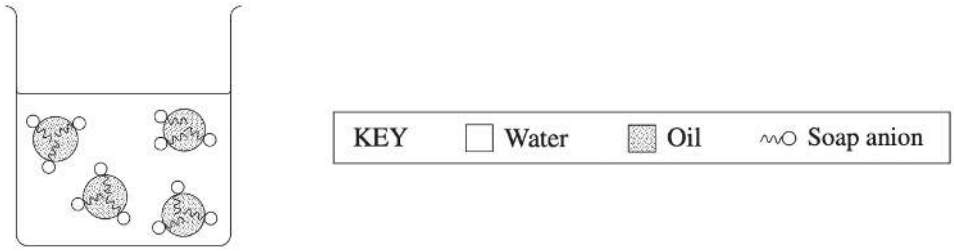
Question 29 (4 marks)

Use the following model to explain the formation of an emulsion. **4**



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Question 30 (8 marks)

20.0 mL of 0.0010 mol L^{-1} barium chloride was mixed with 30.0 mL 0.20 mol L^{-1} sodium sulfate and the product was filtered.

(a) Calculate the concentration of each ion in the filtrate. **4**

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Question 30 continued on page 25

(b) The student repeated the experiment with a different set of starting concentrations. The concentrations of the species in the filtrate were:

Species	$Ba^{2+}(aq)$	$Cl^{-}(aq)$	$Na^{+}(aq)$	$SO_4^{2-}aq)$
Concentration (mol L^{-1})	1.2×10^{-7}	1.6×10^{-5}	1.8×10^{-3}	8.9×10^{-4}

The filtrate was divided into two small beakers, labelled A and B. Beaker A had an equal volume of 0.10 $molL^{-1}$ sodium hydroxide added to it. Beaker B had an equal volume of 0.10 $molL^{-1}$ $AgNO_3$ added to it.

Deduce whether a precipitate formed in either, or both, of the beakers. **4**

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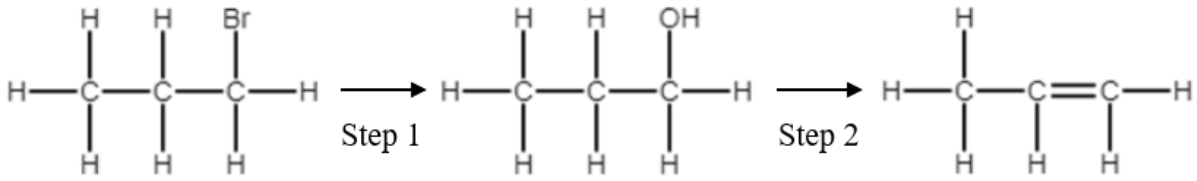
Question 31 (4 marks)

A chemist synthesises a series of molecules using the following reaction pathway:



Describe a relevant chemical test that could be used to confirm the identity of the functional group in product of each step, with reference to the appropriate observation.

(a) Step 1 **2**

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(b) Step 2 **2**

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Question 32 (6 marks)

Potash is a solid fertiliser supplement that can contain a variety of different potassium salts. A particular brand is known to advertise a claim that it contains only K_2SO_4, K_2CO_3, and KNO_3 in an optimised ratio by mass of 1:2:4.

A 24.31 g portion of fertilizer granules from this brand was completely dissolved in 0.500 L of water. A 25.00 mL aliquot of the solution was titrated with 0.100 mol L^{-1} of barium nitrate according to the reaction shown.

$$2\ Ba(NO_3)_2(aq) + K_2SO_4(aq) \rightarrow BaSO_4(s) + 2KNO_3(aq)$$

$$2\ Ba(NO_3)_2(aq) + K_2CO_3(aq) \rightarrow BaCO_3(s) + 2KNO_3(aq)$$

This precipitation titration was repeated three additional times and it was found that the average mass of dried precipitate obtained was 0.849 g from an average titre volume of 40.90 mL.

A separate 25.00 mL aliquot of fertilizer solution was treated with 50 mL of 0.197 mol L^{-1} hydrochloric acid. The resultant solution was then titrated with a standardised sodium hydroxide solution which held a concentration of 0.179 mol L^{-1}. This method was repeated multiple times to obtain the following set of results.

Titre	*Volume of NaOH (aq) added (mL)*
1	24.10
2	22.35
3	22.45
4	22.40

Do the results from this experiment support the manufacturer's claim? Support your answer with calculations. **6**

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Question 32 continued on page 29

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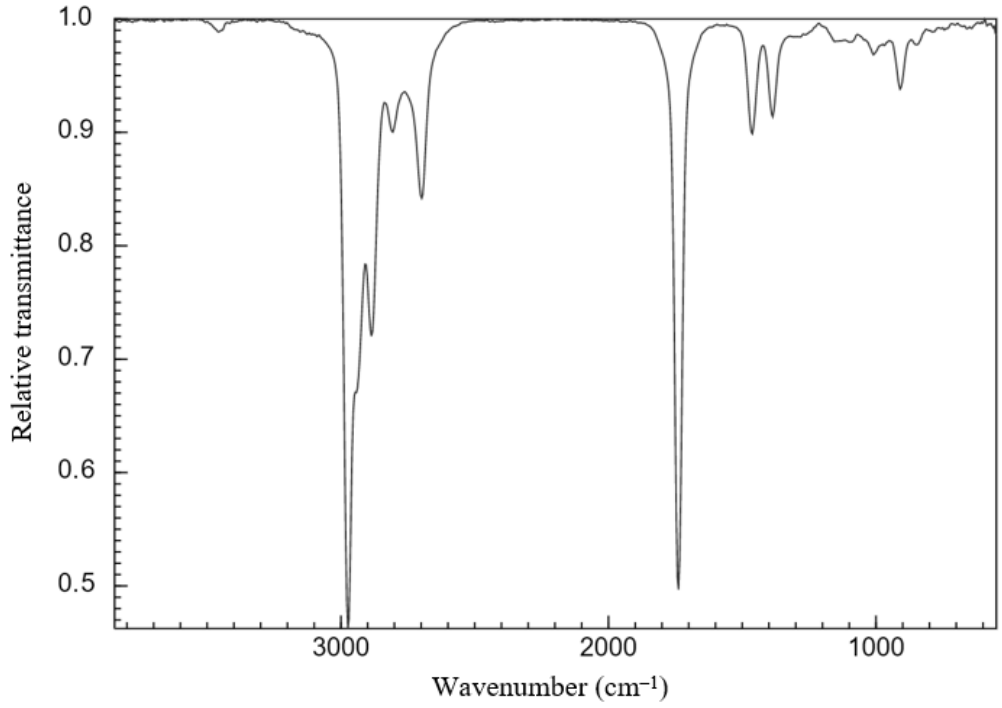
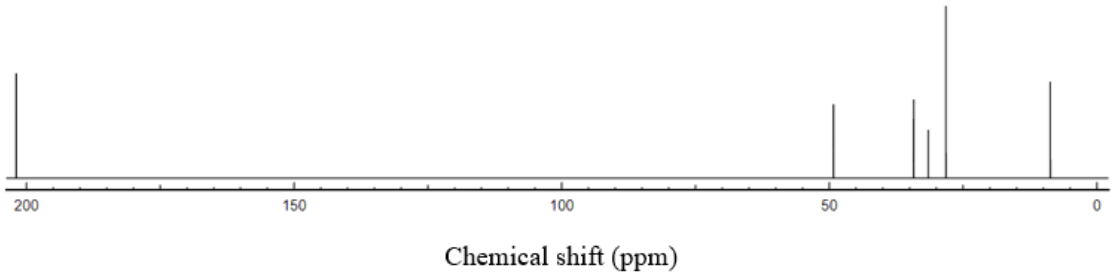
Question 33 (7 marks)

The following data was obtained from the analysis of an organic compound with a molecular formula of $C_7H_{14}O$.

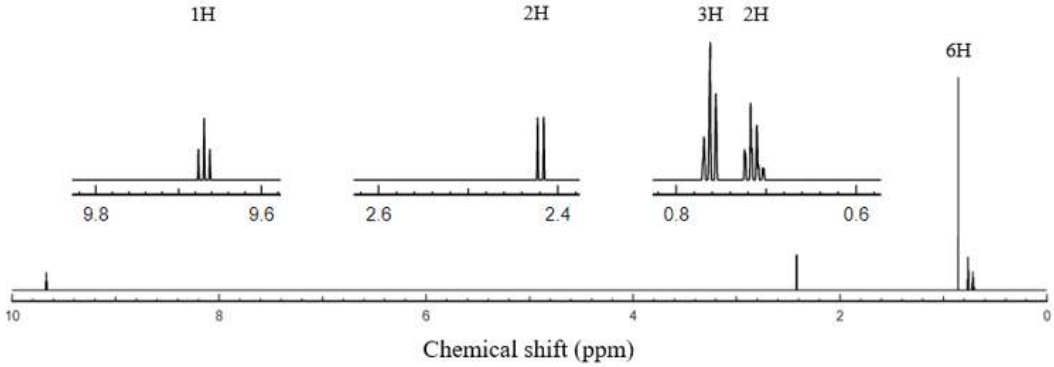
Infrared Spectrum



Carbon-13 NMR



Proton NMR



In the space provided, draw the structural formula of this compound that is consistent with all the information provided. Justify your selected structure with reference to the relevant features from each of the spectra.

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Question 34 (10 marks)

A student is studying the oxidation of the manganate ion to the permanganate ion using a transition metal containing oxidant X^{2+}:

$$MnO_4^{2-}(aq) + X^{2+}(aq) \rightleftharpoons MnO_4^{-}(aq) + X^{+}(aq) \quad \Delta H = 77.7 \text{ kJ mol}^{-1}$$

(a) Calculate the mass of potassium manganate required to make 25.0 mL of 0.0400 M solution. **2**

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(b) The student then adds this solution to 25.0 mL of 0.0600 mol L^{-1} X^{2+} solution in an insulated vessel containing a temperature sensor. The sensor reading is initially 24.1 °C.

Once equilibrium is established, the concentration of the manganate ion is 0.00800 mol L^{-1}.

Calculate the final temperature of the insulated vessel. **4**

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Question 34 continued on page 33

(c) Justify the value of $K_{eq} = 1$ for this reaction. **2**

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(d) Explain what can be deduced about ΔG and ΔS for this reaction. **2**

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End of Test

Part B extra writing space
If you use this space, clearly indicate which question you are answering.

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Part B extra writing space
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Type of proton		δ/ppm
$Si(CH_3)_4$	(TMS)	0
R—CH_3		0.7–1.3
R—CH_2—R		1.2–1.5
R—CHR_2		1.5–2.0
H_3C—CO—	(aldehydes, ketones or esters)	2.0–2.5
—CH—CO—	(aldehydes, ketones or esters)	2.1–2.6
H_3C—O—	(alcohols or esters)	3.2–4.0
—CH—O—	(alcohols or esters)	3.3–5.1
R_2—CH_2—O—	(alcohols or esters)	3.5–5.0
R—OH		1–6
R_2C=CHR	(alkene)	4.5–7.0
R—CHO	(aldehyde)	9.4–10.0
R—COOH		9.0–13.0

Answers 2022 JRAHS Chemistry Trial

1. How many straight chain esters have the formula $C_6H_{12}O_2$?

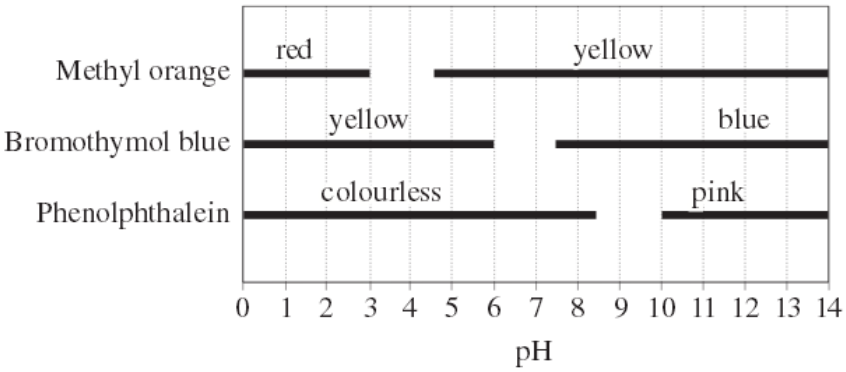
   A. 3

   B. 4

   C. 5

   D. 6

2. The chart below shows the colour ranges for three common indicators.



Equal volumes of a particular solution are poured into three separate beakers and a few drops of one indicator only, is added to one of each beaker.

The resulting colours are shown below:

Indicator	*Colour*
Bromothymol blue	Yellow
Methyl Orange	Yellow
Phenolpthalein	Colourless

What is the pH range of the solution?

   A. 3.0 – 4.5

   B. 4.5 – 6.0

   C. 6.0 – 7.5

   D. 6.0 -8.5

3. Which of the following statements about equilibrium systems is true?

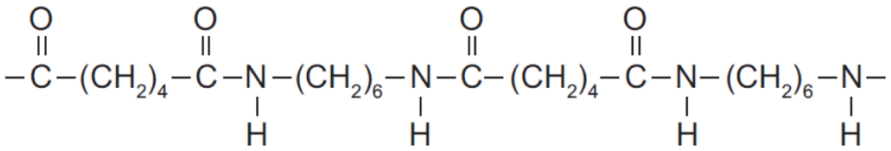
A. Increasing the temperature of an equilibrium system causes a greater increase in number of collisions in the endothermic direction than in the exothermic direction.

B. Increasing the pressure of an equilibrium system causes a greater increase in number of collisions in the endothermic direction than in the exothermic direction.

C. Increasing the volume of an equilibrium system causes a greater increase in the number of collisions in the side with more moles of gas than the side with fewer moles of gas.

D. Increasing the concentration of an equilibrium system causes a greater increase in the number of collisions in the side with more moles of gas than the side with the fewer moles of gas.

4. Nylon 6,6 is a polymer with the following structure.



Which combination gives the correct monomers used and the type of polymerisation undergone to form nylon 6,6?

	monomer	*monomer*	*Type of polymerization*
A.	$HOOC(CH_2)_4COOH$	$H_2N(CH_2)_6NH_2$	addition
B.	**$HOOC(CH_2)_4COOH$**	**$H_2N(CH_2)_6NH_2$**	**condensation**
C.	$HOOC(CH_2)_4\,NH_2$	$H_2N(CH_2)_6COOH$	addition
D.	$HOOC(CH_2)_4\,NH_2$	$H_2N(CH_2)_6COOH$	condensation

5. A sample liquid of compound Q did not decolourise when acidified potassium permanganate was added to it.

Which of the following is a possible identity for compound Q?

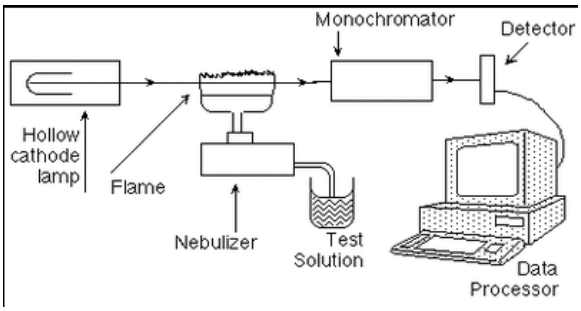
A. Pentan-1-ol

B. Pentan-2-ol

C. Cyclopentene

D. 2-methylpentan-2-ol

6. The diagram shows the components of an atomic absorption spectrophotometer.



Which component allows for a valid experiment to be carried out when testing for the concentration of a particular metal ion in a solution that contains other metal ions?

A. Flame

B. Detector

C. Monochromator

D. Hollow cathode lamp

7. Bitter yams contain high levels of toxic oxalates. In the Tiwi Islands, bitter yam plants are placed in streams for several days as part of a ritual to make the plants safe to eat.

Which concept does this best demonstrate?

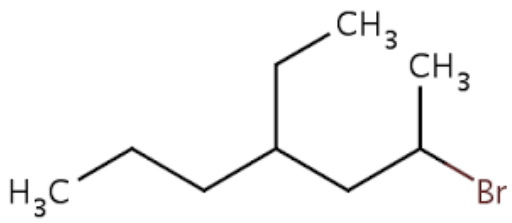
A. Static equilibrium

B. Dynamic equilibrium

C. Open system

D. Closed system

8. What is the name of the compound drawn below?



A. 2-bromo-4-ethylheptane

B. 1-bromo-3-ethyl-1-methylhexane

C. 4-ethyl-2-bromoheptane

D. 4-ethyl-6-bromohexane

9. The mass of magnesium carbonate that will dissolve in 1 L of water is closest to

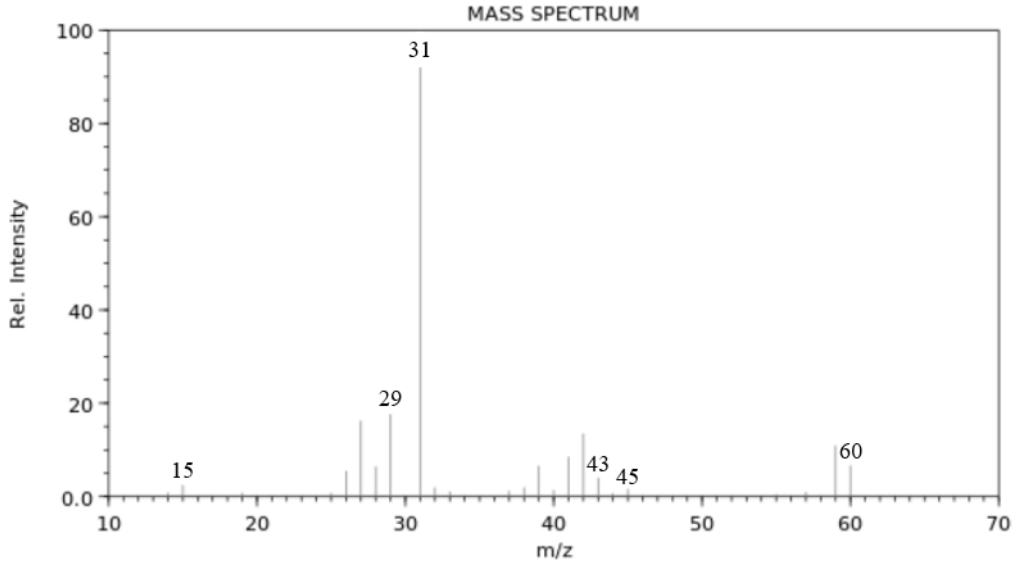
A. 2.6 mg

B. 22 mg

C. 0.22 g

D. 0.26 g

10. The mass spectrum for a position isomer of propanol is shown.



Which isomer of propanol was analysed and what fragment could confirm this?

	Isomer	*Fragment*
A.	Propan-1-ol	43
B.	**Propan-1-ol**	**29**
C.	Propan-2-ol	31
D.	Propan-2-ol	45

11. A solution contained a mixture of ions comprised of magnesium, calcium and lead.

Which of the following correctly lists the reagents in an order whereby the metals could be individually isolated via selective precipitation?

A. NaBr, Na_2CO_3, NaOH

B. NaCl, Na_2SO_4, Na_3PO_4

C. Na_2SO_4, NaI, Na_3PO_4

D. $NaNO_3$, NaOH, Na_2CO_3

12. When pure ammonium chloride is dissolved in pure water at a temperature of 25° C, the pH of the final solution is less than 7.

Which statement best explains that the pH < 7 for the resultant solution?

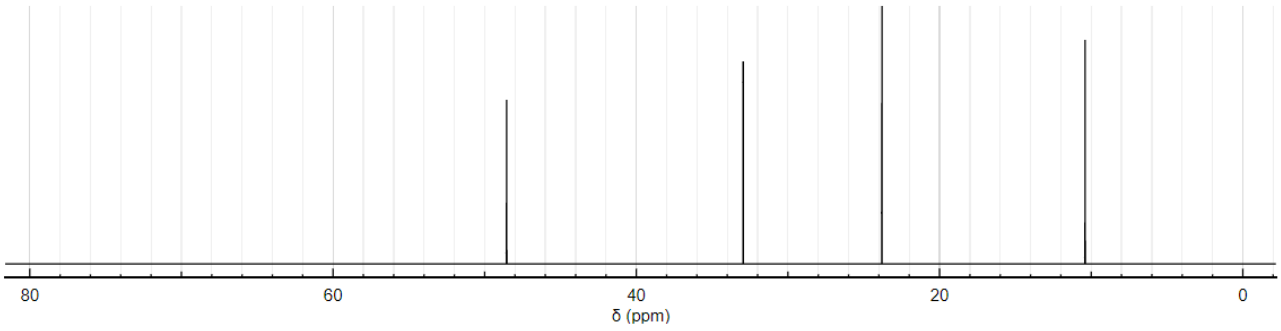
A. Ammonium ions accept protons from water, leaving hydroxide ions in solution.

B. Chloride ions make the solution acidic.

C. Ammonium ions combine with water molecules to give ammonium hydroxide.

D. Water molecules accept protons from ammonium ions forming hydronium ions in solution.

13. The carbon-13 NMR spectrum for butan-2-amine is shown.



Which signal corresponds to the carbon atom directly attached to the amine group?

A. 10.4 ppm

B. 23.8 ppm

C. 33.0 ppm

D. 48.6 ppm

14. Iodine, a silver solid, sublimes to produce a purple gas. A crystal of iodine was placed into a sealed container. When equilibrium was reached at t=20 minutes, a purple gas could be seen.

A change was made to the system and a new equilibrium was established which had a more intense purple colour to the gas, compared to the colour at t=20 minutes.

Which change could account for a more intense purple colour, as outlined above?

A. The pressure of the system was reduced.

B. The volume of the container was halved.

C. The temperature of the container was increased.

D. More crystal was added to the container.

15. The molar heat of neutralisation is -55 kJ mol^{-1}.

What is the heat released when 40 mL of 0.40 $molL^{-1}$ sodium hydroxide reacts with 100 mL of 0.10 $molL^{-1}$ sulfuric acid?

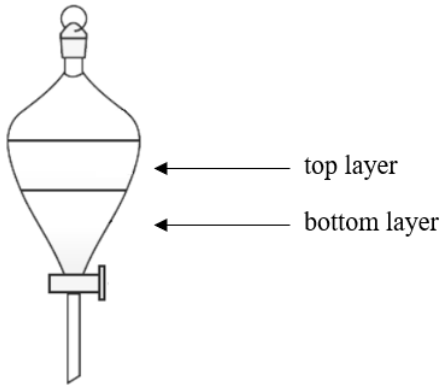
A. 0.55 kJ

B. 0.88 kJ

C. 1.1 kJ

D. 1.8 kJ

16. An experiment was carried out to synthesise butylethanoate. The resultant mixture was transferred to a separating funnel as illustrated in the diagram.



Which of the following tests could be used to determine the presence of unreacted carboxylic acid molecules?

A. Treating the bottom layer with $NaHCO_3$.

B. Addition of sodium metal to the bottom layer.

C. Isolating the top layer and checking for a fruity smell.

D. Reacting the top layer with $K_2Cr_2O_7$ and a few drops of H_2SO_4.

17. 12 mL of a gaseous hydrocarbon was reacted with 90 mL of oxygen at 25°C. On cooling to 25°C, the residual mixture of gases had a volume of 72 mL. This was shaken with potassium hydroxide solution to remove the carbon dioxide and as a consequence, the volume of gas dropped to 36 mL consisting of oxygen only.

What was the gaseous hydrocarbon?

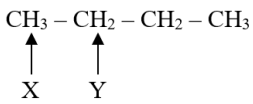
A. propane

B. propene

C. butane

D. butene

18. A molecule of butane is shown.



What is the multiplicity of signals X and Y in the ^1H spectrum of butane?

	X	*Y*
A.	**Triplet**	**Quartet**
B.	Quartet	Triplet
C.	Triplet	Quintet
D.	Quartet	Quintet

19. In the fermentation of a glucose ($C_6H_{12}O_6$) sample, 5.6 L of gas was produced at 35°C and 95 kPa of pressure.

What mass of ethanol was produced in this fermentation reaction?

A. 4.2 g

B. 4.8 g

C. 9.2 g

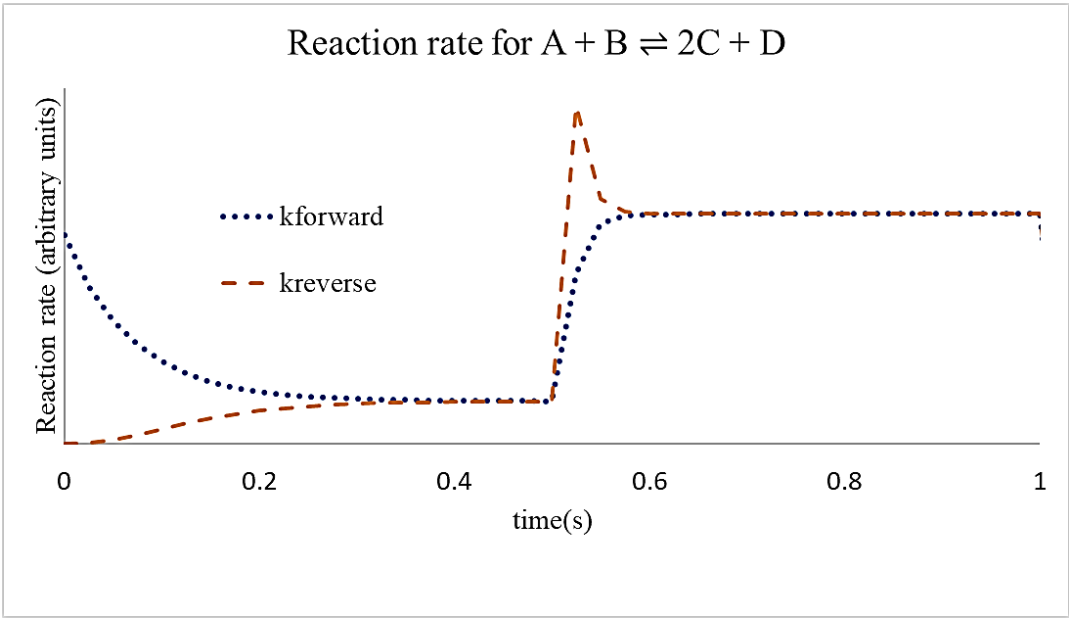
D. 9.6 g

20. A gaseous reaction between molecules A and B occurs as follows:

$$A(g) + B(g) \rightleftharpoons 2C(g) + D(g) \quad \Delta H = 12 \text{ kJ mol}^{-1}.$$

A and B are introduced into a sealed reaction vessel, and the system comes to equilibrium by t=0.4 s. At t=0.5 s a change is made to the system and the system re-establishes a new equilibrium.

A graph of reaction rate as a function of time is shown below.



Which of the following changes to the system is consistent with the reaction rate graphs?

	Change occurring at t=0.5 s
A.	Doubling of reaction volume
B.	Increase of reaction temperature
C.	**Halving of reaction volume**
D.	Decrease of reaction temperature

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 ○

Question 21 (4 marks)

Discuss the changes in the development of theories of acids and bases with reference to Arrhenius and Bronsted-Lowry theories using the chemical reaction below. **4**

$$HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)$$

Sample Answer:

Arrhenius – acid produced H-ions and bases OH -ions in water(aqueous) solution.
Eg $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
A acid A base
Did not account for bases without OH – ions eg CO_3 and acid base reaction not in aqueous solution eg HCl and NH_3 both are gases and do react without water.
Bronsted -Lowry – broader definition, acids are proton donors and bases are proton acceptors; an acid -base reaction involves an exchange of protons from an acid to a base; accounted for HCl/NH_3 gases reacting(no water) and HCl is B-L acid proton donor and NH_3 is B-L base proton acceptor.

Marking Criteria	*Mark(s)*
• Correct and complete information including definition for both theories of acids and bases and referring explicitly to the given equation for the theories of Arrhenius and Bronsted-Lowry	5
• Correct and complete information about the theories without referring to the given equation	4
• Some correct information for both theories referring to given equation	3
• Some correct information without examples for both theories	2
• One correct detail about one theory	1

Question 22 (5 marks)

Ammonia is a weak base with a Kb value of 1.8×10^{-5}.
Determine the pH of a 0.500 $molL^{-1}$ ammonia solution. **5**

Kb $=1.8 \times 10^{-5}$, $NH_{3(aq)} + H_2O \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$

$Kb = [NH_4^+][OH^-]/[NH_3] = 1.8 \times 10^{-5}$

	$[NH_3]$	$[NH_4^+]$	$[OH^-]$
Initial	0.5	0	0
Change	-x	x	x
Equilibrium	0.5 - x	x	x

as ammonia is a weak acid assume $[NH_3]$ at equilibrium is same as at start.

assume $[OH\text{-}]eq = [NH_3]eq$ then $[OH^-]^2 = Kb[NH_3]$

$K_b = x^2/0.5 - x = 1.8 \times 10^{-5}$

Thus $x^2 = 1.8 \times 10^{-5} \times 0.5$

Thus $x = 0.003$ mol L^{-1}

so $pOH = -\log_{10}[OH^-] = \log_{10}[0.003] = 2.523$

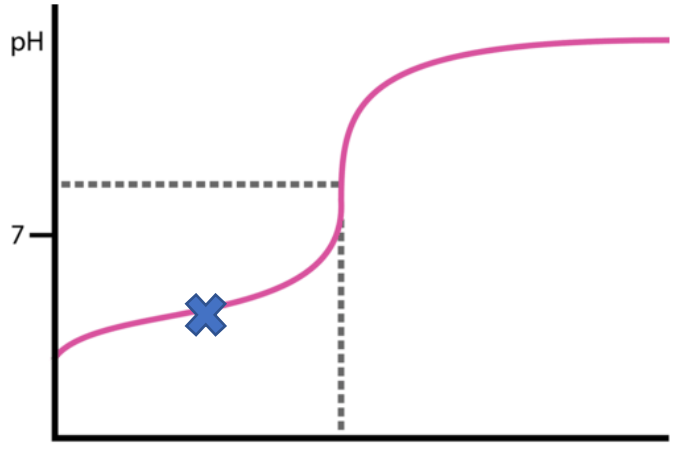
$pH + pOH = 14$ so $pH = 14 - pOH = 14 - 2.523 = 11.5$

Marking Criteria	*Mark(s)*
• Correct calculation of pH showing all working	5
• One error in calculation or information	4
• Two errors in calculation or information	3
• More than two errors	2
• One correct calculation or information	1

Question 23 (4 marks)

The graph below shows a titration with ethanoic acid and sodium hydroxide.

(a) Indicate on the graph the point which shows the buffering zone with an "X". **1**



Titration curve of a weak acid (CH_3COOH) with a strong base (NaOH)

"X" should be half-way below end-point on the graph

Marking Criteria	*Mark(s)*
• Correct label position for "X" showing buffering zone	1

(b) Explain the chemical reactions in the buffering zone. **3**

Sample Answer : The buffering zone is where there is very small change in pH as this is where the ethanoic acid molecules are reacting with the small amounts of base added, and thus small changes in pH are occurring. As the base is continually added more of the acid is used and the equilibrium is shifting to the right until all the acid is used and the equivalence point is reached. At the equivalence point there is a sharp change in pH as shown by the steep vertical point of the graph.
The ethanoic acid is a weak acid hence there is an equilibrium as shown :
$CH_3COOH_{(aq)} + OH^-_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H_2O_{(l)}$
As OH^- is added the equilibrium shifts to the right(as in Le Chetalier's principle) to use up the small amounts of added base. This maintains the pH of the solution hence there is a resistance to the change in pH until enough base is added so that all the $CH_3COOH_{(aq)}$ is consumed then the pH changes rapidly.

Marking Criteria	*Mark(s)*
• Correct and complete explanation for buffering zone including equilibrium equation for ethanoic acid reacting with the base ions	4
• Correct explanation without equilibrium equation for ethanoic acid	3
• Some correct information about buffering zone	2
• One correct detail about buffering zone	1

Question 24 (4 marks)

A diesel engine vehicle can use either petrodiesel or biodiesel as a fuel.

Some properties of the two fuels are given below.

Fuel	*Major component*	*Energy content (MJ/kg)*	*Density (kg/L)*
Petrodiesel	$C_{12}H_{26}$	43	0.89
Biodiesel	$C_{19}H_{32}O_2$	38	0.89

(a) Assume that combustion occurs in an unlimited supply of oxygen and use the data from the table to calculate the number of litres of biodiesel that are required to be burnt to produce the same amount of energy as 2.5 kg of petrodiesel. **3**

2.5 kg of petrodiesel $\rightarrow$ 2.5 x 43 MJ = 107.5 MJ
1.0 kg biodiesel $\rightarrow$ 38 MJ
x kg $\rightarrow$ 107.5 MJ
x = 107.5/38 = 2.83 kg
V biodiesel using density
0.89 kg $\rightarrow$ 1 L
2.83 kg $\rightarrow$ x L
x = 2.83/0.89 = 3.18 L

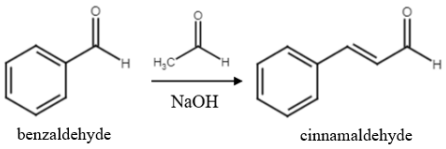
Marking Criteria	*Mark(s)*
• Correctly calculates the volume of biodiesel showing all relevant working	3
• Most relevant working shown	2
• Some relevant working shown	1

(b) Suggest ONE advantage of using biodiesel instead of petrodiesel.
Biodiesel is made from renewable sources and can be replenished whereas petrodiesel is made from fossil fuels which are non-renewable and are finite.
Biodiesel can undergo complete combustion as it contains an oxygen atom.

Marking Criteria	*Mark(s)*
• Gives one advantage of using biodiesel instead of petrodiesel	1

Question 25 (4 marks)

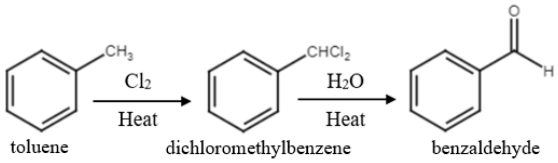
Cinnamaldehyde is an organic molecule responsible for the cinnamon flavour and odour in food products. It is commonly synthesised from benzaldehyde using the following reaction:



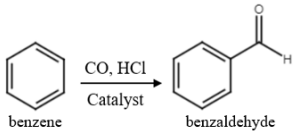
benzaldehyde cinnamaldehyde

The benzaldehyde precursor can be derived from one of two reaction pathways:

Pathway 1



Pathway 2



Discuss the design considerations made for these reaction pathways. **4**

Sample answer:

Pathway 1 implements heating for both steps in the reaction pathway. This is a beneficial consideration as using heat increases the overall kinetic energy of the reactant molecules resulting in a faster rate of reaction. It raises the efficiency of the overall synthesis by reducing the time required to complete each step. Note that, heating apparatus can prove to be expensive in terms of setup and operating costs.

Pathway 2 utilises a catalyst in the reaction pathway. The instalment of a catalyst lowers the activation energy needed to carry out the reaction, which is advantageous as it improves the rate of reaction and in turn the efficiency of the process. An added benefit is that this allows the process to be carried out at a lower operating temperature reducing costs.

Pathway 2 carries out a direct synthesis of the product in one step. This method is highly efficient as it yields a greater atom economy, where less materials are required for the synthesis as well as a reduction in the amount of waste produced. Note that, multistep reactions often result in a cumulative loss of yield which is not desirable.

NOTE: The acknowledgement that chlorine and / or carbon monoxide gas accompanied by the specific safety procedures involved with their handling was also considered an appropriate design consideration.

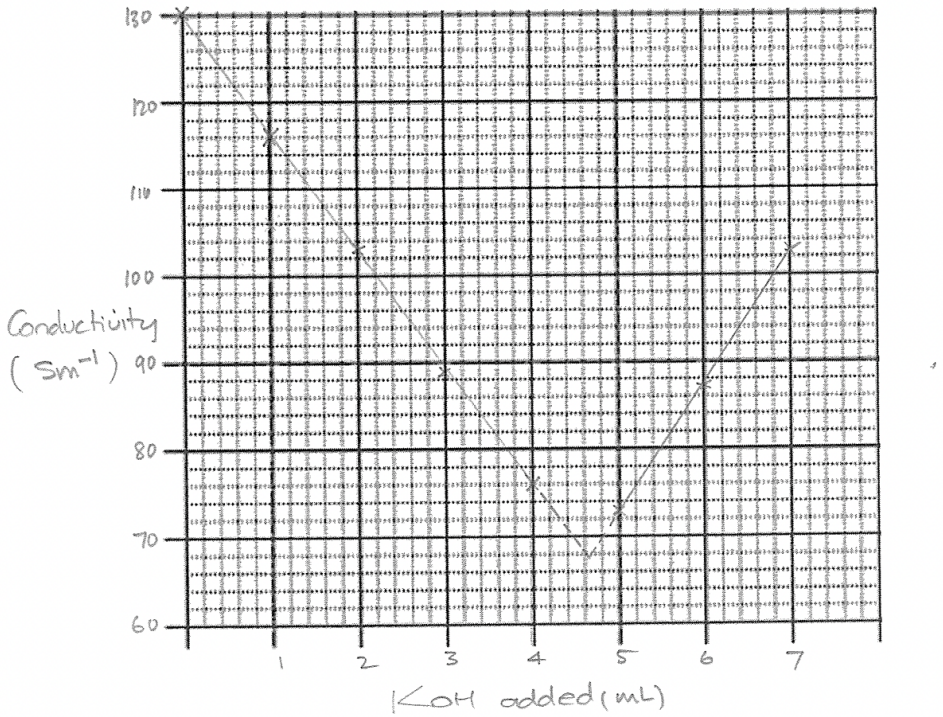
Marking Criteria	*Mark(s)*
• Discusses the benefits and / or limitations of three design considerations (temperature, catalyst, number of steps, handling of toxic gases).	4
• Explains the benefits of two design considerations. **OR** • Describes three design considerations.	3
• Explains the benefit of one design consideration. **OR** • Describes at least two design considerations.	2
• Provides some relevant information.	1

Question 26 (5 marks)

The endpoint of a titration may be determined using a conductivity meter.

(a) Draw the conductivity curve for the titration of 0.01 $molL^{-1}$ potassium hydroxide with 10.00 mL of hydrochloric acid using the data provided. **4**

Potassium hydroxide added (mL)	0	1	2	3	4	5	6	7
Conductivity (Sm^{-1})	130	116	103	89	76	73	87	103



Marking Criteria	*Mark(s)*
• Correct graph features, axes, scale, plots, intersecting lines of best fit	4
• Most graph features correct	3
• Some graph features correct	2
• Relevant graph feature	1

(b) Account for the conductivity value not being zero at the end point. **1**

At the endpoint there are spectator potassium and chloride ions present in the solution that are able to conduct charge.

Marking Criteria	*Mark(s)*
• Accounts for the conductivity at the endpoint	1

Question 27 (6 marks)

The difference in the electronegativity of atoms can be used to determine the polarity of a bond. The electronegativity values for a range of elements are presented in the following table.

Element	*Electronegativity*
Hydrogen	2.1
Carbon	2.5
Nitrogen	3.0
Oxygen	3.5
Fluorine	4.0

(a) Using the information provided, compare the intramolecular bonds present in the molecules of separate pure samples of tetrafluoromethane and ammonia. **3**

Sample answer:

feature	tetrafluoromethane	ammonia
formula	CF_4	NH_3
Difference in electronegativity	4-2.5 = 1.5	3.0 - 2.1 = 0.9
Intramolecular bonds	Polar covalent	Polar covalent

Marking Criteria	*Mark(s)*
• Compares the intramolecular bonding present in each molecule using the data provided and giving the formula for each compound	3
• Compares the intramolecular bonding present in each molecule OR • uses the data provided to determine the difference in electronegativity with formulae or identifies covalent bonds OR • Data is used for one compound, formula given and identifies polar covalent bonds	2
• provides some relevant information	1

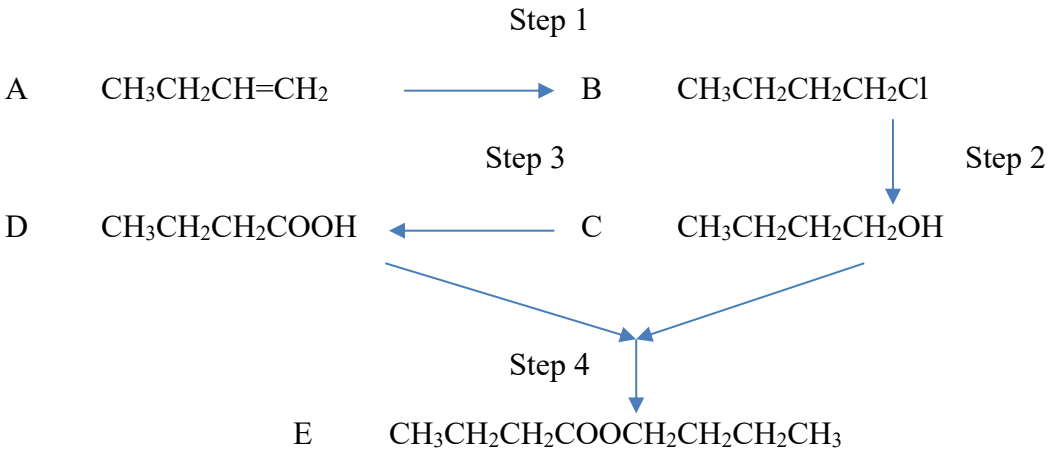
(b) Explain the intermolecular forces present in pure samples of tetrafluoromethane and ammonia. **3**

	CF_4	NH_3
Polarity of the molecule	Non-polar as the polarity cancels out as the molecule is symmetrical	Polar with a net dipole towards the nitrogen that is significantly more electronegative than the hydrogen
Intermolecular forces	Dispersion forces as the molecules are non-polar	Hydrogen bonding between the hydrogen and nitrogen atoms of separate molecules and dispersion forces

Marking Criteria	*Mark(s)*
• **Explains** the intermolecular forces present between each compound including the polar/nonpolar nature of the molecules	3
• Outlines the intermolecular forces present between each compound OR • Describes the intermolecular forces present in one compound	2
• Provides some relevant information	1

Question 28 (9 marks)

The following scheme can be used to prepare an ester.



(a) Identify compounds A, B, C, D and E.

Compound	*Name*
A	*But-1-ene*
B	*1-chlorobutane*
C	*Butan-1-ol*
D	*Butanoic acid*
E	*Butyl butanoate*

Marking Criteria	*Mark(s)*
• 5 correct names	3
• 3 or 4 correct names	2
• Incorrect prefix, correct homologous series OR 1 or 2 correct names	1

(b) Identify the reagents/conditions for steps 1, 2, 3 and 4 and the type of reaction e.g oxidation.

Step	*Reagents/conditions*	*Type of reaction*
1	*Add HCl solution*	*addition*
2	*Add sodium hydroxide solution*	*substitution*

3	*Acidified potassium permanganate solution*	*oxidation*
4	*Concentrated sulfuric acid/ reflux*	*esterification*

Marking Criteria	*Mark(s)*
• All correct reagents/conditions and types of reactions	4
• 5,6 or 7 correct answers	3
• 3 or 4 correct answers	2
• 2 correct answers	1

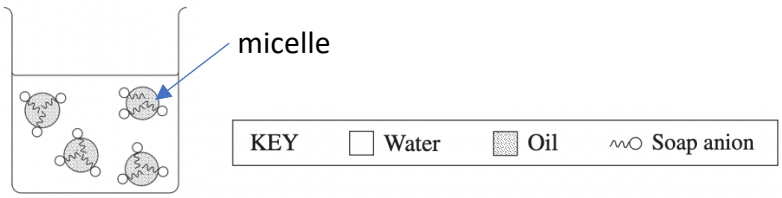
(c) Outline two reasons for preparing an ester in the school laboratory under reflux. **2**

The reflux condenser condenses volatile reactants and returns them to the reaction flask. Heating under reflux allows the reaction to proceed at a higher temperature, increasing reaction rate.

Marking Criteria	*Mark(s)*
• Outlines two reasons for refluxing	2
• Outlines one reason for refluxing	1

Question 29 (4 marks)

Use the following model to explain the formation of an emulsion. **4**



The soap anion has a long nonpolar hydrocarbon tail and a polar carboxylate head.(circle) . The non-polar hydrocarbon tails form dispersion forces with the non-polar oil, embedding themselves in the oil droplet. The polar carboxylate ends form dipole-dipole forces and H-bonds with polar water molecules and are outside the oil. These droplets form micelles with the tails in the oil and the polar heads on the outside. These droplets repel each other because of the negative polar heads of the soap anion on the outside of the droplets causing the droplets to remain dispersed forming an emulsion, droplets of one immiscible liquid suspended in another liquid.

Marking criteria	*Marks*
• *Defines an emulsion (DE) AND* • *Explains the formation of an emulsion referring to the model (C, Mo, MR)*	4
• *Describes the formation of an emulsion (combinations of C, Mo, MR, M, E,)*	3
• *Gives an outline of the formation of an emulsion (C; C MR; C Mo)*	2
• *Identifies some features of the soap anion OR* • *Gives some relevant information*	1

Question 30 (8 marks)

20.0 mL of 0.0010 mol L^{-1} barium chloride was mixed with 30.0 mL 0.20 mol L^{-1} sodium sulfate and the product was filtered.

(a) Calculate the concentration of each ion in the filtrate. **4**

Sample answer:

Sample answer:

For the reaction between barium chloride and sodium sulfate,
$BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaO_4(s) + 2NaCl(aq)$.

Initially:
$[Ba^{2+}] = 0.001 \times (20/50) = 4 \times 10^{-4}$ mol L^{-1}, $[Cl^-] = 2 \times [Ba^{2+}] = 8 \times 10^{-4}$ mol L^{-1}
$[SO_4^{2-}] = (0.2) \times (30/50) = 1.2 \times 10^{-1}$ mol L^{-1}, $[Na^+] = 2 \times [SO_4^{2-}] = 2.4 \times 10^{-1}$ mol L^{-1}

The K_{sp} for this rection is given by: $K_{sp} = [Ba^{2+}][SO_4^{2-}] = 1.08 \times 10^{-10}$.

$Q = [Ba^{2+}][SO_4^{2-}] = 4 \times 10^{-6} \times 1.2 \times 10^{-4} = 4.8 \times 10^{-10} > 1.08 \times 10^{-10}$ so precipitate formed

As $[SO_4^{2-}] > [Ba^{2+}]$, the barium is the limiting reagent, but in reality, there is some Ba^{2+} remaining in solution according to the equilibrium:

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightleftharpoons BaSO_4(s)$

	$Ba^{2+}(aq)$ +	$SO_4^{2-}(aq)$ ⇌	$BaSO_4(s)$
Initial	4×10^{-4}	1.2×10^{-1}	Solid, not included
Change	-x	-x	
Final	(4×10^{-4}) - x	1.2×10^{-1} -x	
	9×10^{-10}	1.2×10^{-1}	

$(4 \times 10^{-4} - x)(1.2 \times 10^{-1} - x) = 1.08 \times 10^{-10}$
$x < 4 \times 10^{-4}$ (can't have negative concentration), which is very much smaller than 1.2×10^{-1}, so approximate $(1.2 \times 10^{-1} - x)$ as 1.2×10^{-1}. But 4×10^{-4} -x is equal to the final concentration of barium ions.
$[Ba^{2+}] \times (0.12) = 1.08 \times 10^{-10}$
$[Ba^{2+}] = 1.08 \times 10^{-10} / 0.12 = 9 \times 10^{-10}$

(Sanity check: $9 \times 10^{-10} \times 1.2 \times 10^{-1} = 1.08 \times 10^{-10}$)

Concentration of the spectator ions Na^+ and Cl^- remains unchanged.

Concentration in filtrate:
$[Ba^{2+}] = 9 \times 10^{-10}$ mol L^{-1}, $[SO_4^{2-}] = 1.2 \times 10^{-1}$ mol L^{-1}, $[Cl^-] = 8 \times 10^{-4}$ mol L^{-1}, $[Na^+] = 2.4 \times 10^{-1}$ mol L^{-1}

Marking Criteria	*Mark(s)*
• Correct chemical equation with state • Correct calculation of concentration for all ions	4
• Four of the following • Correct chemical equation with state • Correct concentration of ions after mixing (before precipitation) • Correct size of change in ICE table • Correct solution of ICE table • Correct concentration of species • OR • All correct neglecting equilibrium	3
• 2-3 of the following • Correct chemical equation with state • Correct calculation of the number of moles of barium chloride and sodium sulfate • Correct concentration of ions after mixing (before precipitation) • Correct size of change in ICE table • Correct solution of ICE table	2
• Some relevant calculations • OR • Balanced chemical equation	1

Comments: there were some common errors in student responses.

- *Assuming that the reaction goes to completion is usually OK for working out the mass of the precipitate, but never for calculating the concentration of the ions forming the precipitate. The table of results on the next page should have been a clue.*
- *Some students who did realise that equilibrium was important calculated the concentration of Ba^{2+} in a saturated solution starting from water ($K_{sp} = x^2$). This can't be done given the significantly larger amount of SO_4^{2-} present.*
- *A significant number of students did not recognise that the concentration of the spectator ions remains unchanged, instead calculating the number of moles of NaCl based on $BaCl_2$ being a limiting reagent, leading to a very low value for $[Na^+]$, and other variations on this idea.*

The student repeated the experiment with a different set of starting concentrations. The concentrations of the species in the filtrate was:

Species	$Ba^{2+}(aq)$	$Cl^-(aq)$	$Na^+(aq)$	$SO_4^{2-}(aq)$
Concentration (mol L^{-1})	1.2×10^{-7}	1.6×10^{-5}	1.8×10^{-3}	8.9×10^{-4}

The filtrate was divided into two small beakers, labelled A and B. Beaker A had an equal volume of 0.1 M sodium hydroxide added to it. Beaker B had an equal volume of 0.1 M $AgNO_3$ added to it.

(b) Deduce whether a precipitate formed in either or both of the beakers. **4**

Sample Answer

Beaker A: testing $Ba^{2+}_{(aq)} + 2OH^-_{(aq)} \rightleftharpoons Ba(OH)_{2(s)}$ $K_{sp} = [Ba^{2+}][OH^-]^2 = 2.55 \times 10^{-4}$
$Q = [Ba^{2+}][OH^-]^2 = (0.6 \times 10^{-7})(0.05)^2 = 1.5 \times 10^{-10} < K_{sp}$ so no precipitate will form
As the barium was in the filtrate, no need to test for barium sulfate or chloride. Sodium salts are soluble, so no need to test further.

Beaker B: testing $2Ag^+_{(aq)} + SO_4^{2-}{}_{(aq)} \rightleftharpoons Ag_2SO_4(s)$ $K_{sp} = [Ag^+]^2[SO_4^{2-}] = 1.2 \times 10^{-5}$
$Q = [Ag^+]^2[SO_4^{2-}] = (0.05)^2(4.45 \times 10^{-4}) = 1.1 \times 10^{-6} < K_{sp}$ so no precipitate will form
But, Cl^- still present
Testing $Ag^+_{(aq)} + Cl^-_{(aq)} \rightleftharpoons AgCl\,(s)$ $K_{sp} = [Ag^+][Cl^-] = 1.77 \times 10^{-10}$
$Q = [Ag^+][Cl^-] = (0.05)(0.8 \times 10^{-5}) = 4 \times 10^{-7} > K_{sp}$ so precipitate will form.
Nitrates are soluble, so no need to test further.

Beaker A has no precipitate, beaker B has a precipitate.

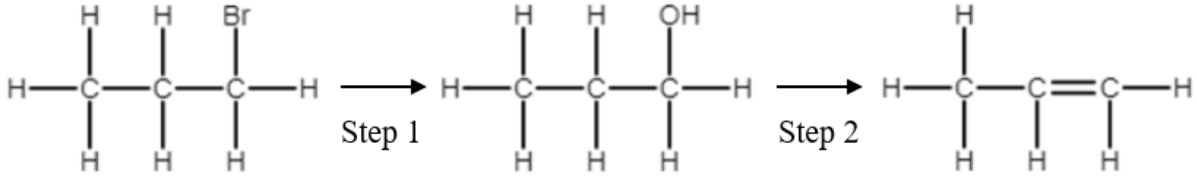
Marking Criteria	*Mark(s)*
• Identifies no precipitate in beaker A and 1 precipitate in beaker B • Justifies answer with relevant equations and full working	4
• Identifies no precipitate for barium and hydroxide	3

• Tests $AgSO_4$ in beaker B • Justifies answer with relevant equations and full working • OR • Tests for $Ba(OH)_2$ and AgCl precipitates and justifies answer with relevant equations and full working with one type of mistake	
• 2-3 of the following • Correct chemical equation with state • Correct concentration of 3 of the ions after mixing (barium, sulfate, silver, hydroxide, chloride) • Correct expression for 2 likely preciptates of Q or K_{sp} • Correctly deduces precipitate formation based on Q and identifies K_{sp} • Tests for precipitate in each beaker justifies answer with relevant equations and full working with two types of mistake	2
• Some relevant calculation(s) or equation(s)	1

Comments: many students forgot to reduce the concentration when the two solutions were mixed. A small number of students did not use any of the data or give any equations. It is not possible to just use the solublity rules to work out anything sensible for this question, as the solubility rules are for a particular concentration of the pure salt in water, not with non-stoichiometric concentrations of the ions. There was no need to test for $BaSO_4$ as a precipitate as it had already been filtered ($Q<K_{sp}$) and was then diluted, without any more Ba^{2+} or SO_4^{2-} added.

Question 31 (4 marks)

A chemist synthesises a series of molecules using the following reaction pathway:



Describe a relevant chemical test that could be used to confirm the identity of the functional group in product of each step, with reference to the appropriate observation.

(a) Step 1 **2**

Sample answer:
A small piece of sodium metal could be added to the product to test for the presence of an alcohol. This would create a vigorous reaction where that would produce a significant amount of hydrogen gas bubbles.

Alternative answers include: ceric ammonium nitrate changes from yellow to red, acidified potassium permanganate changes from purple to colourless, acidified potassium dichromate turns changes from orange to green.

Marking Criteria	*Mark(s)*
• Describes a relevant chemical test and the related observation.	2
• Provides some relevant information.	1

(b) Step 2 2

Sample answer:
A few drops of acidified potassium permanganate solution could be added to the product as a means to detect the alkene. This would cause the purple solution to decolourise as the reagent is consumed.

Alternative answers include: bromine water changes from orange / brown to colourless.

Marking Criteria	*Mark(s)*
• Describes a relevant chemical test and the related observation.	2
• Provides some relevant information.	1

Question 32 (6 marks)

Potash is a solid fertilizer supplement that can contain a variety of different potassium salts. A particular brand is known to advertise a claim that it contains only K_2SO_4, K_2CO_3, and KNO_3 in an optimised ratio by mass of 1:2:4.

A 24.31 g portion of fertilizer granules from this brand was completely dissolved in 0.500 L of water. A 25.00 mL aliquot of the solution was titrated with 0.100 mol L^{-1} of barium nitrate according to the reaction shown.

$$Ba(NO_3)_2(aq) + K_2SO_4(aq) \rightarrow BaSO_4(s) + 2KNO_3(aq)$$

$$Ba(NO_3)_2(aq) + K_2CO_3(aq) \rightarrow BaCO_3(s) + 2KNO_3(aq)$$

This precipitation titration was repeated three additional times and it was found that the average mass of dried precipitate obtained was 0.849 g from an average titre volume of 40.90 mL.

A separate 25.00 mL aliquot of fertilizer solution was treated with 50 mL of 0.197 mol L^{-1} hydrochloric acid. The resultant solution was then titrated with a standardised sodium hydroxide solution which held a concentration of 0.179 mol L^{-1}. This method was repeated multiple times to obtain the following set of results.

Titre	*Volume of NaOH (aq) added (mL)*
1	24.10
2	22.35
3	22.45
4	22.40

Do the results from this experiment support the manufacturer's claim? Support your answer with calculations. **6**

The first titre is a rough / outlier and was disregarded.

$v(NaOH)_{avg} = (22.35 + 22.45 + 22.40) / 3 = 22.40 \text{ mL} = 0.0224 \text{ L}$

$n(NaOH) = c \times v = 0.179 \times 0.0224 = 4.01 \times 10^{-3} \text{ mol}$

$n(HCl)_{excess} = 0.197 \times 0.05 = 9.85 \times 10^{-3} \text{ mol}$

$n(HCl)reacted = 9.85 \times 10^{-3} – 4.01 \times 10^{-3} = 5.84 \times 10^{-3} \text{ mol}$

$K_2CO_3 + 2\ HCl \rightarrow 2\ KCl + H_2O + CO_2$

$n(K_2CO_3)_{aliquot} = ½\ n(HCl) = 5.84 \times 10^{-3} / 2 = 2.92 \times 10^{-3} \text{ mol}$

$n(K_2CO_3)_{initial} = 20 \times n(K_2CO_3)_{aliquot} = 5.84 \times 10^{-2} \text{ mol}$

$m(K_2CO_3) = 5.84 \times 10^{-2} \times (39.10 \times 2 + 12.01 + 16.00 \times 3) = 8.07 \text{ g}$

$n(BaCO_3) = n(K_2CO_3) = 2.92 \times 10^{-3} \text{ mol}$

$m(BaCO_3) = 2.92 \times 10^{-3} \times (137.3 + 12.01 + 16.00 \times 3) = 0.576 \text{ g}$

$m(BaSO_4) = 0.849 – 0.576 = 0.273 \text{ g}$

$n(BaSO_4) = 0.273 / (137.3 + 32.07 + 16 \times 4) = 1.17 \times 10^{-3} \text{ mol} = n(K_2SO_4)_{aliquot}$

$n(K_2SO_4)_{initial} = 20 \times n(K_2SO_4)_{aliquot} = 2.43 \times 10^{-2} \text{ mol}$

$m(K_2SO_4) = 2.43 \times 10^{-2} \times (39.10 \times 2 + 32.07 + 16.00 \times 4) = 4.07 \text{ g}$

$m(KNO_3) = 24.31 – 8.07 – 4.07 = 12.17 \text{ g}$

ratio of masses is 4.07 g:8:07 g:12.17 g of K_2SO_4:K_2CO_3:KNO_3, which is approximately 1:2:3 and does not support the manufacturer's claim.

$NaOH + HCl \rightarrow NaCl + H_2O$.

Do the results from this experiment support the manufacturer's claim? Support your answer with calculations. 6

$V\ NaOH = \frac{22.35 + 22.45 + 22.40}{3} = 22.40\,mL$.

HCl leftover over : excess.

$n\ NaOH = c \times V = 0.179 \times 0.02240 = 0.0040096$

$\therefore n\ HCl\ excess = 0.0040096$

$n\ HCl\ originally = c \times V = 0.197 \times 0.05 = 9.85 \times 10^{-3}$

$\therefore HCl\ used = 9.85 \times 10^{-3} - 4 \times 10^{-3} = 5.85 \times 10^{-3}\ mol.$

$K_2CO_3 + 2HCl \rightarrow 2KCl + CO_2 + H_2O$.

$\therefore n\ K_2CO_3 = \frac{1}{2} \times 5.85 \times 10^{-3} = 2.92 \times 10^{-3}\ mol.$ in 25mL

$\therefore n\ K_2CO_3$ in 500mL $= 5.84 \times 10^{-2}\ mol.$

mass $K_2CO_3 = n \times MM = 5.84 \times 10^{-3} \times (2(39.1) + 12.01 + 3(16))$ (138.21)

$= 8.07\ g$.

$n\ K_2CO_3 = n\ BaCO_3 = 5.84 \times 10^{-2}\ mol.$ in 0.5L.

$= 2.92 \times 10^{-3}$ in 25mL.

mass $BaCO_3 = n \times MM = 2.92 \times 10^{-3} \times (137.3 + 12 + 3(16))$

$= 0.576\,g$.

$\therefore$ mass $BaSO_4 = 0.849\,g - 0.576\,g = 0.273\,g$.

$n\ BaSO_4 = \frac{m}{MM} = \frac{0.273}{137.3 + 32.07 + 4(16)} = 1.17 \times 10^{-3}$

$\therefore n\ K_2SO_4 = 1.17 \times 10^{-3}$ in 25mL

~~mass K_2SO_4~~

$n\ K_2SO_4$ originally $= \frac{1.17 \times 10^{-3} \times 500}{25} = 2.34 \times 10^{-2}\ mol.$

mass K_2SO_4 originally $= n \times MM = 2.34 \times 10^{-2} \times ((39.1)2 + 32.07 + 4(16))$ (174.27)

$= 4.08\,g$.

$\therefore$ mass $KNO_3 = 24.31 - (8.07 + 4.08) = 12.16$.

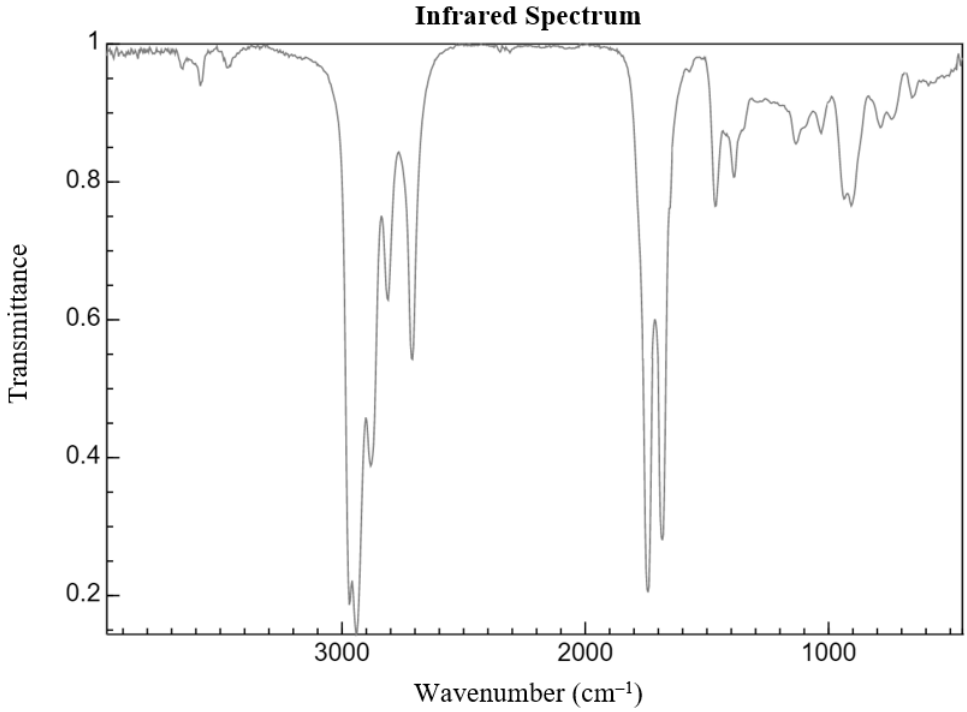
K_2SO_4	K_2CO_3	KNO_3
4.08	8.07	12.16

$\therefore 2 : 3$ does not support manufacturers claim

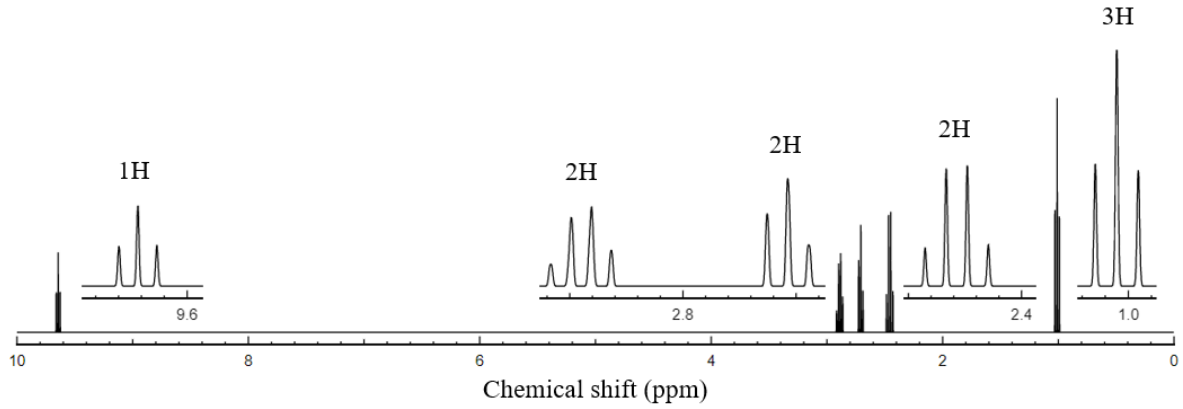
Marking Criteria	*Mark(s)*
• Provides a complete calculation for the ratio of masses of the potassium salts showing all relevant working. • Provides a judgement about the ratio of masses that is consistent with calculations provided.	6
• Provides the main steps for calculating the masses of at least one potassium salts., no judgement given	5
• At least 4 relevant calculations, including the excess HCl used in the back titration.	4
• Provides some steps of the calculations	2 – 3
• Provides one calculation	1

Question 33 (7 marks)

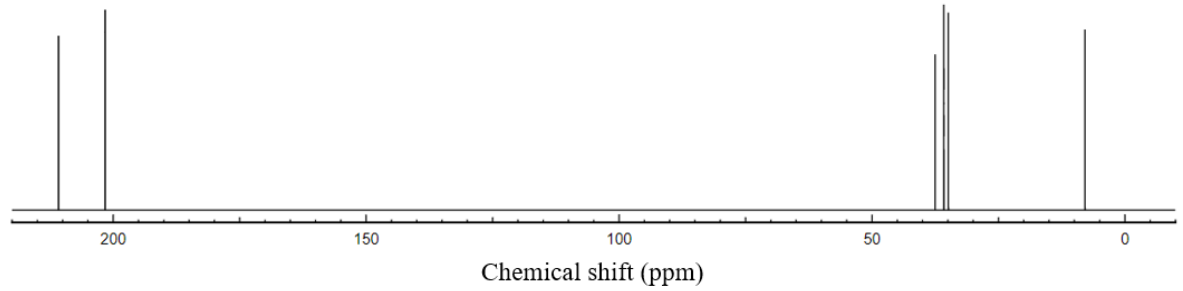
The following data was obtained from the analysis of an organic compound with a molecular formula of $C_6H_{10}O_2$. Proton NMR data is attached at the end of the paper on page 32.



Proton NMR

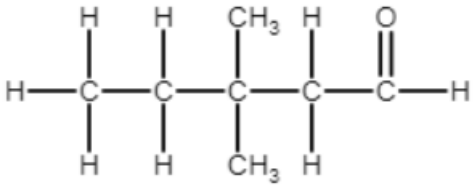


Carbon-13 NMR



In the space provided, draw the structural formula of this compound that is consistent with all the information provided. Justify your selected structure with reference to the relevant features from each of the spectra. **7**

Sample answer:



Infrared Spectrum

The IR spectrum shows one distinct and strong absorption peak at roughly 1750 cm^{-1} which identifies the presence of one C=O bond in the molecule. This suggests that the functional group could either be an aldehyde or ketone. There is no broad O–H bond observed between 2500 – 3000 cm^{-1} which eliminates the possibility of an alcohol functional group in this compound.

Carbon-13 NMR Spectrum

The carbon spectrum displays 6 distinct peaks for the 7 carbon atoms in the molecule, which indicates that there is symmetry present. As a result, there must be two carbon atoms in chemically equivalent environments. There is one signal located above 200 ppm which is diagnostic for aldehydes and ketones.

Proton NMR Spectrum

There is a triplet at 9.66 ppm which contains one hydrogen atom that is adjacent to two other hydrogen atoms. As this signal represents one hydrogen atom that is heavily downfield shifted,

we can conclude that the functional group must be an aldehyde as opposed to a ketone (reference value given on data table). This is coupled with a doublet signal at 2.42 ppm which contains two hydrogen atoms that must have one neighbouring hydrogen atom. Both of these signals correspond to a CH_2CHO segment in the molecule.
There is a triplet signal at 0.76 ppm which contains three hydrogen atoms that is adjacent to two other hydrogen atoms. This is coupled with a quartet signal at 0.71 ppm which contains two hydrogen atoms that has three neighbouring hydrogen atoms. Both of these signals correspond to a CH_3CH_2 (ethyl) chain in the molecule.
There is a singlet signal at 0.90 ppm which contains six hydrogen atoms that is isolated from any neighbouring hydrogen atoms. This likely to be two chemically equivalent CH_3 (methyl) groups in the molecule. As there are four separate carbon chain segments that are not directly connected, there must be a quaternary carbon atom that does not have any hydrogen atoms separating these groups. The compilation of the segments detailed above results in the aldehyde molecule drawn.

Marking Criteria	*Mark(s)*
• Draws the correct structural formula for 3,3-dimethylpentanal (naming not required). • Justifies the correct structure showing an extensive understanding of the interpretation of spectroscopic data. • Refers explicitly to ALL relevant spectroscopic data.	7
• Draws the correct structural formula for 3,3-dimethylpentanal or an appropriate isomer (naming not required). • Justifies the correct structure showing a thorough understanding of the interpretation of spectroscopic data. • Refers to relevant spectroscopic data from all three spectra.	6
• Provides structural formula consistent with analysis. • Shows a sound understanding of the interpretation of spectroscopic data. • Refers to relevant spectroscopic data from at least two spectra.	4 – 5
• Provides an appropriate section of the structural formula. • Shows some understanding of the interpretation of spectroscopic data from at least two spectra.	2 – 3
• Provides some relevant information.	1

Question 34 (10 marks)

A student is studying the oxidation of the manganate ion to the permanganate ion using a transition metal containing oxidant X^{2+}:

$$MnO_4^{2-}\,(aq) + X^{2+}(aq) \rightleftharpoons MnO_4^{-}\,(aq) + X^{+}\,(aq) \quad \Delta H = 77.7 \text{ kJ mol}^{-1}$$

(a) Calculate the mass of potassium manganate required to make 25.0 mL of 0.0400 M solution. **2**

K_2MnO_4 molar mass = 2 x 39.10 + 54.94 + 4 x16.00 = 197.14 g
Moles required = cv = 0.025 x 0.04 = 0.001 mol
Mass required = moles * molar mass = 0.001 x 197.14 = 0.197 g

Marking Criteria	*Mark(s)*
• Correctly calculates mass of potassium manganate	2
• Some relevant calculation	1

Comment: most students were able to complete this. A few forgot the potassium, or didn't notice that it was K_2MnO_4. Some students divided instead of multiplying.

(b) The student then adds this solution to 25.0 mL of 0.0600 M X^{2+} solution in an insulated vessel containing a temperature sensor. The sensor reading is initially 24.1 °C.

Once equilibrium is established, the concentration of the manganate ion is 0.00800 M.

Calculate the final temperature of the insulated vessel. **4**
Initial moles manganate = 0.001
Final moles manganate = cv = 0.05 x 0.0080 = 0.00040
Moles manganate reacted = 0.00060
Heat absorbed = 0.00060 x 77.7 x 1000= 46.6 J
Mass of solution = 50 g
Q = mcΔT
-46.6= 50 x 4.184 x ΔT
ΔT = 0.22 °C
Final T = 24.1 – 0.22 = 23.9 °C

Marking Criteria	*Mark(s)*
• Correctly calculates final temperature	4
• Calculates 3 of the following: • Moles manganate reacted	3

• Heat absorbed by reaction • Temperature change • Final temperature • OR • Calculation with one error	
• Calculates 2 of the following: • Moles manganate reacted • Heat absorbed by reaction • Temperature change • Final temperature • OR • Calculation with 2 errors	2
• Some relevant working	1

Comments: many students mixed up moles with concentration and/or forgot to reduce the concentration when the two solutions were mixed. Better laid out working would have avoided this problem. A significant number of students forgot that the reaction was endothermic. Please be careful when deciding which mass is undergoing the temperature change, in this case you had to assume that it was the water, and use an appropriate value.

(c) Justify the value of $K_{eq} = 1$ for this reaction. **2**

Marking Criteria	*Mark(s)*
• Correctly justifies K_{eq}	2
• Some relevant working	1

Sample answer:

	$MnO_4^{2-}{}_{(aq)}$ +	$X^{2+}{}_{(aq)}$ ⇌	$MnO_4^{-}{}_{(aq)}$ +	$X^{+}{}_{(aq)}$
Initial	0.02	0.03	0	0
Change	-x (-0.0120)	-x	x	x
Final	0.0080	0.0180	0.0120	0.0120

$K_{eq} = [MnO_4^-][X^+]/[MnO_4^{2-}][X^{2+}] = (0.0120 \times 0.0120)/(0.0080 \times 0.0180) = 1.0$

Comments: Just writing the expression for K_{eq} would have been awarded a mark, many students could have done better here. A number of students tried to justify it by stating that since there were the same number of reactants and products, and they were in the same state,

and because it was only a redox reaction exchanging electrons, K_{eq} was 1. This is not true in general, in fact it took me several hour of searching to find a reaction like this that had a value of K_{eq} = 1, and the ions were so exotic that I just called them X so as to avoid confusion. A number of students told me that the concentration of products and reactants were equal, including several who had calculated them to be otherwise.

(d) Explain what can be deduced about ΔG and ΔS for this reaction. **2**

Sample answer:
The calculated value of K_{eq} around 24 °C is 1. This suggests that at equilibrium neither the reactant or product side is strongly favoured. This is consistent with a value for ΔG of zero. As ΔH is quite positive, a positive value of ΔS would be require for ΔG to be around zero as ΔG = ΔH – TΔS (if ΔG = 0, then ΔS = ΔH/T and both ΔH and T are positive, *giving $\Delta S = \Delta H/T$ around 260 J K^{-1} mol^{-1}*).

Marking Criteria	*Mark(s)*
• Provides correct explanation of sign for ΔG and ΔS using cause and effect statement	2
• Some relevant information	1

Comment: there were many answers which demonstrated a variety of misconceptions.

- *Student responses which told me that $\Delta G < 0$ because the reaction was spontaneous. This shows a misunderstanding of equilibria. If you consider the reaction A + B ⇌ C + D, putting A and B will cause the reaction to go forwards. Putting in C and D will make the reaction go backwards. Clearly, forward and reverse can't both be spontaneous.*
- *Student responses which told me that $\Delta G = 0$ because the reaction was at equilibrium. It is true that $\Delta G = 0$ for a system at equilibrium, but the question was about the value for ΔG for the reaction.*
- *Student responses which told me that ΔS was zero as there was no change in the number of moles. While it is true that an increase in gaseous moles or moles of solute will increase entropy, it is not true that no change in gaseous moles or moles of solute implies zero change in entropy.*
- *Student responses which mixed up S and ΔS. S is never negative. ΔS can be positive or negative.*

- *Student responses which are confusing exothermic and endothermic reactions.*