NSW GOVERNMENT

NSW Education Standards Authority

Centre Number

Student Number

2023 **HIGHER SCHOOL CERTIFICATE EXAMINATION**

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A formulae sheet, data sheet and Periodic Table are provided at the back of this paper
- Write your Centre Number and Student Number at the top of this page

Total marks: 100

Section I – 20 marks (pages 2–11)

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

Section II – 80 marks (pages 13–40)

- Attempt Questions 21–37
- Allow about 2 hours and 25 minutes for this section

Section I

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

Use the multiple-choice answer sheet for Questions 1–20.

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1 What is the safest method for disposing of a liquid hydrocarbon after an experiment?

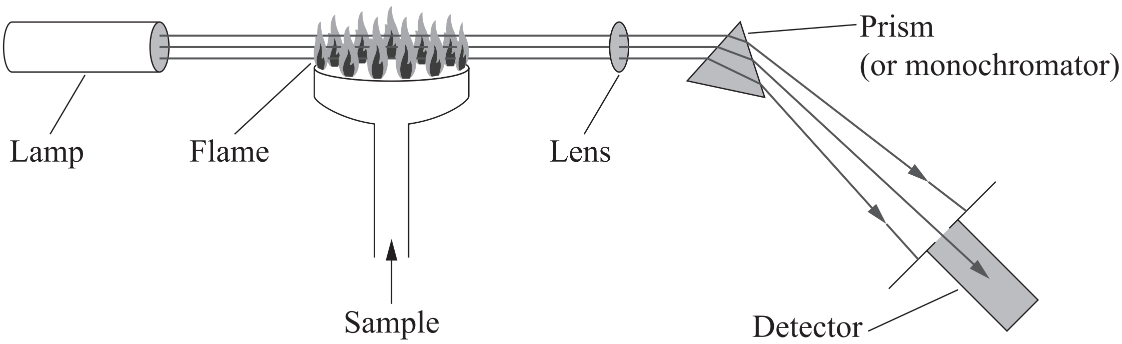
A. Pour it down the sink

B. Place it in a garbage bin

C. Burn it by igniting with a match

D. Place it in a separate waste container

2 The technique illustrated is used to analyse chemical substances in a sample.



What is the technique shown?

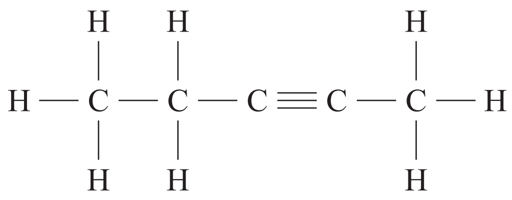
A. Flame test

B. Mass spectrometry

C. Atomic absorption spectroscopy

D. Ultraviolet-visible spectrophotometry

3 The structural formula of a compound is given.



What is the preferred IUPAC name of this compound?

A. Pent-2-ene

B. Pent-2-yne

C. Pent-3-ene

D. Pent-3-yne

4 Sodium chloride dissolves in water according to the following equation.

$$NaCl(s) \rightleftharpoons Na^+(aq) + Cl^-(aq)$$

A saturated solution of NaCl in water contains sodium and chloride ions at the following concentrations.

Ion	*Concentration* (mol L^{-1})
Na^+	6.13
Cl^-	6.13

What is the K_{sp} of sodium chloride?

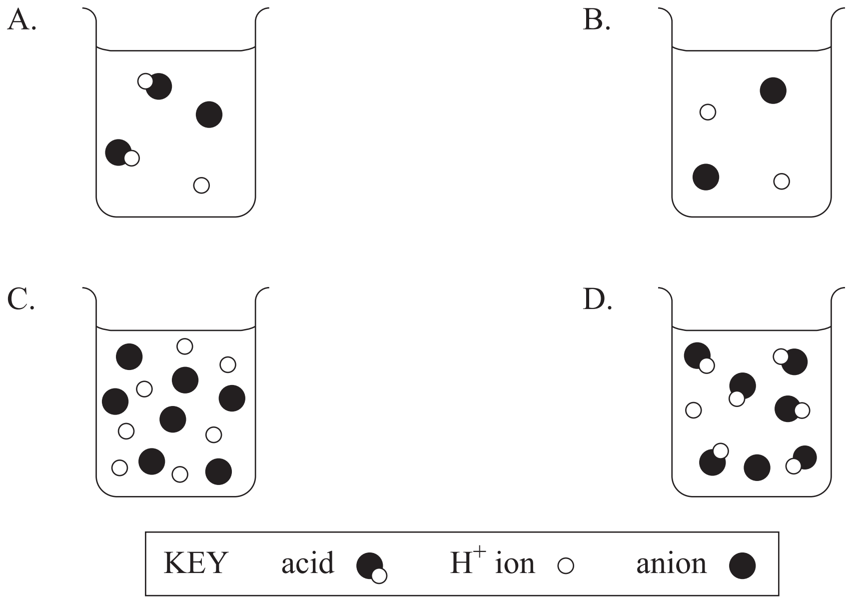
A. 2.65×10^{-2}

B. 8.16×10^{-2}

C. 12.26

D. 37.6

5 Which diagram represents the most concentrated weak acid?



6 The pH of a solution changes from 8 to 5.

What happens to the concentration of hydrogen ions during this change of pH?

A. It increases by a factor of 3.

B. It decreases by a factor of 3.

C. It increases by a factor of 1000.

D. It decreases by a factor of 1000.

7 A mixture of 0.8 mol of $CO(g)$ and 0.8 mol of $H_2(g)$ was placed in a sealed 1.0 L container. The following reaction occurred.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

When equilibrium was established, the mixture contained 0.5 mol of $CO(g)$.

What amount of $H_2(g)$ was present at equilibrium?

A. 0.2 mol

B. 0.4 mol

C. 0.6 mol

D. 1.0 mol

8 How many structural isomers have the molecular formula $C_3H_6F_2$?

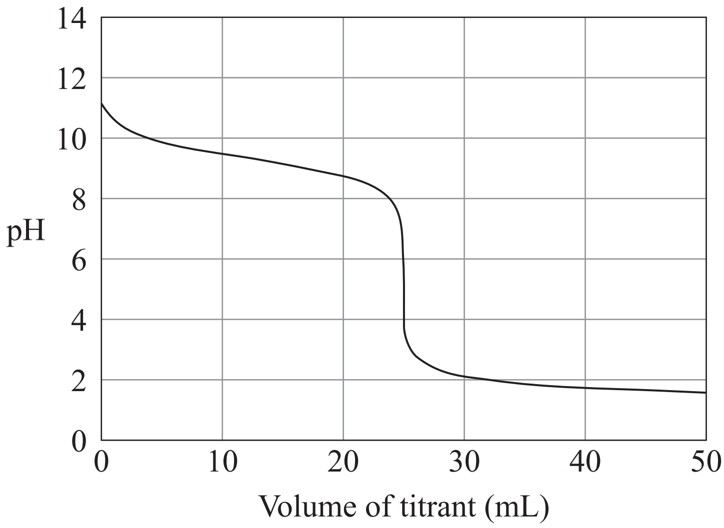
A. 2

B. 3

C. 4

D. 5

9 A titration was performed using two solutions of equal concentration, producing the following titration curve.



Which combination of solutions does the titration curve represent?

A. Addition of a weak base to a weak acid

B. Addition of a weak base to a strong acid

C. Addition of a strong acid to a weak base

D. Addition of a strong acid to a strong base

10 Which of the following correctly lists the compounds in order of increasing boiling point?

A. Heptane < heptan-2-one < heptan-1-o1 < heptanoic acid

B. Heptane < heptan-1-o1 < heptan-2-one < heptanoic acid

C. Heptanoic acid < heptan-2-one < heptan-1-o1 < heptane

D. Heptanoic acid < heptan-1-o1 < heptan-2-one < heptane

11 An indicator solution was obtained by boiling a flower in water.

Flower water indicator chart

Colour	Red			Purple			Blue		Blue-green		Green-yellow	
pH	1	2	3	4	5	6	7	8	9	10	11	12

Two solutions were tested with this indicator.

Which row of the table correctly identifies the colour of each solution?

	H_2SO_4 (1×10^{-5} mol L^{-1})	NaOH (5×10^{-5} mol L^{-1})
A.	Red	Green-yellow
B.	Red	Blue-green
C.	Purple	Blue-green
D.	Purple	Green-yellow

12 The industrial production of ammonia is represented by the Haber process reaction shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -91.8 \text{ kJ mol}^{-1}$$

Factors such as temperature and pressure need to be considered in order to maximise yield.

Which of the following is correct?

A. A lower pressure would result in a higher yield.

B. A higher pressure would result in a higher yield.

C. A lower temperature would result in a lower yield.

D. A higher temperature would result in a higher yield.

13 The table shows four separate tests used to identify a dilute, aqueous sample of a compound.

Test number	*Test*	*Observations*
1	Test with red litmus	Stays red
2	Add Ba^{2+} ions to a sample	White precipitate formed
3	Add OH^- ions to a sample	Brown precipitate formed
4	Add Cl^- ions to a sample	White precipitate formed

Which compound would produce the observations shown?

A. Silver sulfate

B. Lead(II) acetate

C. Iron(II) bromide

D. Magnesium carbonate

14 What volume of 0.540 mol L^{-1} hydrochloric acid will react completely with 1.34 g of sodium carbonate?

A. 11.7 mL

B. 23.4 mL

C. 29.9 mL

D. 46.8 mL

15 The table gives the heat of combustion of three different alcohols at 25°C.

Alcohol	*Heat of combustion* (kJ g^{-1})
Methanol	22.68
Ethanol	29.67
Butan-1-ol	36.11

Which of the following gives the best approximation for the molar heat of combustion of propan-1-ol, expressed in kJ g^{-1}?

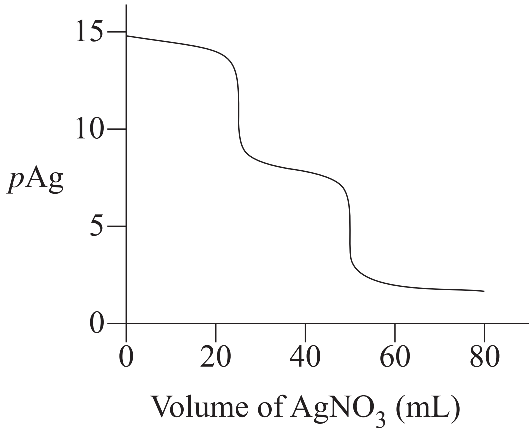
A. $\left(\dfrac{22.68 + 29.67 + 36.11}{3}\right)$

B. $\left(\dfrac{29.67 + 36.11}{2}\right)$

C. $\left(\dfrac{22.68 + 29.67}{2}\right)$

D. $\left(\dfrac{3 \times 36.11}{4}\right)$

16 A solution contains potassium iodide and potassium chloride. It was analysed by performing a precipitation titration using silver nitrate. The titration curve for this reaction is shown, where $pAg = -\log_{10}[Ag^+]$.



Why is this a valid and correct procedure for quantifying the amount of each anion present in the mixture?

A. AgCl would precipitate out first, followed by AgI.

B. AgI would precipitate out first, followed by AgCl.

C. Both AgI and AgCl precipitate out of the solution together.

D. Neither AgCl nor AgI would precipitate out of the solution.

17 What mass of lead(II) iodide ($MM = 461 \text{ g mol}^{-1}$) will dissolve in 375 mL of water?

A. 0.233 g

B. 0.293 g

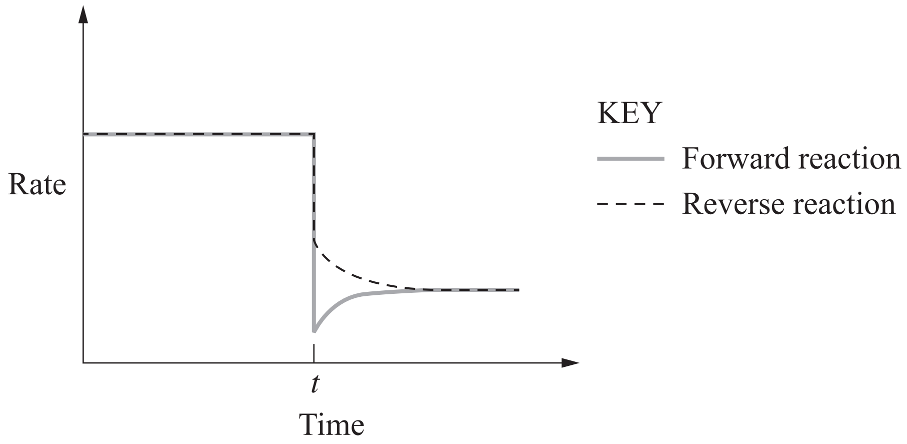
C. 0.369 g

D. 0.621 g

18 Carbon dioxide reacts with hydrogen gas to form carbon monoxide and water vapour in a sealed flask, according to the following equation.

$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g)$$

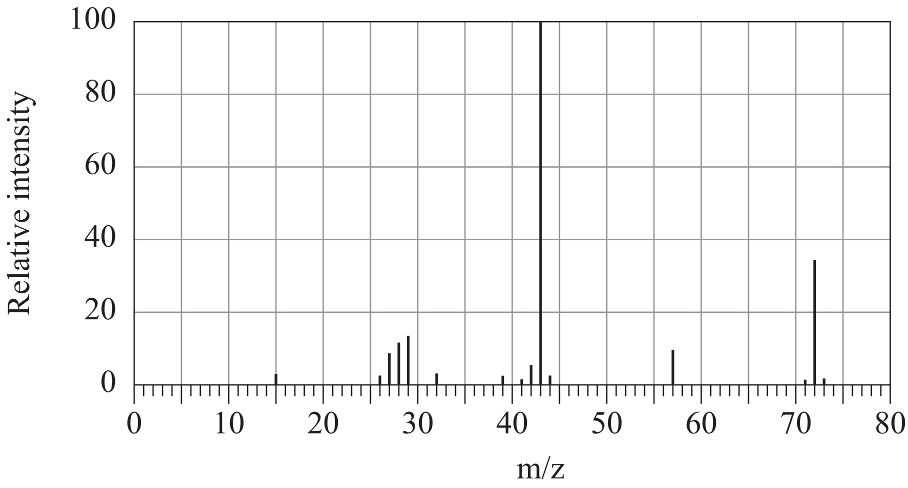
A temperature change was imposed on the equilibrium system at time *t* and the rates of both the forward and reverse reactions were monitored.



Which row of the table correctly identifies the nature of both temperature change at time *t* and the ΔH of the forward reaction?

	Temperature change at time t	*ΔH of the forward reaction*
A.	Decrease	+
B.	Decrease	–
C.	Increase	+
D.	Increase	–

19 The diagram shows a simplified mass spectrum for butan-2-one.



Which equation best represents the process that produces the particle responsible for the peak at m/z 43?

A. $CH_3COCH_2CH_3^+ \rightarrow CH_3CO + {}^+CH_2CH_3$

B. $CH_3COCH_2CH_3^+ \rightarrow CH_3CO^+ + CH_2CH_3$

C. $CH_3COCH_2CH_3^+ \rightarrow CH_3CH_2CH_2 + {}^+CHO$

D. $CH_3COCH_2CH_3^+ \rightarrow CH_3CH_2CH_2^+ + CHO$

20 Nitrogen monoxide and oxygen combine to form nitrogen dioxide, according to the following equation.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad K_{eq} = 2.47 \times 10^{12}$$

A 2.00 L vessel is filled with 1.80 mol of $NO_2(g)$ and the system is allowed to reach equilibrium.

What is the equilibrium concentration of $NO(g)$?

A. 0.00 mol L^{-1}

B. 4.34×10^{-5} mol L^{-1}

C. 6.90×10^{-5} mol L^{-1}

D. 8.69×10^{-5} mol L^{-1}

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Centre Number

Student Number

Chemistry

Section II Answer Booklet

Do NOT write in this area.

80 marks
Attempt Questions 21–37
Allow about 2 hours and 25 minutes for this section

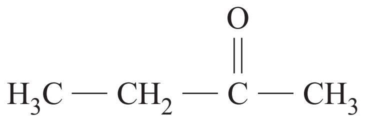
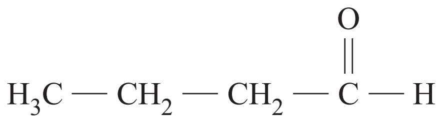
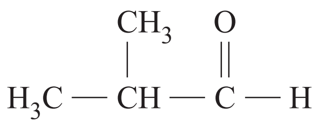
Instructions

- Write your Centre Number and Student Number at the top of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- Extra writing space is provided at the back of this booklet.
  If you use this space, clearly indicate which question you are answering.

Please turn over

Question 21 (2 marks)

Some isomers with the formula C_4H_8O are shown. **2**

butan-2-one 
butanal 
2-methylpropanal 

Name ONE pair of functional group isomers and ONE pair of chain isomers from the structures above.

Type of isomer	*Pair of isomers*
Functional group	.... and ....
Chain	.... and ....

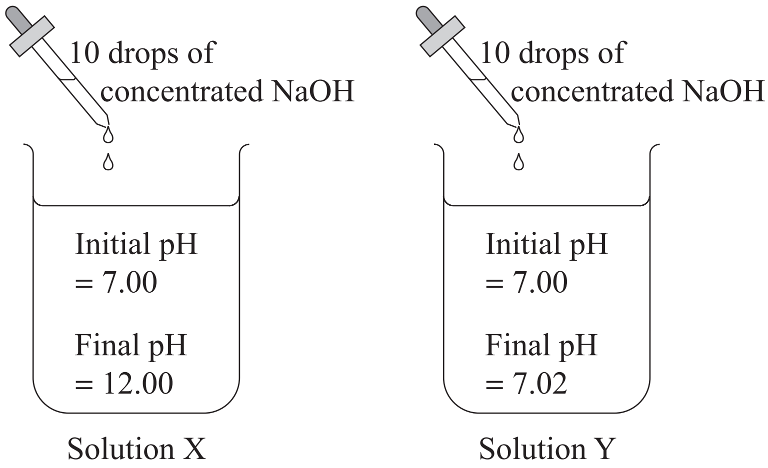
Question 22 (4 marks)

Explain how the following substances would be classified under the Arrhenius and Brønsted−Lowry definitions of acids. Support your answer with relevant equations. **4**

- $HCl(aq)$
- $NH_4Cl(aq)$

Question 23 (3 marks)

The pH of two solutions, X and Y, were measured before and after 10 drops of concentrated NaOH was added to each. **3**



Explain the pH changes that occurred in solutions X and Y.

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Question 24 (2 marks)

The hydrogen oxalate ion $\left(HC_2O_4^-\right)$ is classified as amphiprotic. **2**

Describe, using chemical equations, how this ion is amphiprotic.

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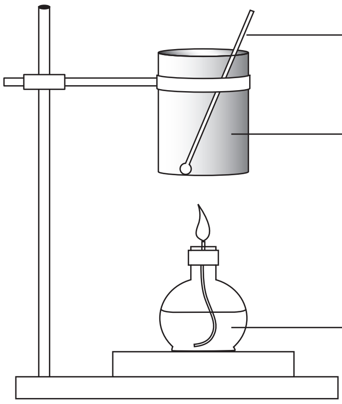
Please turn over

Question 25 (5 marks)

A student used the apparatus shown to investigate the combustion of octan-1-ol.



The following results were obtained by the student.

Mass of water heated	=	205 g
Initial temperature of water	=	23.7°C
Final temperature of water	=	60.4°C

The following data are given.

Molar enthalpy of combustion of octan-1-ol	=	-5294 kJ mol^{-1}
Molar mass of octan-1-ol	=	130.23 g mol^{-1}

(a) Assuming that no energy released by this combustion is lost to the surroundings, calculate the mass of octan-1-ol burnt. **3**

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Question 25 continues on page 19

Question 25 (continued)

(b) Explain ONE advantage of using a biofuel compared to fossil fuels. **2**

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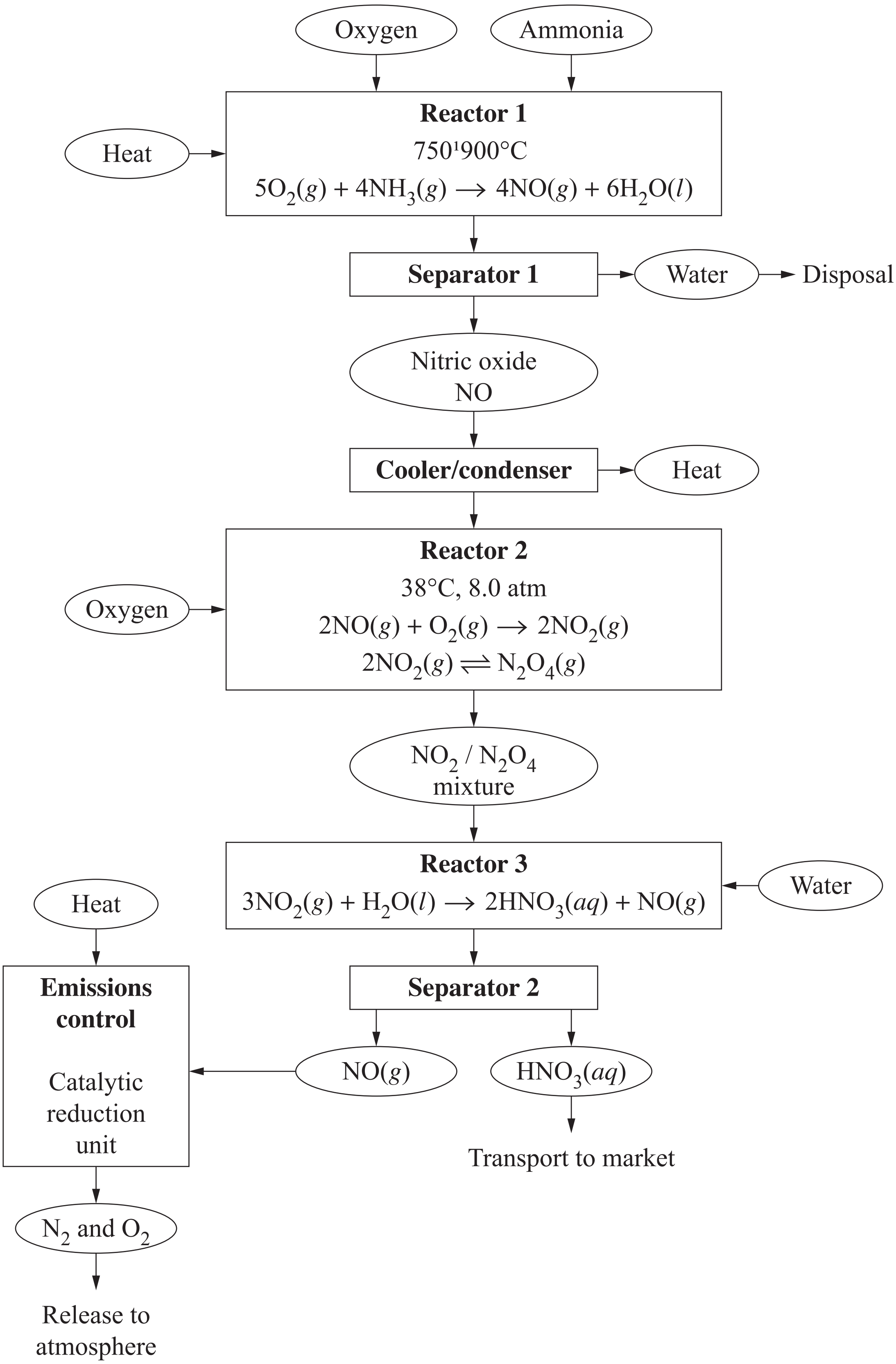
End of Question 25

Please turn over

Question 26 (5 marks)

Nitric acid can be produced industrially using the process shown.



Question 26 continues on page 21

Question 26 (continued)

(a) A mixture of NO_2 and N_2O_4 enters Reactor 3, where only NO_2 is consumed by the reaction with water. **2**

Explain, with respect to Le Chatelier's principle, what happens to the N_2O_4.

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(b) Explain TWO improvements that can be made to the design of the process shown. **3**

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End of Question 26

Question 27 (4 marks)

A student has been asked to produce 185 mL of ethanol ($MM = 46.068 \text{ g mol}^{-1}$) by fermenting glucose using yeast, as shown in the equation. **4**

$$C_6H_{12}O_6(aq) \longrightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

Given that the density of ethanol is 0.789 g mL^{-1}, calculate the volume of carbon dioxide gas produced at 310 K and 100 kPa.

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Question 28 (5 marks)

Alkene Q undergoes an addition reaction with chlorine gas to form compound R.

(a) Describe a chemical test that could be done in a school laboratory to confirm that Q is an alkene. Include expected observations in your answer. **2**

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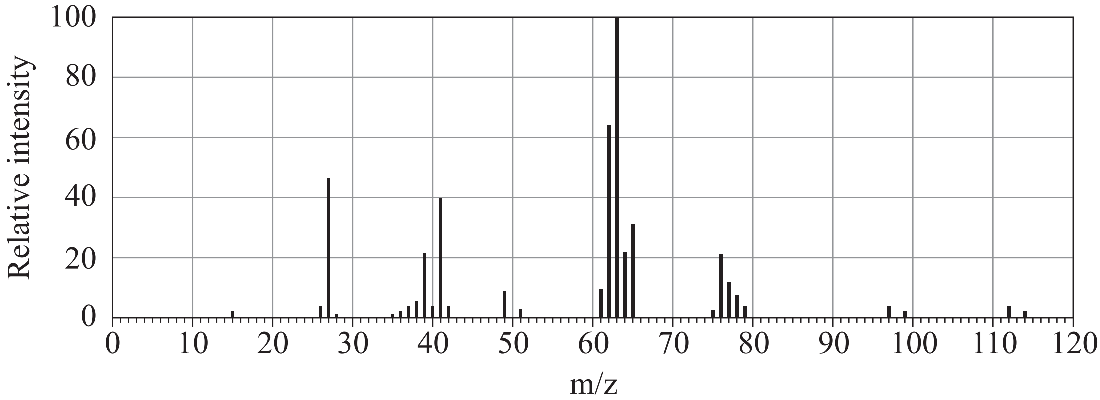
(b) Compound R was analysed and found to contain approximately 32% carbon by mass. The mass spectrum of compound R is shown. **3**



Provide a structural formula for compound R. Support your answer with calculations.

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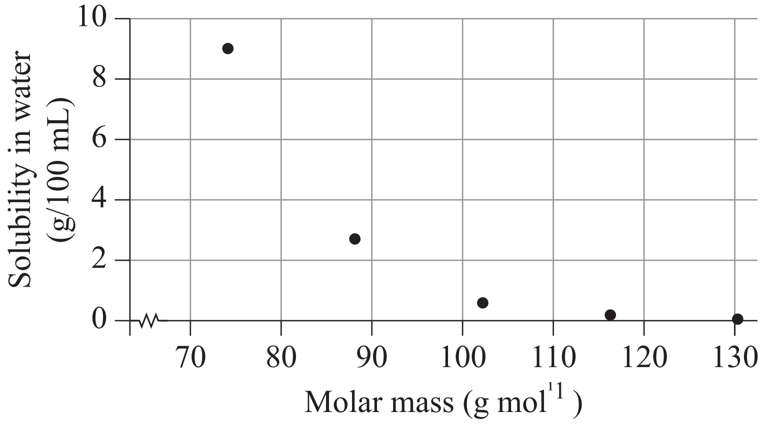
Structural formula of compound R:

Question 29 (3 marks)

The following graph shows the solubility of some alkan-1-ols in water at 20°C. **3**



Explain the relationship between the trend shown in the graph and the relevant intermolecular forces.

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Question 30 (4 marks)

A water sample contains at least one of the following anions at concentrations of $1.0\ \text{mol L}^{-1}$. **4**

- bromide (Br^-)
- carbonate $\left(CO_3^{2-}\right)$

Outline a sequence of tests that could be performed in a school laboratory to confirm the identity of the anion or anions present. Include expected observations and TWO balanced chemical equations in your answer.

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Question 31 (7 marks)

Copper(II) ions (Cu^{2+}) form a complex with lactic acid $(C_3H_6O_3)$, as shown in the equation. 7

$$Cu^{2+}(aq) + 2C_3H_6O_3(aq) \rightleftharpoons \left[Cu\left(C_3H_6O_3\right)_2\right]^{2+}(aq)$$

This complex can be detected by measuring its absorbance at 730 nm. A series of solutions containing known concentrations of $\left[Cu\left(C_3H_6O_3\right)_2\right]^{2+}$ were prepared, and their absorbances measured.

Concentration of $\left[Cu\left(C_3H_6O_3\right)_2\right]^{2+}$ (mol L^{-1})	*Absorbance*
0.000	0.00
0.010	0.13
0.020	0.28
0.030	0.43
0.040	0.57
0.050	0.72

Two solutions containing Cu^{2+} and $C_3H_6O_3$ were mixed. The initial concentrations of each in the resulting solution are shown in the table.

Species	*Initial concentration* (mol L^{-1})
Cu^{2+}	0.056
$C_3H_6O_3$	0.111

When the solution reached equilibrium, its absorbance at 730 nm was 0.66 .

You may assume that under the conditions of this experiment, the only species present in the solution are those present in the equation above, and that $\left[Cu\left(C_3H_6O_3\right)_2\right]^{2+}$ is the only species that absorbs at 730 nm.

With the support of a line graph, calculate the equilibrium constant for the reaction.

Question 31 continues on page 27

Question 31 (continued)

End of Question 31

Question 32 (5 marks)

The ammonium ion content of mixtures can be determined by boiling the mixture with a known excess of sodium hydroxide. This converts the ammonium ions into gaseous ammonia, which is removed from the system. **5**

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

The excess sodium hydroxide can then be titrated with an acid solution of known concentration.

A fertiliser containing ammonium ions was analysed as follows.

- A sample of fertiliser was treated with 50.00 mL of 1.124 mol L^{-1} sodium hydroxide solution and the solution boiled.
- After all of the ammonia was removed, the resulting solution was transferred to a 250.0 mL volumetric flask and made up to the mark with deionised water.
- 20.00 mL aliquots of this solution were titrated with 0.1102 mol L^{-1} hydrochloric acid, giving the following results.

Titration	*Volume HCl* (mL)
1	22.65
2	22.05
3	22.00
4	21.95

Question 32 continues on page 29

Question 32 (continued)

Calculate the mass of ammonium ions in the sample of fertiliser.

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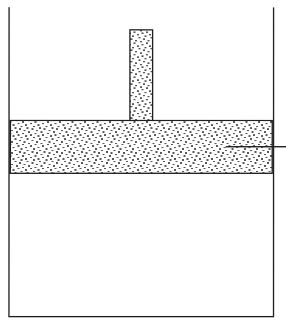
End of Question 32

Question 33 (6 marks)

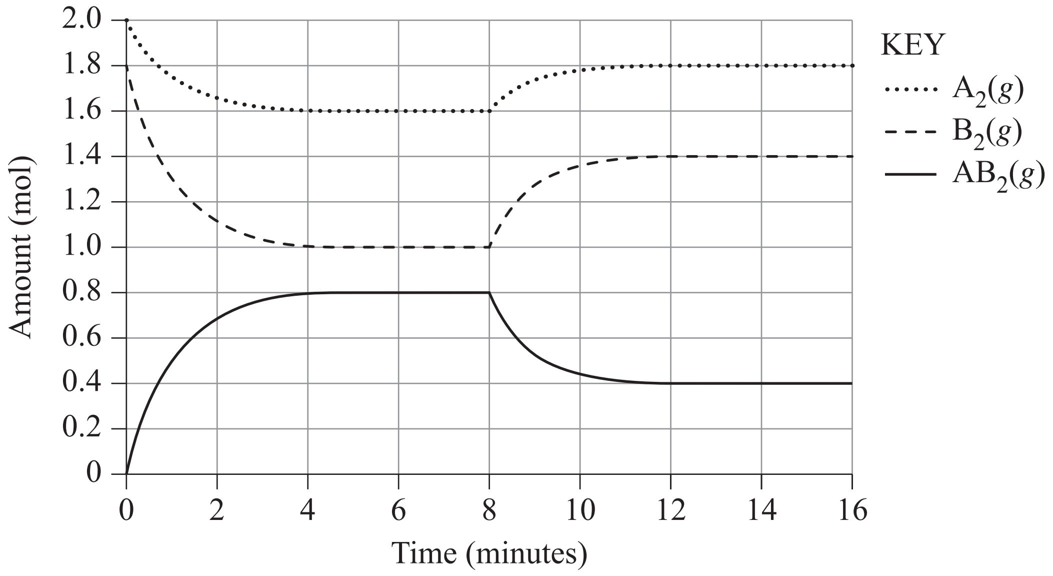
Gases A_2 and B_2 are placed in a closed container of variable volume, as shown.



The reaction between these substances is as follows.

$$A_2(g) + 2B_2(g) \rightleftharpoons 2AB_2(g) \qquad \Delta H = -10 \text{ kJ mol}^{-1}$$

The following graph shows changes in the amounts (in mol) of these three substances over time in this container.



Question 33 continues on page 31

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Question 33 (continued)

(a) Explain what is happening in this system between 6 minutes and 8 minutes. **2**

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(b) Explain TWO different factors that could result in the disturbance at 8 minutes. **4**

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End of Question 33

Question 34 (5 marks)

When 125 mL of a magnesium nitrate solution is mixed with 175 mL of a 1.50 mol L^{-1} sodium fluoride solution, 0.6231 g of magnesium fluoride (MM = 62.31 g mol^{-1}) precipitates. The K_{sp} of magnesium fluoride is 5.16×10^{-11}. **5**

Calculate the equilibrium concentration of magnesium ions in this solution.

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Question 35 (6 marks)

(a) A 0.2000 mol L^{-1} solution of dichloroacetic acid $(CHCl_2COOH)$ has a pH of 1.107. Dichloroacetic acid is monoprotic. **3**

Calculate the K_a for dichloroacetic acid.

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(b) The following data apply to the ionisation of acetic acid (CH_3COOH) and trichloroacetic acid (CCl_3COOH). **3**

	CH_3COOH	CCl_3COOH
pK_a	4.76	0.51
$\Delta H°$ (kJ mol^{-1})	−0.1	+1.2
$\Delta S°$ (J K^{-1} mol^{-1})	−91.6	−5.8
$-T\Delta S°$ (kJ mol^{-1})	+27.3	+1.7
$\Delta G°$ (kJ mol^{-1})	+27.2	+2.9

Explain the relative strength of these acids with reference to the data.

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Question 36 (9 marks)

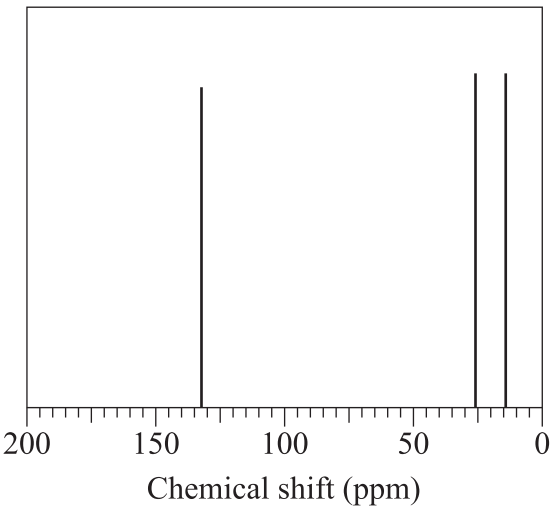
An organic reaction pathway involving compounds A, B and C is shown in the flow chart. **9**

$$\mathbf{A} \xrightarrow{\text{Dilute } H_2SO_4} \mathbf{B} \xrightarrow[H^+/\text{heat}]{KMnO_4} \mathbf{C}$$

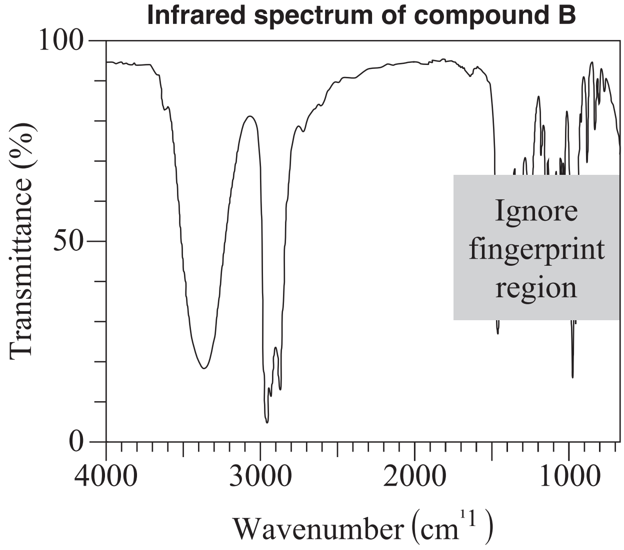
The molar mass of A is 84.156 g mol^{-1}.

A chemist obtained some spectral data for the compounds as shown.

^{13}C NMR spectrum of compound A



Infrared spectrum of compound B



SDBSWeb: https://sdbs.db.aist.go.jp
National Institute of Advanced Industrial Science and Technology, June 2022

Data from ^1H NMR spectrum of compound C

Chemical shift (ppm)	*Relative peak area*	*Splitting pattern*
1.01	3	Triplet
1.05	3	Triplet
1.65	2	Multiplet
2.42	2	Triplet
2.46	2	Quartet

^1H NMR chemical shift data

Type of proton	δ/ppm
$R-C\mathbf{H}_3$, $R-C\mathbf{H}_2-R$	0.7–1.7
$\mathbf{H}_3C-CO-$, $-C\mathbf{H}_2-CO-$ (aldehydes, ketones, carboxylic acids or esters)	2.0–2.6
$R-CH\mathbf{O}$	9.4–10.0
$R-COO\mathbf{H}$	9.0–13.0

Question 36 continues on page 35

Question 36 (continued)

Identify the functional group present in each of compounds A to C and draw the structure of each compound. Justify your answer with reference to the information provided.

Compound A	Functional group: ....
Compound B	Functional group: ....
Compound C	Functional group: ....

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Question 36 continues on page 36

Question 36 (continued)

End of Question 36

Question 37 (5 marks)

When performing industrial reductions with $CO(g)$, the following equilibrium is of great importance.

$$2CO(g) \rightleftharpoons CO_2(g) + C(s) \qquad K_{eq} = 10.00 \text{ at } 1095 \text{ K}$$

A 1.00 L sealed vessel at a temperature of 1095 K contains $CO(g)$ at a concentration of 1.10×10^{-2} mol L^{-1}, $CO_2(g)$ at a concentration of 1.21×10^{-3} mol L^{-1}, and excess solid carbon.

(a) Is the system at equilibrium? Support your answer with calculations. **2**

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(b) Carbon dioxide gas is added to the system above and the mixture comes to equilibrium. The equilibrium concentrations of $CO(g)$ and $CO_2(g)$ are equal. Excess solid carbon is present and the temperature remains at 1095 K. **3**

Calculate the amount (in mol) of carbon dioxide added to the system.

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End of paper

Section II extra writing space

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Chemistry

FORMULAE SHEET

$n = \dfrac{m}{MM}$	$c = \dfrac{n}{V}$	$PV = nRT$
$q = mc\Delta T$	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$	$\mathrm{pH} = -\log_{10}[\mathrm{H}^+]$
$pK_a = -\log_{10}[K_a]$	$A = \varepsilon lc = \log_{10}\dfrac{I_o}{I}$	

Avogadro constant, N_A .... $6.022 \times 10^{23}\ \mathrm{mol}^{-1}$

Volume of 1 mole ideal gas: at 100 kPa and
at 0°C (273.15 K) .... 22.71 L
at 25°C (298.15 K) .... 24.79 L

Gas constant .... $8.314\ \mathrm{J\ mol^{-1}\ K^{-1}}$

Ionisation constant for water at 25°C (298.15 K), K_w .... 1.0×10^{-14}

Specific heat capacity of water .... $4.18 \times 10^{3}\ \mathrm{J\ kg^{-1}\ K^{-1}}$

DATA SHEET

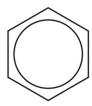
Solubility constants at 25°C

Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	Lead(II) hydroxide	1.43×10^{-15}
Calcium hydroxide	5.02×10^{-6}	Lead(II) phosphate	8.0×10^{-43}
Calcium phosphate	2.07×10^{-29}	Lead(II) sulfate	2.53×10^{-8}
Calcium sulfate	4.93×10^{-5}	Magnesium carbonate	6.82×10^{-6}
Copper(II) carbonate	1.4×10^{-10}	Magnesium hydroxide	5.61×10^{-12}
Copper(II) hydroxide	2.2×10^{-20}	Magnesium phosphate	1.04×10^{-24}
Copper(II) phosphate	1.40×10^{-37}	Silver bromide	5.35×10^{-13}
Iron(II) carbonate	3.13×10^{-11}	Silver chloride	1.77×10^{-10}
Iron(II) hydroxide	4.87×10^{-17}	Silver carbonate	8.46×10^{-12}
Iron(III) hydroxide	2.79×10^{-39}	Silver hydroxide	2.0×10^{-8}
Iron(III) phosphate	9.91×10^{-16}	Silver iodide	8.52×10^{-17}
		Silver phosphate	8.89×10^{-17}
		Silver sulfate	1.20×10^{-5}

Infrared absorption data

Bond	Wavenumber/cm^{-1}
N—H (amines)	3300–3500
O—H (alcohols)	3230–3550 (broad)
C—H	2850–3300
O—H (acids)	2500–3000 (very broad)
C≡N	2220–2260
C=O	1680–1750
C=C	1620–1680
C—O	1000–1300
C—C	750–1100

^{13}C NMR chemical shift data

Type of carbon		δ/ppm
—C—C—		5–40
R—C—Cl or Br		10–70
R—C(=O)—C—		20–50
R—C—N<		25–60
—C—O—	alcohols, ethers or esters	50–90
>C=C<		90–150
R—C≡N		110–125
		110–160
R—C(=O)—	esters or acids	160–185
R—C(=O)—	aldehydes or ketones	190–220

UV absorption

(This is not a definitive list and is approximate.)

Chromophore	λ_{max} (nm)
C—H	122
C—C	135
C=C	162

Chromophore	λ_{max} (nm)
C≡C	173 178 196 222
C—Cl	173
C—Br	208

Some standard potentials

$K^+ + e^-$	$\rightleftharpoons$	$K(s)$	–2.94 V
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	$Ba(s)$	–2.91 V
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	$Ca(s)$	–2.87 V
$Na^+ + e^-$	$\rightleftharpoons$	$Na(s)$	–2.71 V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.36 V
$Al^{3+} + 3e^-$	$\rightleftharpoons$	$Al(s)$	–1.68 V
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	$Mn(s)$	–1.18 V
$H_2O + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-$	–0.83 V
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	$Zn(s)$	–0.76 V
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44 V
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	$Ni(s)$	–0.24 V
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	$Sn(s)$	–0.14 V
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	$Pb(s)$	–0.13 V
$H^+ + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00 V
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(aq) + 2H_2O$	0.16 V
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	$Cu(s)$	0.34 V
$\frac{1}{2}O_2(g) + H_2O + 2e^-$	$\rightleftharpoons$	$2OH^-$	0.40 V
$Cu^+ + e^-$	$\rightleftharpoons$	$Cu(s)$	0.52 V
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	I^-	0.54 V
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	I^-	0.62 V
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	0.77 V
$Ag^+ + e^-$	$\rightleftharpoons$	$Ag(s)$	0.80 V
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	Br^-	1.08 V
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	Br^-	1.10 V
$\frac{1}{2}O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O	1.23 V
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	Cl^-	1.36 V
$\frac{1}{2}Cr_2O_7^{2-} + 7H^+ + 3e^-$	$\rightleftharpoons$	$Cr^{3+} + \frac{7}{2}H_2O$	1.36 V
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	Cl^-	1.40 V
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	1.51 V
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	F^-	2.89 V

Aylward and Findlay, *SI Chemical Data* (5th Edition) is the principal source of data for the standard potentials. Some data may have been modified for examination purposes.

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium

Actinoids

89 Ac Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Standard atomic weights are abridged to four significant figures.

Elements with no reported values in the table have no stable nuclides.

Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version).

The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

2023 HSC Chemistry
Marking Guidelines

Section I

Multiple-choice Answer Key

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

Section II

Question 21

Criteria	Marks
• Identifies TWO correctly classified pairs of isomers	2
• Identifies ONE correctly classified pair of isomers OR • Identifies TWO correct pairs of isomers but incorrectly classifies both	1

Sample answer:

Type of isomer	*Pair of Isomers*
Functional group	Butan-2-one and butanal
Chain	Butanal and 2-methylpropanal

Question 22

Criteria	Marks
• Classifies both substances with respect to Arrhenius and Brønsted−Lowry theories • Provides two relevant chemical equations	4
• Classifies one substance with respect to Arrhenius and Brønsted−Lowry theories • Provides a relevant chemical equation OR • Classifies both substances with respect to Arrhenius OR Brønsted−Lowry theory • Provides a relevant chemical equation OR • Classifies both substances with respect to Arrhenius and Brønsted−Lowry theories	3
• Classifies one substance with respect to Arrhenius and Brønsted−Lowry theories OR • Classifies both substances with respect to Arrhenius OR Brønsted−Lowry theory	2
• Provides some relevant information	1

Sample answer:

According to Arrhenius, acids are hydrogen-containing compounds that dissociate in water to give H^+ ions. HCl(*aq*) would be considered an acid by Arrhenius as it produces H^+ ions in water.

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

Arrhenius would **not** recognise the salt NH_4Cl as an acid, as the predominant ions present in aqueous solution are ammonium and chloride.

In Brønsted−Lowry theory, acids are defined as proton donors. HCl(*aq*) is a proton donor and therefore a Brønsted−Lowry acid.

Ammonium chloride (NH_4Cl) is classified as a Brønsted−Lowry acid as the ammonium ion donates a proton to water and forms a hydronium ion.

$$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$$

Question 23

Criteria	Marks
• Provides a sound explanation of the pH changes that occur in both solutions	3
• Provides an explanation of the pH change in one of the solutions	2
• Provides some relevant information	1

Sample answer:

The pH of solution X changed significantly when base was added, while the pH of solution Y showed only a small change in pH. This indicates that solution Y contains a buffer while solution X does not.

When NaOH was added to solution X, the addition of OH^- ions from the base, causing the increase in pH (as $pH = -\log_{10}[H_3O^+]$).

In solution Y, these OH^- ions react with the buffer solution, which minimises the change in $[H_3O^+]$ and therefore pH.

Question 24

Criteria	Marks
• Demonstrates $HC_2O_4^-$ is able to accept and donate protons • Includes correct chemical equations	2
• Provides some relevant information	1

Sample answer:

$HC_2O_4^-$ can either accept H^+ or donate a H^+, as illustrated in the equations below:

$$HC_2O_4^-(aq) + H^+(aq) \rightleftharpoons H_2C_2O_4(aq)$$

$$HC_2O_4^-(aq) + OH^-(aq) \rightleftharpoons H_2O(l) + C_2O_4^{2-}(aq)$$

As it can either accept or donate H^+, $HC_2O_4^-$ can be described as amphiprotic.

Question 25 (a)

Criteria	Marks
• Calculates the mass of octan-1-ol burnt	3
• Provides some correct steps of the calculation	2
• Provides some relevant information	1

Sample answer:

Heat absorbed by water = mass of water $\times\, c \times \Delta T$

$q = 205 \text{ g} \times 4.18 \text{ J K}^{-1} \text{ g}^{-1} \times 36.7 \text{ K}$

$q = 31\ 448 \text{ J}$

$q = 31.448 \text{ kJ}$

$$n(\text{octan-1-ol}) = \frac{-31.448 \text{ kJ}}{-5294 \text{ kJ mol}^{-1}} = 5.94 \times 10^{-3} \text{ mol}$$

$m(\text{octan-1-ol}) = 5.94 \times 10^{-3} \text{ mol} \times 130.23 \text{ g mol}^{-1} = 0.774 \text{ g}$

Question 25 (b)

Criteria	Marks
• Explains ONE advantage of using a biofuel	2
• Provides some relevant information	1

Sample answer:

Combustion of biofuels derived from plants will have a lower greenhouse impact as the carbon dioxide released during combustion will replace that used in photosynthesis, unlike fossil fuels.

Answers could include:

Biofuels are biodegradable. Thus, spills pose less of an environmental threat compared to fossil fuels, which can cause long-term contamination to the environment.

Biofuels are produced from renewable resources. Compared to fossil fuels, biofuels are more sustainable.

Question 26 (a)

Criteria	Marks
• Explains the depletion of N_2O_4 in Reactor 3 with respect to Le Chatelier's principle	2
• Provides some relevant information	1

Sample answer:

NO_2 and N_2O_4 exist as an equilibrium system in Reactor 2 as shown:

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

NO_2 is a reactant in Reactor 3 and is consumed by the reaction in Reactor 3, causing a disturbance to this equilibrium system. According to Le Chatelier's Principle, the position of equilibrium will shift to counter the depletion of NO_2, causing the decomposition and depletion of N_2O_4. Ultimately, all of the N_2O_4 will decompose to form NO_2.

Question 26 (b)

Criteria	Marks
• Explains TWO appropriate improvements to the design of the process	3
• Identifies TWO appropriate improvements to the design of the process OR • Explains ONE appropriate improvement to the design of the process	2
• Provides some relevant information	1

Sample answer:

Water produced at Separator 1 can be recycled and used in Reactor 3, where it is needed as a reactant, instead of being sent for disposal. This improvement will allow for the conservation of water as a resource.

The heat released from the cooler/condenser after Reactor 1 can be recovered and used in the Emissions control step, where energy input is required. This improvement will allow for a reduction in energy consumption and therefore costs associated with the Emissions control step.

Answers could include:

Recycling of NO from Reactor 3 into Reactor 2, conserving resources and reducing the amount of oxygen and ammonia needed to produce NO in Reactor 1.

The use of a catalyst in Reactor 1 to lower the activation energy required and therefore the energy consumed. This would decrease the high temperature required.

Question 27

Criteria	Marks
• Calculates the volume of carbon dioxide produced	4
• Provides the main steps of the calculation	3
• Provides some steps of the calculation	2
• Provides some relevant information	1

Sample answer:

Calculate mass of ethanol required from density

$$\rho = \frac{m}{V}$$

m(ethanol) = 0.789 g mL^{-1} × 185 mL = 146 g

$$n(\text{ethanol}) = \frac{m}{MM} = \frac{146\text{ g}}{46.068\text{ g mol}^{-1}} = 3.17\text{ mol}$$

$$V = \frac{nRT}{P}$$

$$V = \frac{3.17\text{ mol} \times 8.314\text{ J K}^{-1}\text{ mol}^{-1} \times 310\text{ K}}{100\text{ kPa}}$$

$$= 81.7\text{ L}$$

Question 28 (a)

Criteria	Marks
• Describes an appropriate test to confirm the alkene, including expected observations	2
• Provides some relevant information	1

Sample answer:

A few drops of bromine water are added to a sample of alkene Q in a test tube. The bromine water is decolourised by alkene Q.

Answers could include:

Addition of potassium permanganate, which is decolourised by alkene Q.

Question 28 (b)

Criteria	Marks
• Provides the structural formula with supporting calculations	3
• Provides a substantially correct structural formula, with some calculation steps	2
• Provides some relevant information	1

Sample answer:

The molecular ion is present in the mass spectrum at m/z = 114.

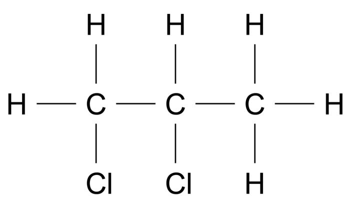
Atomic mass of carbon in compound R = 32% of 114 = 36

Number of carbon atoms in a molecule of compound R = 36/12 = 3.0

Non-carbon mass = 114 − 36 = 78

Therefore, exactly two Cl atoms are present in a molecule of compound R.

So compound R has the molecular formula $C_3H_6Cl_2$, and the following structure.



Answers could include:

The molecular ion at m/z = 112.

Question 29

Criteria	Marks
• Provides a thorough explanation of the relationship between the trend and named intermolecular forces	3
• Provides a sound explanation of the relationship	2
• Provides some relevant information	1

Sample answer:

As the molar mass increases, the chain length increases. As the chain length increases, the solubility of alkan-1-ols in water decreases. Shorter chain alcohols dissolve in water due to the formation of hydrogen bonds between the hydroxyl group of the alcohol and water molecules. However, as the chain length increases, the dispersion forces between the alkyl groups become more significant which decreases the solubility of alkan-1-ols in water.

Question 30

Criteria	Marks
• Demonstrates a thorough understanding of anion testing in an appropriate sequence with expected observations • Includes TWO balanced chemical equations including states	4
• Demonstrates a sound understanding of anion testing with expected observation(s) and/or a correct chemical equation	3
• Demonstrates some understanding of anion testing	2
• Provides some relevant information	1

Sample answer:

- Add aqueous nitric acid – bubbles indicate carbonate present:
  Acid removes carbonate for further testing of sample
  $2H^+(aq) + CO_3^{2-}(aq) \longrightarrow CO_2(g) + H_2O(l)$
- Add silver nitrate solution – creamy precipitate indicates bromide present
- $Ag^+(aq) + Br^-(aq) \longrightarrow AgBr(s)$.

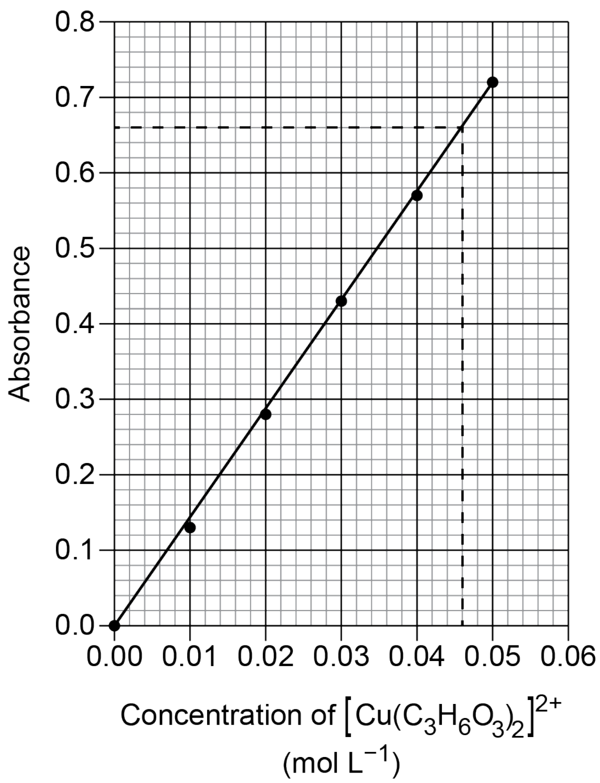
Answer could include:

- Add excess silver nitrate solution – precipitate produced
- Add dilute nitric acid to the precipitate
  - If bubbles are formed and a brown precipitate dissolves then carbonate was present
  - If a creamy precipitate remains then bromide was present

Question 31

Criteria	Marks
• Calculates the equilibrium constant, supported by a correct line graph	7
• Provides a substantially correct graph and correct calculations OR • Provides a correct graph and substantially correct calculations	6
• Provides a graph with some correct features • Performs one or more steps of the calculation	4–5
• Provides a graph with some correct features OR • Performs some steps of the calculation	2–3
• Provides some relevant information	1

Sample answer:



Reading from the graph, an absorbance of 0.66 corresponds to a $[Cu(C_3H_6O_3)_2]^{2+}$ concentration of 0.046 mol L^{-1}.

	$Cu^{2+}(aq)$	+	$2C_3H_6O_3(aq)$	$\rightleftharpoons$	$[Cu(C_3H_6O_3)_2]^{2+}(aq)$
Initial	0.056		0.111		0
Change	−0.046		−0.092		+0.046
Equilibrium	0.010		0.019		0.046

$$K_{eq} = \frac{\left[\left[Cu\left(C_3H_6O_3\right)_2\right]^{2+}\right]}{\left[Cu^{2+}\right]\left[C_3H_6O_3\right]^2} = \frac{0.046}{0.010 \times 0.019^2} = 1.3 \times 10^4$$

Question 32

Criteria	Marks
• Calculates the mass of ammonium ions in the sample to four significant figures	5
• Provides a substantially correct calculation	4
• Provides main steps in the calculation	3
• Provides some relevant steps in the calculation	2
• Provides some relevant information	1

Sample answer:

$V(\text{HCl, average}) = \dfrac{22.05 + 22.00 + 21.95}{3} = 22.00 \text{ mL} = 0.02200 \text{ L}$

$n(\text{HCl}) = 0.02200 \text{ L} \times 0.1102 \text{ mol L}^{-1} = 2.424 \times 10^{-3} \text{ mol}$

$n(\text{NaOH, excess, in 20 mL aliquot}) = 2.424 \times 10^{-3} \text{ mol}$

$n(\text{NaOH, excess, in 250.0 mL flask}) = \dfrac{250.0 \text{ mL}}{20.00 \text{ mL}} \times 2.424 \times 10^{-3} \text{ mol} = 3.031 \times 10^{-2} \text{ mol}$

$n(\text{NaOH, total}) = 0.0500 \text{ L} \times 1.124 \text{ mol L}^{-1} = 5.620 \times 10^{-2} \text{ mol}$

$n(\text{NaOH reacting with } NH_4^+) = 5.620 \times 10^{-2} \text{ mol} - 3.031 \times 10^{-2} \text{ mol} = 2.590 \times 10^{-2} \text{ mol}$

$n(NH_4^+) = 2.590 \times 10^{-2} \text{ mol}$

$m(NH_4^+) = 2.590 \times 10^{-2} \text{ mol} \times 18.042 \text{ g mol}^{-1} = 0.4672 \text{ g}$

Question 33 (a)

Criteria	Marks
• Explains what is happening in the system	2
• Provides some relevant information	1

Sample answer:

The system is at equilibrium between 6 and 8 minutes. Both forward and reverse reactions proceed at the same rate, so the amounts of reactants and products remain constant.

Question 33 (b)

Criteria	Marks
• Demonstrates an extensive understanding of TWO different factors that could result in the disturbance	4
• Demonstrates a sound understanding of the factors that could result in the disturbance	3
• Demonstrates some understanding of at least ONE factor that could result in the disturbance	2
• Provides some relevant information	1

Sample answer:

At 8 minutes, there is no instantaneous change in the amount of any substance present, but subsequently AB_2 is consumed, and A_2 and B_2 are produced. This could result from two changes:

- An increase in temperature that decreases the equilibrium constant, *K*. This means that the reaction quotient, *Q*, will be greater than *K*, so AB_2 will be consumed and A_2 and B_2 produced as *Q* approaches *K* and the system reaches equilibrium again.

- Increase in volume of the container. This will increase the reaction quotient, *Q*, while *K* stays the same, so AB_2 will be consumed and A_2 and B_2 will be produced as *Q* approaches *K* and the system reaches equilibrium again.

Answers could include:

- Reference to relative rates of forward and reverse reactions.
- Reference to Le Chatelier's Principle

Question 34

Criteria	Marks
• Calculates the equilibrium concentration of $[Mg^{2+}]$	5
• Provides a substantially correct calculation	4
• Provides most steps for calculating $[Mg^{2+}]$	3
• Provides some steps for calculating $[Mg^{2+}]$	2
• Provides some relevant information	1

Sample answer:

$MgF_2(s) \rightleftharpoons Mg^{2+}(aq) + 2F^-(aq)$

$$n(MgF_2) = \frac{0.6231\text{ g}}{62.31\text{ g mol}^{-1}} = 1.000 \times 10^{-2}\text{ mol}$$

Initial $n(F^-) = 0.175\text{ L} \times 1.50\text{ mol L}^{-1} = 0.263\text{ mol}$

$n(F^-)$ remaining after precipitation $= 0.263\text{ mol} - 2 \times 1.00 \times 10^{-2}\text{ mol} = 0.243\text{ mol}$

$[F^-]$ remaining after precipitation $= \dfrac{0.243\text{ mol}}{0.300\text{ L}} = 0.808\text{ mol L}^{-1}$

$K_{sp} = [Mg^{2+}][F^-]^2$

Assuming that the equilibrium $[F^-]$ is 0.808 mol L^{-1}, as K_{sp} is small,

$$[Mg^{2+}] = \frac{5.16 \times 10^{-11}}{0.808^2} = 7.90 \times 10^{-11}\text{ mol L}^{-1}$$

Question 35 (a)

Criteria	Marks
• Calculates the K_a	3
• Provides some steps for calculating the K_a	2
• Provides some relevant information.	1

Sample answer:

$[H^+] = 10^{-pH} = 10^{-1.107} = 0.0782 \text{ mol L}^{-1}$

$CHCl_2COOH(aq) \rightleftharpoons H^+(aq) + CHCl_2COO^-(aq)$

	$CHCl_2COOH(aq)$	$\rightleftharpoons$	$H^+(aq)$	$CHCl_2COO^-(aq)$
Initial	0.2000		0	0
Change	–0.0782		+0.0782	+0.0782
Equilibrium	0.1218		0.0782	0.0782

$$K_a = \frac{[H^+][CHCl_2COO^-]}{[CHCl_2COOH]}$$

$$= \frac{[0.0782][0.0782]}{[0.1218]}$$

$$= 0.0501$$

Question 35 (b)

Criteria	Marks
• Explains why trichloroacetic acid is a stronger acid than acetic acid, with reference to the data	3
• Identifies that trichloroacetic acid is a stronger acid than acetic acid, with reference to some relevant data	2
• Provides some relevant information	1

Sample answer:

The pK_a of trichloroacetic acid is lower than the pK_a of acetic acid, so trichloroacetic acid is a stronger acid than acetic acid.

The major difference between the data for the two acids is the magnitude of the ΔS° terms. Both are negative and will make an unfavourable contribution to the ΔG°; however, the value for acetic acid is much larger than that for trichloroacetic acid. This means that ionisation of acetic acid is less favourable than it is for trichloroacetic acid, making the latter the stronger acid.

Answers could include:

Reference to $-T\Delta S^\circ$ or $T\Delta S^\circ$

Question 36

Criteria	Marks
• Draws the correct structure of compounds A to C • Justifies the correct structures showing an extensive understanding of the interpretation of spectroscopic data and reaction pathways • Refers to relevant spectroscopic data for all compounds	9
• Draws the correct structure of compounds A to C • Justifies the correct structures showing a thorough understanding of the interpretation of spectroscopic data and reaction pathways. • Refers to relevant spectroscopic data for most compounds	7–8
• Draws structures for compounds A to C with correct functional groups • Shows a sound understanding of the interpretation of spectroscopic data and reaction pathways. • Uses relevant information presented in the question to explain structures	5–6
• Demonstrates some understanding of different reactions AND/OR • Demonstrates some understanding of the interpretation of spectroscopic data	3–4
• Provides some relevant information	1–2

Sample answer:

Compound A is an alkene as it is able to undergo an addition reaction to add water across a carbon—carbon double bond to form Compound B, which must be an alcohol since it is the product of the hydration reaction.

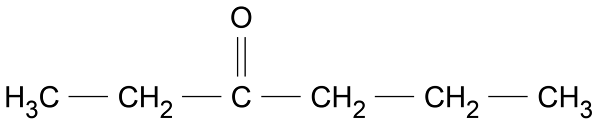
The ^{13}C NMR spectrum of Compound A confirms it is an alkene as the peak at 132 ppm corresponds to the C=C atoms. There are 3 peaks in the spectrum indicating there are 3 carbon environments. However, the molar mass of compound A is 84.156 g mol^{-1} suggesting there is symmetry within the molecule.

The IR spectrum of Compound B has a broad peak at approximately 3400 cm^{-1} which is consistent with the presence of an hydroxyl group and confirms B is an alcohol. Oxidation of Compound B with acidified potassium permanganate produces Compound C which must be a carboxylic acid if B is a primary alcohol, or a ketone if B is a secondary alcohol.

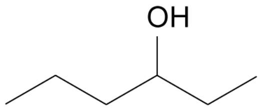
The ^{1}H NMR spectrum of C does not contain any peaks between 9.0−13.0 ppm so it cannot be a carboxylic acid. Compound C is therefore a ketone and Compound B is a secondary alcohol. There are 5 peaks in the ^{1}H NMR spectrum indicating there are 5 hydrogen environments. The assignments of the peaks based on the integration and splitting patterns are:

- 1.01 ppm and 1.05 ppm: CH_3 (next to a CH_2)
- 1.65 ppm: CH_2 (with multiple neighbouring hydrogens)
- 2.42 ppm: CH_2 (next to the ketone C=O and a CH_2)
- 2.46 ppm: CH_2 (next to the ketone C=O and a CH_3)

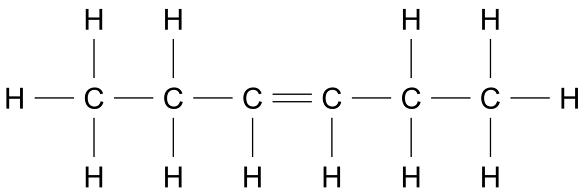
Combining this information Compound C is:



Compound B must therefore be the following secondary alcohol:



And compound A must be the following symmetrical alkene, which has a molar mass of 84.156 g mol^{-1}.



Question 37 (a)

Criteria	Marks
• Calculates Q and compares to K to determine whether the system is in equilibrium	2
• Provides some relevant information	1

Sample answer:

$$K_{eq} = \frac{[CO_2]}{[CO]^2}$$

$$Q = \frac{1.21 \times 10^{-3}}{\left(1.10 \times 10^{-2}\right)^2} = 10.0 = K_{eq}$$

Since $Q = K_{eq}$, the system is at equilibrium.

Question 37 (b)

Criteria	Marks
• Calculates the amount of CO_2 added to the system	3
• Provides some relevant steps in the calculation	2
• Provides some relevant information	1

Sample answer:

$$K_{eq} = \frac{[CO_2]}{[CO]^2}$$

Since $[CO] = [CO_2]$, $K_{eq} = \dfrac{[CO]}{[CO]^2} = \dfrac{1}{[CO]} = 10.00$

So $[CO] = \dfrac{1}{10.00} = 0.1000 \text{ mol L}^{-1} = [CO_2]$

	$2CO(g)$	$\rightleftharpoons$	$CO_2(g)$	+	$C(s)$
Initial	1.10×10^{-2}		1.21×10^{-3}		
Change	+0.0890		+0.0988		
Equilibrium	0.1000		0.1000		

Since 1 mol of CO_2 gives 2 mol of CO:

$n(CO_2)$ required to be added to increase $[CO_2]$ = 0.0988 mol

$n(CO_2)$ total = 0.0988 mol + $n(CO_2$ required to make CO)

$n(CO_2)$ required to be added to increase [CO] = $\dfrac{0.0890}{2}$ = 0.0445 mol

Total $n(CO_2)$ added = 0.0445 + 0.0988 = 0.143 mol

2023 HSC Chemistry
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