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 $\times$ ΔT

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

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

$q = 31.448\ \text{kJ}$

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

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

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.

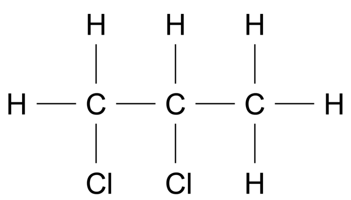
Atomic mass of carbon in compound R = 32% of 114 = 36

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
- $Ag^{+}(aq) + Br^{-}(aq) \longrightarrow AgBr(s)$.

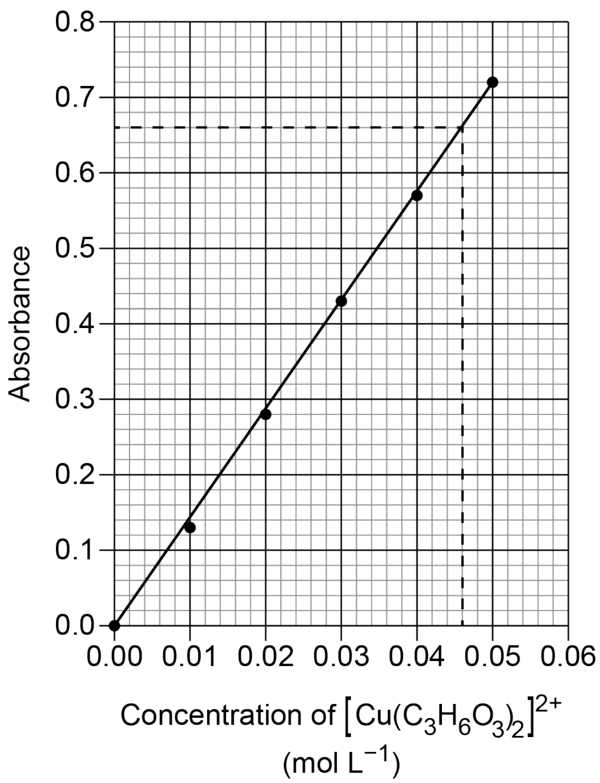
Answer could include:

- 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 $= 0.263 \text{ mol} - 2 \times 1.00 \times 10^{-2} \text{ mol} = 0.243 \text{ mol}$

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

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

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.

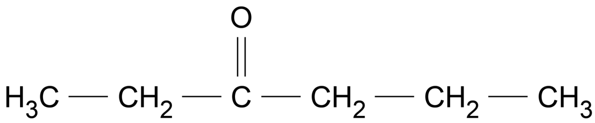
The ^{13}C NMR spectrum of Compound A confirms it is an alkene as the peak at 132 ppm corresponds to the C=C atoms. There are 3 peaks in the spectrum indicating there are 3 carbon environments. However, the molar mass of compound A is 84.156 g mol^{-1} suggesting there is symmetry within the molecule.

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.

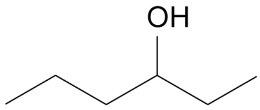
The ^{1}H NMR spectrum of C does not contain any peaks between 9.0−13.0 ppm so it cannot be a carboxylic acid. Compound C is therefore a ketone and Compound B is a secondary alcohol. There are 5 peaks in the ^{1}H NMR spectrum indicating there are 5 hydrogen environments. The assignments of the peaks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

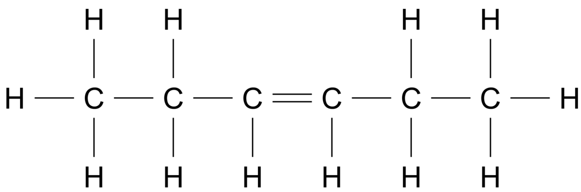
Combining this information Compound C is:



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

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

	$2CO(g)$	$\rightleftharpoons$	$CO_2(g)$	+	$C(s)$
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] = $\frac{0.0890}{2}$ = 0.0445 mol

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

2023 HSC Chemistry Mapping Grid

Section I

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12	1	Mod 5 Factors that Affect Equilibrium Mod 8 Chemical Synthesis and Design	12-15
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Section II

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