2024 HSC Chemistry Marking Guidelines

Section I

Multiple-choice Answer Key

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

Section II

Question 21

Criteria	Marks
• Identifies both products	2
• Provides some relevant information	1

Sample answer:

Hydrogen and magnesium acetate/ethanoate

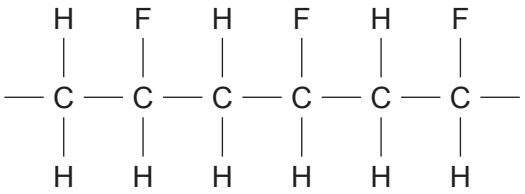
Answers could include:

H_2 and $Mg(CH_3COO)_2$

Question 22

Criteria	Marks
• Provides a correct structural formula	2
• Provides some relevant information	1

Sample answer:



Question 23

Criteria	Marks
• Provides a sound relationship between the observed colour change and K_{eq}	3
• Provides some information about changes in concentration of reactants and/or products	2
• Provides some relevant information	1

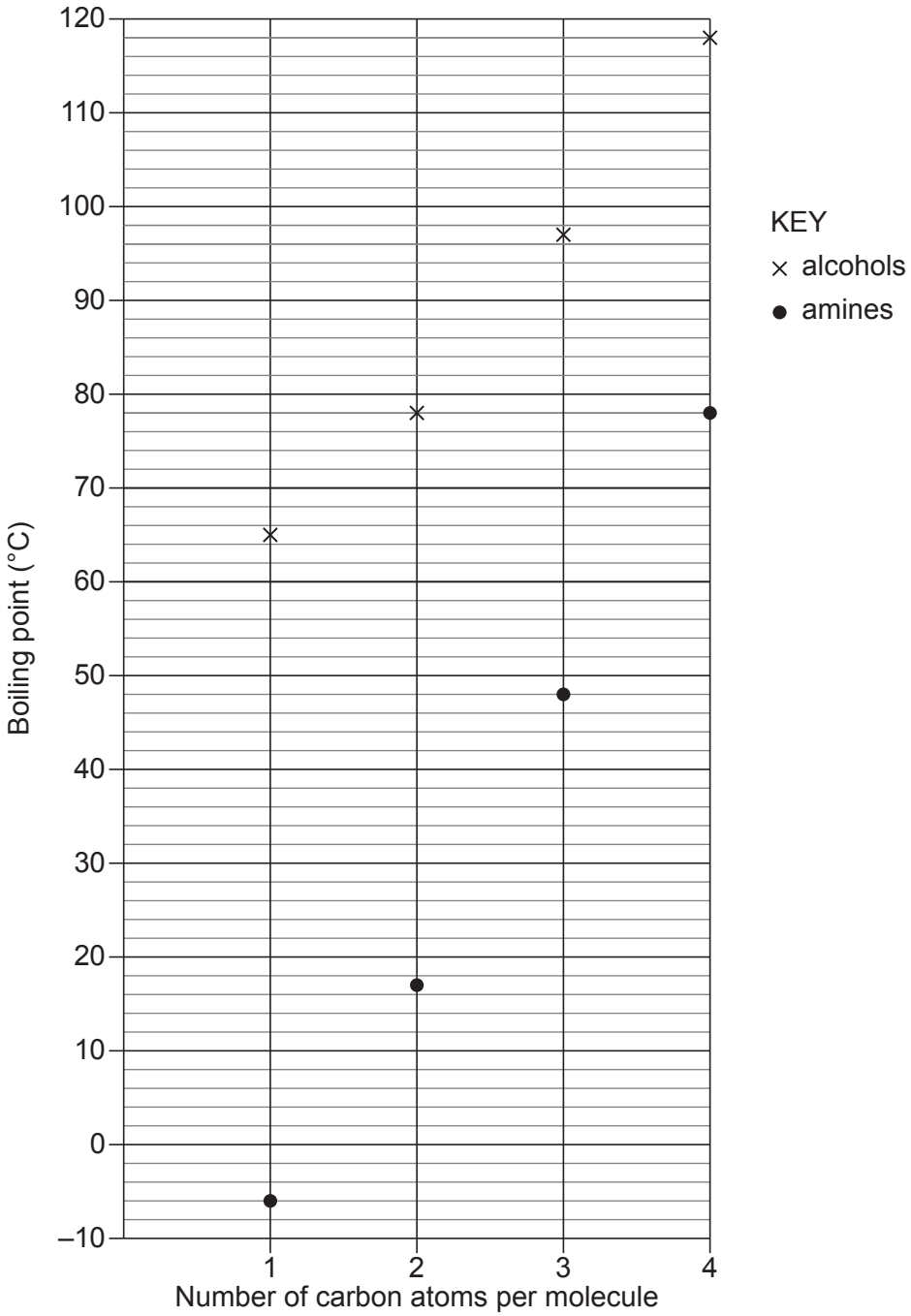
Sample answer:

The mixture becomes more blue as temperature is increased, which suggests that the concentration of $\left[CoCl_4\right]^{2-}$ is increasing. This means that an increase in temperature favours the forward reaction. This response will result in a larger value of K_{eq} as $K_{eq} = \dfrac{\left[\left[CoCl_4\right]^{2-}\right]}{\left[\left[Co(H_2O)_6\right]^{2+}\right]\left[Cl^-\right]^4}$.

Question 24 (a)

Criteria	Marks
• All correct points plotted • Correct scale and label on *y*-axis • Each series identified	3
• Two of three features included (correct points, label/scale *y*-axis, each series identified)	2
• Provides some relevant information	1

Sample answer:



Question 24 (b)

Criteria	Marks
• Explains increase in boiling point with increasing carbon number due to increasing dispersion forces • Explains difference in boiling point between series with reference to difference in strength of hydrogen bonding	4
• Explains ONE trend OR • Describes trends	3
• Makes a relevant comparison to a data series	2
• Provides some relevant information	1

Sample answer:

For both the alcohols and the amines, dispersion forces will increase with increasing carbon number, due to increased number of electrons present, leading to increased boiling points.

However, for any given carbon number, the alcohol has stronger hydrogen bonding than the corresponding amine, as oxygen has a higher electronegativity than nitrogen, so the alcohols all have higher boiling points than the corresponding amines.

Question 25

Criteria	Marks
• Calculates the correct concentration of phosphate ions, in mol L^{-1}	4
• Provides the main steps of the calculation	3
• Provides some steps of the calculation	2
• Provides some relevant information	1

Sample answer:

Concentration of diluted sample $= 0.78$ mg L^{-1}

Concentration of phosphate ions in original sample in mg $L^{-1} = 1000 \times 0.78$ mg $L^{-1} = 780$ mg $L^{-1} = 0.78$ g L^{-1}

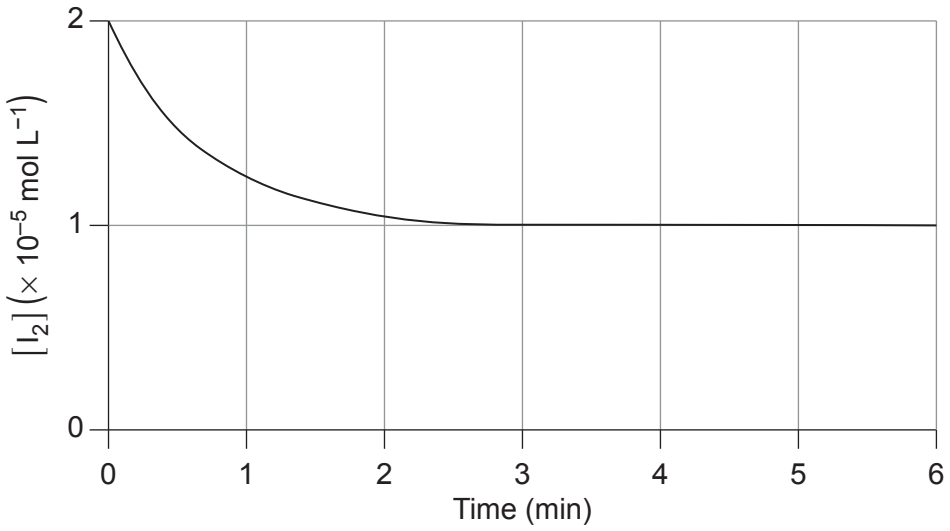
Molar mass of $PO_4^{3-} = (30.97 + 4 \times 16.00) = 94.97$ g mol^{-1}

Concentration of phosphate ions in mol $L^{-1} = \dfrac{0.78}{94.97} = 0.0082$ mol L^{-1}

Question 26 (a)

Criteria	Marks
• Provides a correct graph	2
• Provides one correct feature	1

Sample answer:



Question 26 (b)

Criteria	Marks
• Provides an explanation of the rate of reaction with clear link to $[I_2]$ and collision theory	3
• Provides some description of the rate of reaction with link to $[I_2]$ and/or collision theory	2
• Provides some relevant information	1

Sample answer:

The initial high $[I_2]$ results in more frequent successful collisions and a high rate of forward reaction. As the reaction proceeds, I_2 is consumed, so $[I_2]$ decreases, so the reaction rate decreases. After $t = 3$ min, the system is at equilibrium so the rates of the forward and reverse reactions are the same, so $[I_2]$ is constant.

Question 27

Criteria	Marks
• Demonstrates a thorough understanding of the procedure and qualitative ion testing • Includes a balanced chemical equation, including states	4
• Demonstrates a sound understanding of the procedure and qualitative ion testing	3
• Demonstrates some understanding of the procedure and qualitative ion testing	2
• Provides some relevant information	1

Sample answer:

If only barium ions are present, they will give a precipitate in step 1 of this procedure $\left(Ba^{2+}(aq) + SO_4{}^{2-}(aq) \longrightarrow BaSO_4(s)\right)$, so the conclusion that only barium ions are present will be correct.

If lead(II) ions are present, they will also precipitate at step 1 of this procedure. This will leave insufficient lead(II) ions in solution to give a precipitate in step 3. The conclusion reached will be that only barium ions are present, which is incorrect.

Question 28

Criteria	Marks
• Shows that both acids do not dissociate completely in water and that iodic acid is stronger	3
• Provides some information relating to of the dissociation of one or both acids	2
• Provides some relevant information	1

Sample answer:

For both acids, $\left[H_3O^+\right] = 10^{-pH} = 10^{-1.151} = 0.0706$ mol L^{-1}, which is less than the acid concentration. Accordingly, both acids do not dissociate completely in water and are weak.

Since a smaller concentration of iodic acid is required to give a pH of 1.151 compared to sulfamic acid, iodic acid must ionise to a greater extent than sulfamic acid, ie iodic acid must be a stronger acid than sulfamic acid.

Question 29

Criteria	Marks
• Calculates the pH of the resulting solution	4
• Provides most relevant steps of the calculation	3
• Provides some relevant steps of the calculation	2
• Provides some relevant information	1

Sample answer:

$n(\text{NaOH}) = 0.150\ \text{L} \times 0.20\ \text{mol L}^{-1} = 0.030\ \text{mol}$

$n(H_2SO_4) = 0.100\ \text{L} \times 0.10\ \text{mol L}^{-1} = 0.010\ \text{mol}$

$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

$n(\text{NaOH required for reaction with } H_2SO_4) = 2 \times 0.010\ \text{mol} = 0.020\ \text{mol}$

$n(\text{NaOH in excess}) = 0.030\ \text{mol} - 0.020\ \text{mol} = 0.010\ \text{mol}$

$$[\text{NaOH}] = \frac{0.010\ \text{mol}}{0.250\ \text{L}} = 0.040\ \text{mol L}^{-1}$$

$p(\text{OH}) = -\log_{10}(0.040) = 1.40$

$\text{pH} = 14.00 - 1.40 = 12.60$

Question 30

Criteria	Marks
• Calculates correct amount of CO(*g*) added	4
• Provides the main steps of the calculation	3
• Provides some steps of the calculation	2
• Provides some relevant information	1

Sample answer:

Changes in $\left[H_2O\right] = (0.400 - 0.200) = 0.200 \text{ mol L}^{-1} = 0.200 \text{ mol in 1 L}$

ICE table:

	$n(H_2)$ in 1 L (mol)	$n(CO_2)$ in 1 L (mol)	$n(H_2O)$ in 1 L (mol)	$n(CO)$ in 1 L (mol)
Initial	1.000	0.500	0.400	$2.000 + x$
Change	$+0.200$	$+0.200$	-0.200	-0.200
Equib	1.200	0.700	0.200	$1.800 + x$

$$K_{eq} = \frac{[H_2O][CO]}{[H_2][CO_2]}$$

$$1.600 = \frac{[0.200][1.800 + x]}{[1.200][0.700]}$$

$$x = \frac{1.600 \times 1.200 \times 0.700}{0.200} - 1.800$$

$$x = 4.92 \text{ mol in 1 L}$$

Question 31

Criteria	Marks
• Correctly compares the processes and justifies preferred approach	3
• Compares one aspect of the processes	2
• Provides some relevant information	1

Sample answer:

The atom economy for the reaction with DMC is 48.4% compared to the phosgene reaction at 35.9%. As a result, there is less waste in the process involving the less harmful DMC. Less ammonia is also required (2 moles, in place of 4 for phosgene).

This comparison identifies the production of urea from DMC as the preferred approach in terms of atom economy, toxicity of starting materials and quantities of harmful reactants required.

Question 32

Criteria	Marks
• Calculates the concentration of Cd^{2+} ions to 3 significant figures	4
• Provides most relevant steps of the calculation	3
• Provides some relevant steps of the calculation	2
• Provides some relevant information	1

Sample answer:

$Cd_3(PO_4)_2(s) \rightleftharpoons 3Cd^{2+}(aq) + 2PO_4{}^{3-}(aq)$

Let s mol $Cd_3(PO_4)_2(s)$ dissolve per litre

$K_{sp} = [Cd^{2+}]^3[PO_4{}^{3-}]^2 = (3s)^3(2s)^2 = 108s^5$

$s = \sqrt[5]{\dfrac{2.53 \times 10^{-33}}{108}} = 1.19 \times 10^{-7}$

$[Cd^{2+}] = 3s = 3.56 \times 10^{-7}$ mol L^{-1}

Question 33 (a)

Criteria	Marks
• Identifies correct shape around both central carbon atoms in the reactant and product molecules	2
• Provides some relevant information	1

Sample answer:

The shape around the central carbon in the reactant molecule is trigonal planar, whereas the shape around the central carbon atom in the product is tetrahedral.

Question 33 (b)

Criteria	Marks
• Provides a sound explanation of how key ^{13}C NMR spectral features can be used to monitor the reaction	3
• Provides some explanation of how key ^{13}C NMR spectral features can be used to monitor the reaction	2
• Provides some relevant information	1

Sample answer:

In the ^{13}C NMR spectrum of the reaction mixture at the start of the reaction, there will be two (2) signals, due to the 2 different carbons (C═O and CH_3) in the reactant molecule. However, as the reaction proceeds, the C═O bond is transformed to H—C—OH. Therefore, a new signal will appear in the ^{13}C NMR spectrum of the reaction mixture that corresponds to the different carbon environment in the product. This peak will appear as the reaction proceeds, while the original peak for C═O will disappear.

Question 34

Criteria	Marks
• Provides a thorough explanation of the shape of the graph • Includes TWO balanced chemical equations	4
• Provides a sound explanation of the shape of the graph • Includes a balanced chemical equation	3
• Demonstrates some understanding of the shape of the graph	2
• Provides some relevant information	1

Sample answer:

Before the equivalence point (below 4.5 mL), hydrochloric acid is being neutralised by the added ammonia:

$$H^+(aq) + NH_3(aq) \longrightarrow NH_4^+(aq)$$

This has the effect of replacing H^+ ions (high conductivity) with NH_4^+ ions (low conductivity), so the conductivity decreases.

After the equivalence point, the excess ammonia added will produce some NH_4^+ and OH^- ions, both of which have greater conductivity than the reactant molecules:

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

This reaction only occurs to a small extent, however, as the NH_4^+ already present in the solution will suppress this ionisation, in accordance with Le Châtelier's Principle. Accordingly, the conductivity only increases slightly after the equivalence point.

Question 35

Criteria	Marks
• Correctly identifies the structure of compounds X, Y and Z • Justifies the correct structures showing an extensive understanding of the interpretation of titration and reaction data • Makes extensive reference to the information provided	7
• Correctly identifies the structure of compounds X, Y and Z • Justifies the correct structures showing a thorough understanding of the interpretation of titration and reaction data • Makes reference to the information provided	6
• Demonstrates a sound understanding of the interpretation of titration and/or reaction data • Uses relevant information presented in the question to explain structures	4–5
• Demonstrates some understanding of the interpretation of titration and/or reaction data	2–3
• Provides some relevant information	1

Sample answer:

X does not undergo an addition reaction with Br_2 or a hydration reaction so does not possess a double bond. Thus, the only structure that can be X is Structure 2.

Y and Z do contain at least one double bond because of the addition and hydration reactions. As 0.100 g of Y reacts with the same amount of Br_2 as 0.200 g of Z, Z must have a molar mass that is double the molar mass of Y.

Only one product is formed from the hydration of Z so Z must be symmetrical around the double bond and Y is not symmetrical.

The equal volumes of Y and Z in the titration is a result of Z having double the molar mass of Y AND being a diprotic acid. Thus, Structure 1 is Y and Structure 3 is Z.

Question 36

Criteria	Marks
• Calculates the enthalpy of reaction	5
• Provides a substantially correct calculation	4
• Provides the main steps in the calculation	3
• Provides some relevant steps in the calculation	2
• Provides some relevant information	1

Sample answer:

$NaHCO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + CO_2(g) + H_2O(l)$

$$n(NaHCO_3) \text{ added} = \frac{14.7 \text{ g}}{84.008 \text{ mol L}^{-1}} = 0.175 \text{ mol}$$

$n(HCl)$ added $= 1.50 \text{ mol} \times 0.120 \text{ L} = 0.180 \text{ mol}$

1 : 1 reaction therefore HCl is in excess and $NaHCO_3$ is the limiting reagent

$m(CO_2 \text{ lost}) = 0.175 \text{ mol} \times (12.01 + 16.00 \times 2) \text{ g mol}^{-1} = 7.70 \text{ g}$

Therefore, total mass of reaction solution $= (14.7 - 7.70) \text{ g} + (1.02 \times 120) \text{ g} = 129 \text{ g}$

$q = mc\Delta T$

$q = 129 \text{ g} \times 3.80 \text{ J K}^{-1} \text{g}^{-1} \times (11.5 - 21.5)°\text{C}$

$q = -4917 \text{ J} = -4.92 \text{ kJ}$

$$\Delta H = \frac{4.92 \text{ kJ}}{0.175 \text{ mol}} = +28.1 \text{ kJ mol}^{-1}$$

Answers could include:

$NaHCO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + CO_2(g) + H_2O(l)$

$$n(NaHCO_3) \text{ added} = \frac{14.7 \text{ g}}{84.008 \text{ mol L}^{-1}} = 0.175 \text{ mol}$$

$n(HCl)$ added $= 1.50 \text{ mol} \times 0.120 \text{ L} = 0.180 \text{ mol}$

1 : 1 reaction therefore HCl is in excess and $NaHCO_3$ is the limiting reagent

Therefore, total mass of reaction solution $= 14.7 \text{ g} + (1.02 \times 120 \text{ g}) = 137.1 \text{ g}$

$q = mc\Delta T$

$q = 137.1 \text{ g} \times 3.80 \text{ J K}^{-1} \text{g}^{-1} \times (11.5 - 21.5)°\text{C}$

$q = -5209.8 \text{ J} = -5.209 \text{ kJ}$

$$\Delta H = \frac{5.209 \text{ kJ}}{0.175 \text{ mol}} = +29.8 \text{ kJ mol}^{-1}$$

Question 37

Criteria	Marks
• Provides an explanation of why the reaction proceeds to completion with reference to the data provided	3
• Demonstrates some understanding of why the reaction proceeds to completion with reference to some of the data provided	2
• Provides some relevant information	1

Sample answer:

The graph shows that reactions with large negative $\Delta G°$ values will have extremely large equilibrium constants, ie they effectively proceed to completion.

For this reaction, $\Delta G° = \Delta H° - T\Delta S° = -217 \text{ kJ mol}^{-1} - (-3 \text{ kJ mol}^{-1}) = -214 \text{ kJ mol}^{-1}$

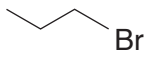
This $\Delta G°$ value is large and negative, which means that the reaction will effectively proceed to completion. Accordingly, this reaction proceeds to completion mostly due to its large, negative $\Delta H°$ value; the $T\Delta S°$ term is small and has little effect.

Question 38

Criteria	Marks
• Draws the correct structure of compounds A, B and E • Explains the correct structures showing an extensive understanding of the interpretation of spectroscopic data and reaction pathways • Refers to relevant spectroscopic data	7
• Draws the correct structure of compounds A, B and E • Explains the correct structures showing a thorough understanding of the interpretation of spectroscopic data and reaction pathways • Refers to most relevant spectroscopic data	6
• Shows a sound understanding of the interpretation of spectroscopic data and reaction pathways • Uses relevant information presented in the question to explain structures • Draws structures for compounds A and B with halogen location correct AND/OR • Draws correct structure for compound E	4–5
• Demonstrates some understanding of the different reactions AND/OR • Demonstrates some understanding of the interpretation of spectroscopic data	2–3
• Provides some relevant information	1

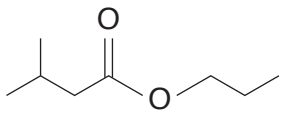
Sample answer:

Compound A



Compound B

Compound E



From the mass spectrum of A, the two peaks at m/z 122/124 indicate the presence of a Br atom (two isotopes of approximately equal abundance) – halogen X in C_3H_7X is Br. The peak at m/z 43 is due to the loss of Br.

There are two isomers of C_3H_7Br: 1-bromopropane and 2-bromopropane. These will produce propan-1-ol and propan-2-ol respectively after substitution with hydroxide. Only propan-2-ol will produce a ketone upon oxidation, so B must be 2-bromopropane and A must be 1-bromopropane.

E is an ester formed from the reaction of 3-methylbutanoic acid with either C (propan-1-ol) or D (propan-2-ol).

The ^{1}H NMR data gives the following information:

- The peak at δ 4.0 ppm is a CH_2 group bonded to an oxygen atom (hence the high chemical shift). This tells us that E is a propyl ester, —$OCH_2CH_2CH_3$.
- The rest of the propyl group gives rise to a CH_2 multiplet (present at δ 1.7 ppm) and a CH_3 triplet (present at δ 0.95 ppm).
- The peak at δ 2.2 ppm is a CH_2 group attached to a carbonyl (C═O) group.
- The remaining peaks integrate for 6 (δ 0.95 ppm doublet) and 1 (δ 2.1 ppm multiplet), which indicates an isopropyl group attached to the CH_2 group, giving the structure for E.

Question 39

Criteria	Marks
• Calculates the K_{eq}	4
• Provides most steps of the calculation	3
• Provides some steps of the calculation	2
• Provides some relevant information	1

Sample answer:

$$K_a = \frac{[H^+][BrCH_2COO^-]}{[BrCH_2COOH]}$$

$$[BrCH_2COOH](aq) = \frac{[H^+][BrCH_2COO^-]}{K_a}$$

$$= \frac{[9.18 \times 10^{-3}][9.18 \times 10^{-3}]}{1.29 \times 10^{-3}}$$

$$= 0.0654 \text{ mol L}^{-1}$$

$$[BrCH_2COOH](\textit{octan-1-ol}) = 0.1000 - 0.0654 - 9.18 \times 10^{-3} = 0.0254 \text{ mol L}^{-1}$$

$$K_{eq} = \frac{[BrCH_2COOH(\textit{octan-1-ol})]}{[BrCH_2COOH(aq)]} = \frac{0.0254 \text{ mol L}^{-1}}{0.0654 \text{ mol L}^{-1}} = 0.390$$

2024 HSC Chemistry

Mapping Grid

Section I

Question	Marks	Content	Syllabus outcomes
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3	1	Mod 6 Properties of Acids and Bases	12-13
4	1	Mod 8 Analysis of Organic Substances	12-5, 12-15
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9	1	Mod 8 Analysis of Organic Substances	12-5, 12-15
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12	1	Mod 7 Nomenclature	12-14
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Section II

Question	Marks	Content	Syllabus outcomes
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26 (a)	2	Mod 5 Factors that Affect Equilibrium	12-4, 12-12
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27	4	Mod 8 Analysis of Inorganic Substances	12-2, 12-6, 12-15
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Question	Marks	Content	Syllabus outcomes
30	4	Mod 5 Calculating the Equilibrium Constant	12-12
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