NSW Education Standards Authority

2022 HSC Chemistry Marking Guidelines

Section I

Multiple-choice Answer Key

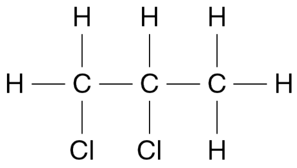
Question	Answer
1	C
2	B
3	D
4	C
5	B
6	D
7	B
8	B
9	A
10	C
11	B
12	D
13	A
14	B
15	C
16	D
17	A
18	D
19	A
20	C

Section II

Question 21

Criteria	**Marks**
• Provides the correct structure	2
• Structure drawn with an addition of at least one chlorine atom	1

Sample answer:



Question 22

Criteria	**Marks**
• Provides a correct base and its conjugate acid	2
• Provides a correct base or conjugate acid from the reaction	1

Sample answer:

Base	*Conjugate acid*
PO_4^{3-}	HPO_4^{2-}

OR

Base	*Conjugate acid*
F^-	HF

Question 23 (a)

Criteria	**Marks**
• Identifies what would happen to the amount of NO(*g*)	1

Sample answer:

Amount of NO would decrease.

Question 23 (b)

Criteria	Marks
• Explains why a catalyst does not affect equilibrium position in terms of reaction rates	2
• Provides some relevant information	1

Sample answer:

A catalyst will increase the rate of the forward and reverse reactions of this system. As both rates increase, the overall equilibrium position is unchanged.

Question 23 (c)

Criteria	Marks
• Identifies the change in NO concentration • Explains the change in terms of collision theory	3
• Shows some understanding of the relationship between collision theory and equilibrium concentrations	2
• Provides some relevant information	1

Sample answer:

When $H_2O(g)$ is removed, there are fewer $H_2O(g)$ molecules to collide with NO in the reverse reaction which decreases the rate. The rate of the forward reaction is therefore proportionally higher. As a result [NO] increases.

Question 24

Criteria	Marks
• Provides a thorough explanation of the trend with reference to dispersion forces	3
• Provides some explanation of the trend	2
• Provides some relevant information	1

Sample answer:

As molar mass increases, the boiling point increases. As molar mass increases, the number of electrons increases which increases the strength of the dispersion forces between molecules. Stronger intermolecular forces require more energy to break and therefore a higher boiling point.

Question 25

Criteria	Marks
• Provides a balanced chemical equation • Explains the difference in pH in terms of weak and strong acids and their relative ionisation	3
• Demonstrates some understanding of weak and strong acids	2
• Provides some relevant information	1

Sample answer:

HCN(aq) is a weak acid, so partially ionises: $HCN(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$. HCl($aq$) is a strong acid and ionises completely. So the $[H^+]$ of the HCN(aq) solution will be lower than the $[H^+]$ of the HCl(aq) solution. As $pH = -\log[H^+]$, the HCN(aq) solution will have a higher pH.

Question 26 (a)

Criteria	Marks
• Correctly calculates the heat energy released	2
• Provides some relevant information	1

Sample answer:

$T_{i(\text{av})} = 21.1°\text{C}$

$\Delta T = 24.4 - 21.1 = 3.3\text{ K}$

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

Mass of final solution = 100.7 g + 102.0 g = 202.7 g

$q = mc\Delta T = 0.2027\text{ kg} \times 4.18 \times 10^3\text{ J K}^{-1}\text{ kg}^{-1} \times 3.3\text{ K} = 2796\text{ J} = 2.796\text{ kJ} = 2.8\text{ kJ}$

Question 26 (b)

Criteria	Marks
• Correctly calculates enthalpy of neutralisation	2
• Provides some relevant information or working	1

Sample answer:

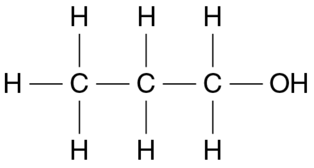
mol of H_2O formed = mol of HCl reacted = 0.1000 L × 0.50 mol = 0.050 mol

$$\Delta H = \frac{2.6\text{ kJ}}{0.050\text{ mol}} = -52\text{ kJ mol}^{-1}$$

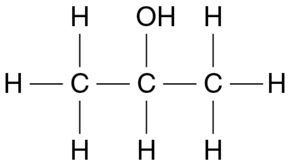
Question 27 (a)

Criteria	Marks
• Draws the correct structure for both isomers of propanol	2
• Draws the correct structure for one isomer of propanol OR • Demonstrates an understanding of the structure of the isomer(s)	1

Sample answer:



$\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-OH}$



$\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{OH}{C}}-\underset{H}{\overset{H}{C}}-H}$

Answers could include:

Other representations

Question 27 (b)

Criteria	Marks
• Describes the use of ^{13}C NMR to identify that the two isomers have different signals and could thus be used to identify the isomer	2
• Provides some relevant information	1

Sample answer:

If the spectrum produced by ^{13}C NMR has 2 signals, then the isomer that is in the labelled bottle is propan-2-ol and if it has three then it is propan-1-ol.

Question 27 (c)

Criteria	Marks
• Writes TWO correct equations with correct products and includes correct reaction conditions	3
• Writes ONE correct equation, with correct product and correct reaction conditions OR • Writes TWO equations with correct product and does not include or includes incorrect reaction conditions	2
• Provides some relevant information	1

Sample answer:

$$CH_3CH_2CH_2OH \xrightarrow{H^+/Cr_2O_7^{2-}} CH_3CH_2COOH$$

$$CH_3CHOHCH_3 \xrightarrow{H^+/Cr_2O_7^{2-}} CH_3COCH_3$$

Answers could include:

- Word equations
- Other representations including skeletal structures
- Other appropriate reagents and corresponding products.

Question 28 (a)

Criteria	Marks
• Correctly identifies the brown precipitate formed	1

Sample answer:

Iron(III) hydroxide

Question 28 (b)

Criteria	Marks
• Correctly calculates the percentage of iron including significant figures	4
• Provides the main steps of the calculation	3
• Provides some relevant steps of the calculation	2
• Provides some relevant information or working	1

Sample answer:

Molar mass of iron(III) oxide (Fe_2O_3) = 159.70 g mol^{-1}

Amount of Fe_2O_3 produced $= \dfrac{4.21 \text{ g}}{159.70 \text{ g mol}^{-1}} = 0.026362$ mol

Amount of Fe = 2 × moles Fe_2O_3 = 2 × 0.026362 = 0.052724 mol

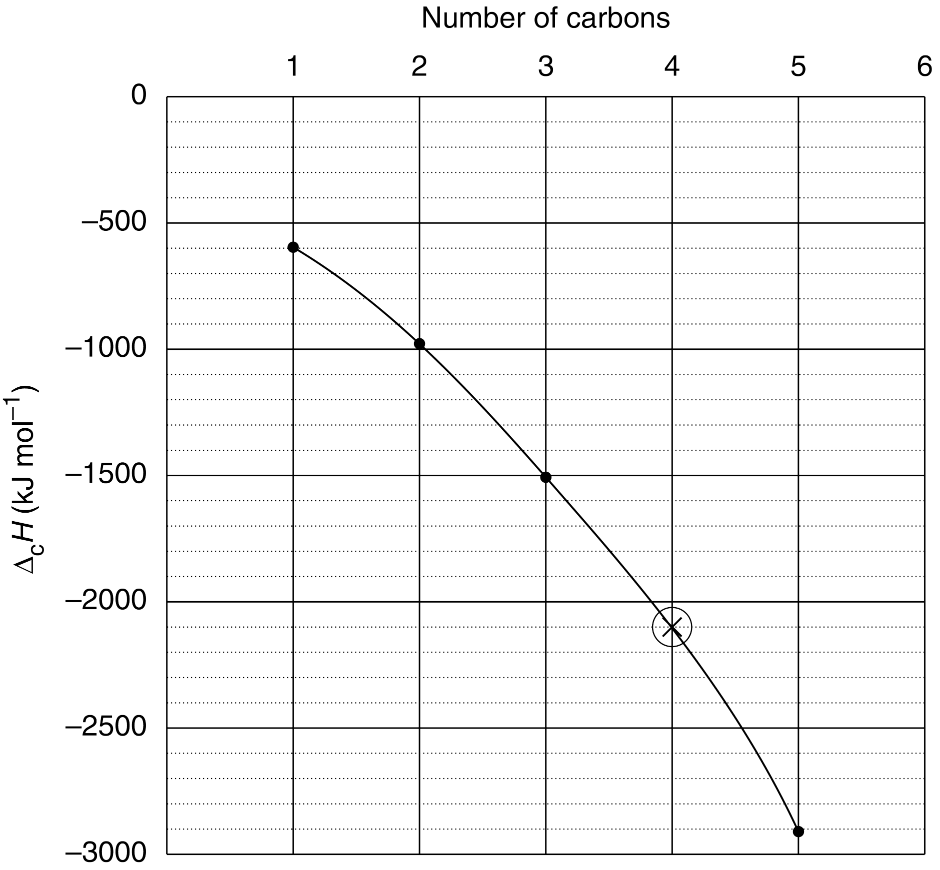
Mass of Fe in sample = 0.052724 mol × 55.85 g mol^{-1} = 2.9446 g

% Fe in original impure sample $= \dfrac{2.9446 \text{ g}}{4.32 \text{ g}} \times 100\% = 68.163\% = 68.2\%$

Question 29 (a)

Criteria	Marks
• Plots the points on the graph correctly, draws a curved line of best fit and estimates the enthalpy of combustion of butan-1-ol including units and negative sign	3
• Provides a substantially correct graph with appropriate estimation OR • Provides a correct graph	2
• Provides some relevant information	1

Sample answer:



Enthalpy of combustion of butan-1-ol ≈ –2100 kJ mol^{-1}

Question 29 (b)

Criteria	Marks
• Provides a justification	2
• Provides some relevant information	1

Sample answer:

In a school laboratory, the calorimeters used are often simple, such as a tin can. There will be significant heat loss as some of the heat is lost to the environment or equipment. The published value is obtained using more appropriate equipment in a standard environment.

Answers could include:

- Incomplete combustion of the alcohol – this produces less heat energy than complete combustion.
- Heat not evenly distributed in water measured and therefore measured to be less than the amount of heat energy produced.

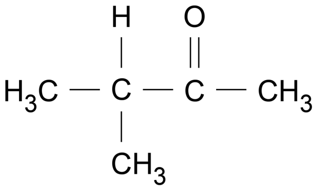
Question 30

Criteria	Marks
• Names and draws correct structure of 3-methylbutan-2-one • Justifies the correct structure showing an extensive understanding of the interpretation of spectroscopic data • Refers explicitly to the relevant spectroscopic data	7
• Draws correct structure for 3-methylbutan-2-one • Justifies the structure showing a thorough understanding of the interpretation of spectroscopic data • Refers to relevant spectroscopic data	6
• Shows a sound understanding of the interpretation of spectroscopic data • Uses relevant information presented in the question to justify the structure of the compound • Provides a name or structural formula consistent with the analysis	4–5
• Demonstrates some understanding of the interpretation of spectroscopic data	2–3
• Provides some relevant information	1

Answers could include:

Structural formula and *name*

3-methylbutan-2-one



$$\begin{array}{ccccccc} & & H & & O & & \\ & & | & & \| & & \\ H_3C & - & C & - & C & - & CH_3 \\ & & | & & & & \\ & & CH_3 & & & & \end{array}$$

Mass spectrum

- Parent molecular ion at M/Z = 86 which is consistent with the named molecule
- The base peak at M/Z = 43 is consistent with fragmentation adjacent to a carbonyl group CH_3CO^+.

IR spectrum

- Strong absorption at 1700 cm^{-1} which is consistent with carbonyl group
- Absence of broad OH stretch between 2500−3000 cm^{-1} eliminates carboxylic acids.

Carbon-13 NMR

- There are five carbons in the molecule, but the spectrum only has four different carbon environments so two carbons must have identical environments
- The signal at 220 ppm is consistent with a carbonyl group
- The signals between 18 and 40 ppm are consistent with CH and CH_3 groups.

Proton NMR

- There are three distinct hydrogen environments
- The septet (1H) is consistent with a CH adjacent to two CH_3 groups
- The singlet (3H) is consistent with a methyl group with no hydrogens on the adjacent carbon. This is consistent with CH_3CO
- The doublet (6H) is consistent with two methyl groups with one neighbouring hydrogen.

Question 31 (a)

Criteria	Marks
• Evaluates the suitability of the method	3
• Demonstrates a sound understanding of the suitability of the method	2
• Provides some relevant information	1

Sample answer:

Le Chatelier's Principle predicts that as the silver ions precipitate, the complex will decompose to release more silver ions. This disturbs the equilibrium to the left.

$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons \left[Ag\left(NH_3\right)_2\right]^+(aq)$$

This will continue until all of the complex is broken up into its ions, so the value obtained from the titration would be the total of both the free and complex silver ions rather than just the free. Therefore the method is unsuitable.

Question 31 (b)

Criteria	Marks
• Correctly calculates the concentration of ammonia	4
• Provides substantially correct calculations	3
• Provides some correct calculations	2
• Provides some relevant information or working	1

Sample answer:

$$K_{eq} = \frac{\left[\left[\mathrm{Ag(NH_3)_2}\right]^+\right]}{\left[\mathrm{Ag^+}\right]\left[\mathrm{NH_3}\right]^2} = 1.6 \times 10^7$$

$$1.6 \times 10^7 \times \left[\mathrm{NH_3}\right]^2 = \frac{\left[\left[\mathrm{Ag(NH_3)_2}\right]^+\right]}{\left[\mathrm{Ag^+}\right]}$$

Since the concentration of free silver is very low, assume the ratio of free to complex silver is approximately equal to 0.010% (1.0×10^{-4}).

$$\frac{\left[\mathrm{Ag^+}\right]}{\left[\left[\mathrm{Ag(NH_3)_2}\right]^+\right]} = 1.0 \times 10^{-4}$$

$$\frac{\left[\left[\mathrm{Ag(NH_3)_2}\right]^+\right]}{\left[\mathrm{Ag^+}\right]} = 1.0 \times 10^{4}$$

$$1.6 \times 10^7 \times \left[\mathrm{NH_3}\right]^2 = 1.0 \times 10^4$$

$$\left[\mathrm{NH_3}\right]^2 = 6.25 \times 10^{-4}$$

$$\left[\mathrm{NH_3}\right] = 2.5 \times 10^{-2}\ \mathrm{mol\ L^{-1}}$$

Question 32 (a)

Criteria	**Marks**
• Correctly calculates the concentration of the citric acid in the undiluted bottle of carbonated soft drink in mol L^{-1}	6
• Provides substantially correct steps for calculating the concentration of the citric acid	5
• Provides the main calculation steps	4
• Provides some calculation steps	2–3
• Provides some relevant information	1

Sample answer:

Titration 1:

Amount of KHP $= 4.989\text{ g} \div 204.22\text{ g mol}^{-1} = 0.02442953677$ moles

Concentration of KHP $= 0.02442953677\text{ moles} \div 0.1000\text{ L} = 0.2442953677\text{ mol L}^{-1}$

Volume KHP = 25.00 mL
Concentration KHP $= 0.2442953677\text{ mol L}^{-1}$
Amount of KHP $= 0.2442953677\text{ mol L}^{-1} \times 0.02500\text{ L} = 0.00610738419$ moles

Volume NaOH = 27.40 mL
Amount of NaOH = moles KHP = 0.00610738419 moles
Concentration NaOH $= 0.00610738419\text{ moles} \div 0.02740\text{ L} = 0.2228972333\text{ mol L}^{-1}$

Titration 2:

Volume NaOH = 13.10 mL
Concentration of NaOH $= 0.\ 2228972333\text{ mol L}^{-1}$
Amount of NaOH $= 0.2228972333\text{ mol L}^{-1} \times 0.01310\text{ L} = 0.00291995375$ moles

Volume of citric acid = 25.00 mL
The ratio of citric acid to NaOH is 1 : 3
Amount of citric acid = moles NaOH ÷ 3 = 0.00097331791 moles (in 25 mL)
Amount of citric acid in 250 mL $= 0.00097331791\text{ moles} \times \dfrac{250.00\text{ mL}}{25.00\text{ mL}} = 0.0097331791$ moles
Amount of citric acid = 0.0097331791 moles (in 75 mL)

Concentration of citric acid =

$$c = \frac{0.0097331791\text{ mol}}{0.07500\text{ L}}$$

$c = 0.1297757213 = 0.1298\text{ mol L}^{-1}$

Question 32 (b)

Criteria	Marks
• Correctly explains the effect of not removing the carbon dioxide on the calculated concentration of citric acid	2
• Provides some relevant information	1

Sample answer:

Carbon dioxide would react with the NaOH during the titration. A greater volume of NaOH would then have been used than was necessary to neutralise the citric acid resulting in a higher calculated concentration of the citric acid than was correct.

Question 33

Criteria	Marks
• Provides an extensive explanation of the selection of reagents, the reaction conditions, any potential hazards and any safety precautions and the yield and purity of the product produced in the chemical synthesis process • Provides correct and relevant chemical equation • Communicates an extensive understanding succinctly and logically	8
• Demonstrates a thorough knowledge of the factors to consider when designing a chemical synthesis process • Succinct and logical response	6–7
• Demonstrates a sound knowledge of at least two factors to consider when designing a chemical synthesis process	4–5
• Demonstrates basic knowledge of the factors to consider when designing a chemical synthesis process	2–3
• Provides some relevant information	1

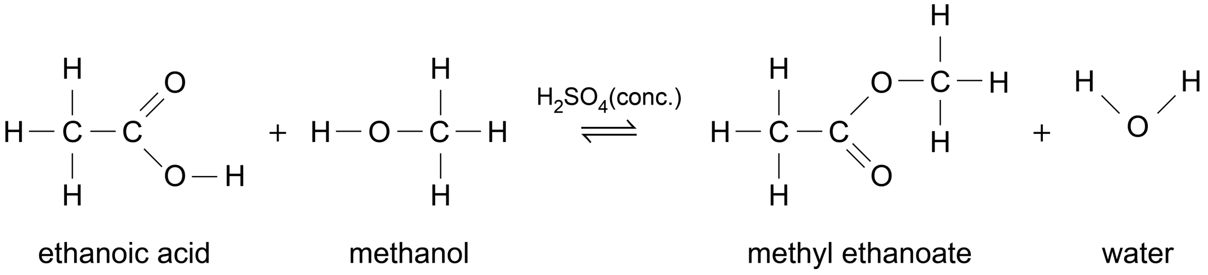
Answers could include:

Process: Esterification

Esterification can be performed in the school laboratory for the acid-catalysed reaction between an alcohol and a carboxylic acid. A student would need to choose an alcohol and carboxylic acid that are relatively non-toxic and readily available. Methanol and ethanoic acid meet these criteria. The reaction also requires an acid catalyst to speed up the reaction, and the acid should be a dehydrating agent as water is produced in the reaction. Concentrated sulfuric acid is therefore suitable.

The reaction between methanol and ethanoic acid produces the ester methyl ethanoate and water.

Chemical equation



Reaction conditions

The conditions for the process must also be considered. In addition to the small amount of concentrated sulfuric acid catalyst, the reaction should be performed under reflux by heating the alcohol, carboxylic acid and concentrated sulfuric acid in a vessel with a condenser tube attached. Reflux enables heat to be used to speed up the reaction without loss of volatile reactants or products and without the build-up of pressure that occurs with a closed vessel reaction.

Safety hazards

- Alcohols are flammable, so do not use open flames. A heating mantle should be used instead of a Bunsen burner.
- Liquid carboxylic acids are corrosive, so wear safety glasses to avoid contact with eyes.
- Concentrated sulfuric acid is corrosive, so only small quantities should be used, and safety glasses must be worn.

Yield and purity

The yield of the reaction is maximised by using a high temperature and reflux for a sufficient time (approximately 30−60 min) but as it is an equilibrium process the reaction mixture will contain methanol, ethanoic acid, water and sulfuric acid as well as the desired methyl ethanoate. This means that the reaction mixture needs to be purified to obtain the methyl ethanoate.

Question 34

Criteria	Marks
• Correctly calculates the volume of solution required	4
• Writes a correct equilibrium expression • Substantially correct calculation	3
• Writes an equilibrium expression and substitutes two correct values	2
• Provides some relevant information	1

Sample answer:

Total NaOCl = $\text{HOCl}_{\text{pool}} + \text{OCl}^{-}{}_{\text{pool}}$

$$\text{pOH} = 14 - \text{pH} = 14 - 7.5 = 6.5$$

$$\left[\text{OH}^-\right] = 10^{-6.5} = 3.16 \times 10^{-7}\ \text{mol L}^{-1}$$

$$\left[\text{HOCl}\right] = 1.3 \times 10^{-4}$$

$$K_{eq} = 3.33 \times 10^{-7} = \frac{\left[\text{OH}^-\right]\left[\text{HOCl}\right]}{\left[\text{OCl}^-\right]}$$

$$\left[\text{OCl}^-\right] = \frac{\left[10^{-6.5}\right] \times \left[1.3 \times 10^{-4}\right]}{\left[3.33 \times 10^{-7}\right]}$$

$$\left[\text{OCl}^-\right] = 1.23 \times 10^{-4}\ \text{mol L}^{-1}$$

$$\left[\text{Cl species}\right] = 1.3 \times 10^{-4}\ \text{mol L}^{-1} + 1.23 \times 10^{-4}\ \text{mol L}^{-1}$$

$$\left[\text{Cl species}\right] = 2.53 \times 10^{-4}\ \text{mol L}^{-1}$$

$$c_1V_1 = c_2V_2$$

$$V_1 = \frac{c_2V_2}{c_1}$$

$$V_1 = V_2 \times \frac{c_2}{c_1} = 1 \times 10^{-4}\text{L} \times \frac{2.53 \times 10^{-4}\ \text{mol L}^{-1}}{2.0\ \text{mol L}^{-1}}$$

$$V_1 = 1.3\ \text{L} = 1\ \text{L}$$

Question 35

Criteria	Marks
• Correctly calculates the K_{sp} value	5
• Provides substantially correct calculation	4
• Provides some relevant steps	2–3
• Provides some relevant working	1

Sample answer:

$n\left(\mathrm{Sr(OH)_2}\right)$ precipitate = 3.93 g ÷ 121.63 g mol^{-1} = 0.03231 mol

$n\left(\mathrm{Sr^{2+}}\right)$ in initial solution = 1.50 mol L^{-1} × 0.0800 L = 0.120 mol

$n\left(\mathrm{Sr^{2+}}\right)$ at equilibrium = 0.120 mol − 0.03231 mol = 0.08769 mol

$\left[\mathrm{Sr^{2+}}\right]$ at equilibrium = 0.8769 mol ÷ 0.1600 L = 0.5481 mol L^{-1}

$n\left(\mathrm{OH^-}\right)$ in initial solution = 0.855 mol L^{-1} × 0.0800 L = 0.0684 mol

$n\left(\mathrm{OH^-}\right)$ at equilibrium = 0.0684 mol – (2 × 0.03231 mol) = 0.00378 mol

$\left[\mathrm{OH^-}\right]$ at equilibrium = 0.00378 mol ÷ 0.1600 L = 0.02363 mol L^{-1}

$K_{sp} = \left[\mathrm{Sr^{2+}}\right]\left[\mathrm{OH^-}\right]^2 = 0.5481 \times (0.02363)^2 = 3.06 \times 10^{-4} = 3.1 \times 10^{-4}$

Question 36

Criteria	Marks
• Provides an explanation for the differences in evaporation for the two systems • Considers changes in enthalpy and entropy	4
• Shows a sound understanding of the differences in evaporation of the two systems • Considers changes in enthalpy AND/OR entropy	3
• Shows some understanding of the differences in evaporation of the two systems AND/OR changes in enthalpy AND/OR entropy	2
• Provides some relevant information	1

Sample answer:

At room temperature the water from the beaker will evaporate, and the water in the bottle will not appear to evaporate. The forward reaction is endothermic. □S would be positive as $H_2O(g)$ has higher entropy than the condensed phase. The forward reaction is non-spontaneous, because □$H > T$□S. The water in the beaker is not at standard conditions. In equilibrium expression terms $Q = [H_2O(g)]$ where $[H_2O(g)]$ is low and therefore $Q < K_{eq}$. Q will remain less than K_{eq} due to the dilution of the evaporated water thus continuously driving the reaction in the forward direction. In the case of the bottle, the $[H_2O(g)]$ will reach a value of $Q = K_{eq}$ and an equilibrium will be established.

2022 HSC Chemistry Mapping Grid

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8	1	Mod 5 Calculating the Equilibrium Constant	12-6, 12-12
9	1	Mod 7 Nomenclature	12-7, 12-14
10	1	Mod 6 Using Brønsted−Lowry Theory	12-5, 12-13
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14	1	Mod 5 Factors that Affect Equilibrium	12-5, 12-12
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Section II

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