Government of **Western Australia**
School Curriculum and Standards Authority

CHEMISTRY

ATAR course examination 2021

Marking key

Marking keys are an explicit statement about what the examining panel expect of candidates when they respond to particular examination items. They help ensure a consistent interpretation of the criteria that guide the awarding of marks.

2021/66878

Section One: Multiple-choice 25% (25 Marks)

Question	Answer
1	d
2	b
3	c
4	a
5	c
6	a
7	b
8	d
9	d
10	a
11	a
12	c
13	d
14	a
15	b
16	c
17	a
18	b
19	d
20	b
21	c
22	d
23	c
24	b
25	a

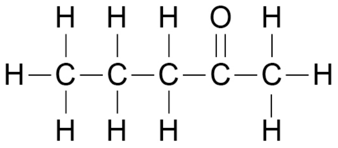
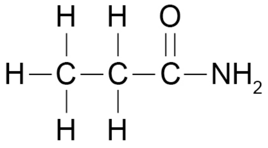
Section Two: Short answer 35% (76 Marks)

Question 26 (8 marks)

A student was given the task of naming and/or drawing the structural formula of some organic compounds. The student, however, made some errors.

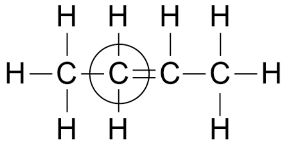
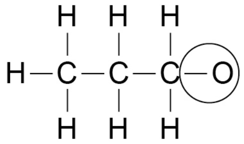
(a) For each of the following organic compounds, state why the name given by the student is incorrect and rename it using IUPAC nomenclature. (4 marks)

Description	Marks
Correct reason for errors	1–2
Correct IUPAC names	1–2
Total	**4**

Structural formula and name given by student	Reason for name being incorrect	IUPAC name
 $CH_3CH_2CH_2COCH_3$ pentan-4-one	Number the chain to give functional group the lowest possible number/incorrect numbering.	pentan-2-one
 $CH_3CH_2CONH_2$ 1-aminopropanone	Incorrect functional groups identified.	propanamide

(b) Circle an error in each structural formula and state why it is an error. (4 marks)

Description	Marks
Errors circled correctly	1–2
Correct reasons for errors identified	1–2
Total	**4**
Note: • Accept other correct responses.	

Student's structural formula	Reason
 $CH_3-CH_2=CH-CH_3$	Recognition that carbon should only have four bonds, e.g. each carbon atom can only form four bonds
 $CH_3CH_2CH_2-O$	Recognition that oxygen must have two single bonds, e.g. H atom missing from oxygen
Note: for first structure, also accept one of the extra Hs circled.	

Question 27 **(11 marks)**

Alcohols exhibit a variety of different chemical properties. For example, some alcohols react with acidified permanganate ions while others do not.

(a) The alcohols in the following table were each heated with excess acidified potassium permanganate solution. Name all organic products formed **during** this process. If there is no reaction, indicate this by writing 'no reaction'. (4 marks)

Name of alcohol	Name(s) of organic compound(s) formed	Marks
2-methylpentan-2-ol	no reaction	1
pentan-1-ol	pentanal **and** pentanoic acid	1 1
pentan-2-ol	pentan-2-one	1
	Total	**4**

(b) Write a balanced overall ionic equation showing the formation of **one** of the organic compounds named in part (a). Only the alcohols listed in the table and acidified potassium permanganate solution can be used. Show your working. (4 marks)

Description	Marks
Oxidation half-equation • correct species • correct balancing	 1 1
Overall redox equation • correct species • correct balancing	 1 1
Total	**4**

Option 1 (pentan-1-ol reacting to form pentanal)
- Oxidation: $C_5H_{12}O(\ell) \rightarrow C_5H_{10}O(\ell) + 2\ H^+(aq) + 2\ e^-$
- Reduction: $MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(\ell)$
- Overall: $5\ C_5H_{12}O(\ell) + 2\ MnO_4^-(aq) + 6\ H^+(aq) \rightarrow 5\ C_5H_{10}O(\ell) + 2\ Mn^{2+}(aq) + 8\ H_2O(\ell)$

or

Option 2 (pentan-1-ol reacting to form pentanoic acid)
- Oxidation: $C_5H_{12}O(\ell) + H_2O(\ell) \rightarrow C_5H_{10}O_2(aq) + 4\ H^+(aq) + 4\ e^-$
- Reduction: $MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(\ell)$
- Overall: $5\ C_5H_{12}O(\ell) + 4\ MnO_4^-(aq) + 12\ H^+(aq) \rightarrow 5\ C_5H_{10}O_2(aq) + 4\ Mn^{2+}(aq) + 11\ H_2O(\ell)$

or

Option 3 (pentan-2-ol reacting to form pentan-2-one)
- Oxidation: $C_5H_{12}O(\ell) \rightarrow C_5H_{10}O(\ell) + 2\ H^+(aq) + 2\ e^-$
- Reduction: $MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(\ell)$
- Overall: $5\ C_5H_{12}O(\ell) + 2\ MnO_4^-(aq) + 6\ H^+(aq) \rightarrow 5\ C_5H_{10}O(\ell) + 2\ Mn^{2+}(aq) + 8\ H_2O(\ell)$

Note:
- No marks allocated for the reduction half equation because it is given in data booklet.
- Equation must use one of the alcohols from part (a) and permanganate ions.
- State symbols are not required for full marks.

(c) The same type of reaction occurs if alcohols are mixed with acidified potassium dichromate solution.

(i) Name this type of reaction. (1 mark)

Description	**Marks**
Oxidation and reduction/redox	1
Total	**1**
Note: • Accept oxidation (of alcohols).	

(ii) State how the reaction observations are different when limited acidified potassium dichromate solution is used instead of limited acidified potassium permanganate solution. (2 marks)

Description	**Marks**
Instead of the reaction colour change being from purple to pale pink/colourless when using acidified permanganate ions.	1
The colour change when using acidified dichromate ions is from orange to deep green.	1
Total	**2**

Question 28 **(9 marks)**

Benzoic acid (C_6H_5COOH) is a weak acid.

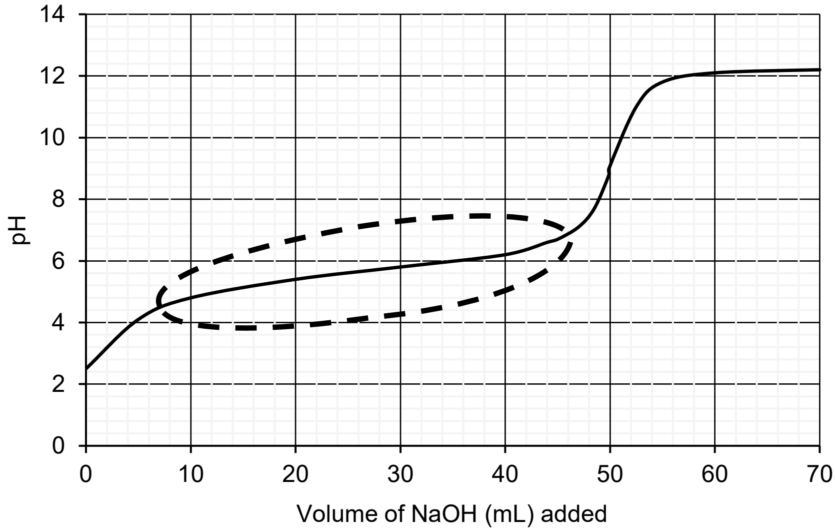
(a) Which of the indicators listed in the following table would be most suitable for use in this titration? With reference to the above titration curve, explain your choice. (3 marks)

Name of Indicator	pH Range
Bromocresol green	3.8–5.4
Azolitmin	4.5–8.3
Cresolphthalein	8.2–9.8
Indigo carmine	11.4–13.0

Description	Marks
The end point of a titration/the indicator changing colour should be as close as possible to the equivalence point.	1
Recognition that the equivalence point of this titration is about pH 9.	1
Therefore, cresolphthalein is the most suitable (because it is the only listed indicator that changes colour at this desired pH).	1
Total	**3**
Note: • No marks allocated for stating that it is a weak acid–strong base titration.	

(b) Buffering is observed during this titration.

(i) Circle the region on the titration curve to show where the buffering occurs. (1 mark)

Description	Marks
	1
Total	**1**

(ii) Define the term buffering and explain why it occurs during this titration in the region that you circled in part (b)(i). Include an equation to support your explanation. (5 marks)

Description	Marks
Buffering is the ability of a solution to resist significant changes to its pH when small quantities of acid or base are added to it.	1
Buffering occurs in the circled region because a weak acid (C_6H_5COOH) and its conjugate base ($C_6H_5COO^-$) are both present.	1
Equation: $C_6H_5COOH(aq) + OH^-(aq) \rightarrow C_6H_5COO^-(aq) + H_2O(\ell)$ **or** $C_6H_5COOH(aq) + H_2O(\ell) \rightleftharpoons C_6H_5COO^-(aq) + H_3O^+(aq)$	1–2
In the buffering region there is no significant/dramatic increase in pH because the added hydroxide ions are consumed by the benzoic acid.	1
Total	**5**
Note: • State symbols are not required in the equation/s. • Equation/s must include the correct arrow/s for full marks to be awarded.	

Question 29 **(7 marks)**

Water can self-ionise.

(a) Show how the tabulated data and Le Châtelier's Principle can be used to deduce whether the self-ionisation of water is exothermic or endothermic. Calculations are not required. (5 marks)

Description	Marks
The data in the table shows that the pH of pure water decreases as the temperature increases.	1
This means that the hydrogen (hydronium) ion concentration increases as the temperature increases.	1
The increase in $[H^+]$ shows the forward reaction (self-ionisation of water) has been favoured at higher temperature.	1
(Le Châtelier's Principle predicts) as temperature increases, the endothermic direction is favoured.	1
The forward reaction (self-ionisation of water) is, therefore, endothermic.	1
Total	**5**

(b) Calculate the $H^+(aq)$ and $OH^-(aq)$ concentrations of pure water at 100.0 °C given that K_w is equal to 5.13×10^{-15} at that temperature. (2 marks)

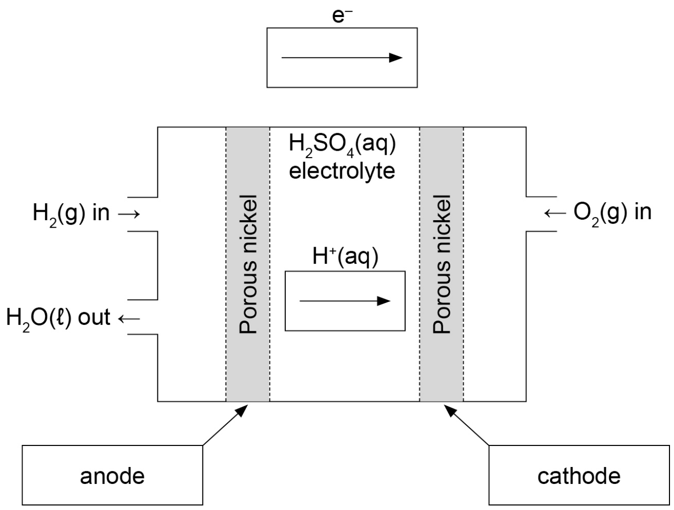
Description	Marks
Recognition that, in pure water, $[H^+] = [OH^-]$ regardless of the temperature	1
$[H^+] = [OH^-] = \sqrt{5.13 \times 10^{-15}} = 7.16 \times 10^{-8}$ mol L^{-1}	1
Total	**2**

Question 30 **(10 marks)**

Fuel cells, such as the one shown in the diagram below, use gaseous hydrogen and oxygen to produce electricity.

(a) Complete the above diagram by adding labels/arrows to show:

- the anode
- the cathode
- the direction of electron flow
- the direction of hydrogen ion flow. (4 marks)

Description	Marks
	1–4
Total	**4**

(b) Write balanced half-equations for the oxidation and reduction reactions and the equation for the overall reaction occurring in this fuel cell. (4 marks)

Description	Marks
Oxidation reaction: $H_2(g) \rightarrow 2\ H^+(aq) + 2e^-$	1
Reduction reaction: $O_2(g) + 4\ H^+(aq) + 4e^- \rightarrow +\ 2\ H_2O(\ell)$	1
Overall redox reaction: $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(\ell)$ • correct species • correct balancing	 1 1
Total	**4**
Note: • State symbols are not required for full marks. • Equations must have merit to award marks for the overall reaction if either half reaction is incorrect, i.e. alkaline fuel cell equation is used.	

(c) This fuel cell typically produces 0.7 V, which is significantly less than the predicted value of 1.23 V. State **two** specific conditions of this cell that would account for this observation. (2 marks)

Description	Marks
Any two relevant points. Answers may include: • The gas pressure is higher than standard pressure. • The cell runs between 25 °C and 90 °C. • Potential energy produced may be converted to heat. • Drop in voltage due to resistance in components.	1–2
Total	**2**

Question 31 **(9 marks)**

Iron corrosion occurs in two stages. During the first stage, an electrochemical cell is established on the iron surface, with electron transfer and Fe^{2+} ion formation occurring.

(a) Write half-equations and the overall balanced equation for the reaction occurring in the above electrochemical cell. State symbols are not required. (4 marks)

Description	Marks
Oxidation half-equation $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$	1
Reduction half-equation $O_2(g) + 4\ H^+(aq) + 4e^- \rightarrow 2\ H_2O(\ell)$ **or** $O_2(g) + 2\ H_2O(\ell) + 4e^- \rightarrow 4\ OH^-(aq)$	1
Redox equation 1 mark for correct species based on the half equations provided 1 mark for correct balancing $2\ Fe(s) + O_2(g) + 4\ H^+(aq) \rightarrow 2\ Fe^{2+}(aq) + 2\ H_2O(\ell)$ **or** $2\ Fe(s) + O_2(g) + 2\ H_2O(\ell) \rightarrow 2\ Fe(OH)_2(s)$	1–2
Total	**4**
Note: • State symbols not required.	

(b) During the second stage of iron corrosion, the newly formed Fe^{2+} ions migrate away from the iron surface and react with water and dissolved oxygen to form rust. The balanced equation for this reaction is shown below.

$$4\ Fe^{2+}(aq) + O_2(g) + 6\ H_2O(\ell) \rightarrow 2\ Fe_2O_3.H_2O(s) + 8\ H^+(aq)$$

Use oxidation numbers to show that this reaction is a redox reaction. (2 marks)

Description	Marks
The oxidation number of iron changes (increases) from +2 to +3.	1
The oxidation number of oxygen changes (decreases) from 0 to –2.	1
Total	**2**

A corrosion chemist inspected an outdoor playground and found that most of the equipment containing iron showed signs of corrosion. The chemist suggested several different methods for protecting the playground equipment from further corrosion, including the use of sacrificial anodes.

(c) State what is a sacrificial anode. (1 mark)

Description	Marks
A sacrificial anode is a piece of metal (that is connected to another metal) that is more easily oxidised/corroded than the metal being protected from corrosion (and so oxidises in preference to the metal being protected).	1
Total	**1**

Question 31 (continued)

(d) State the name of a metal that can be used as a sacrificial anode to protect the equipment from further corrosion. Use Standard Reduction Potentials to justify your choice. (2 marks)

Description	Marks
Name of one specific metal that is below iron on the Standard Reduction Potential Table (chromium, zinc, manganese, or magnesium).	1
Statement acknowledging that the selected metal has a more negative E° for reduction (or a more positive E° for oxidation) when compared to iron.	1
Total	**2**
Note: • Do not accept reactive Group 1 metals or calcium.	

Question 32 **(14 marks)**

Ammonia is manufactured industrially by the Haber process, the reaction equation being:

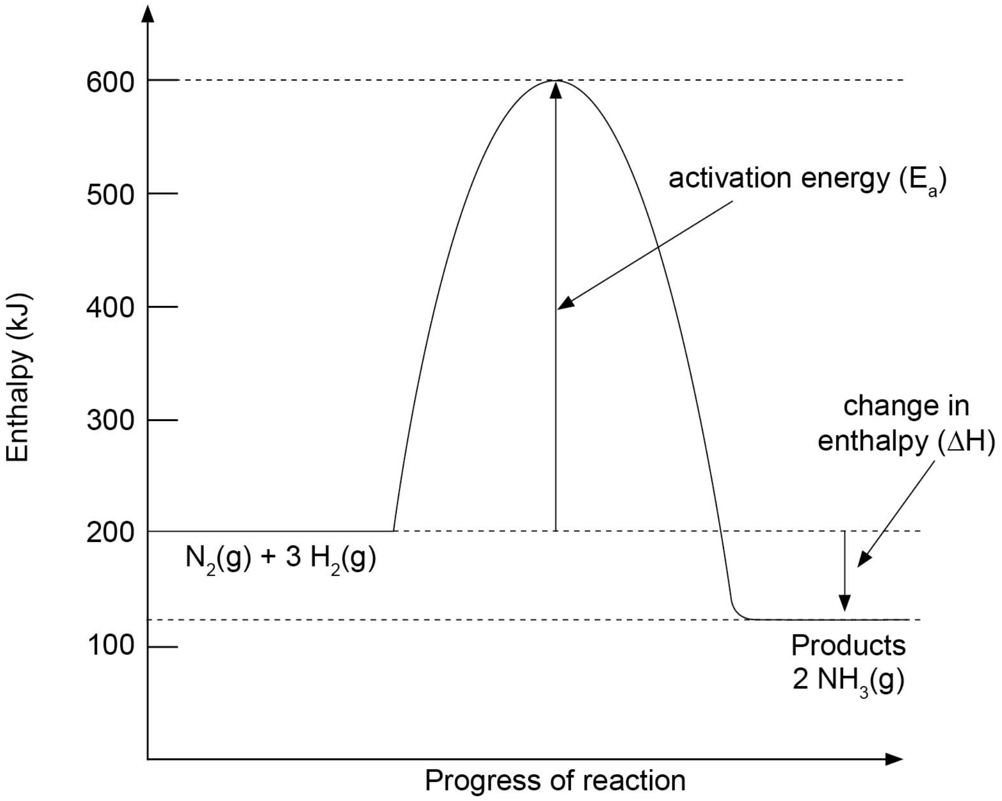
$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g) + 92\ kJ$$

(a) Write the equilibrium constant expression for this reaction. (2 marks)

Description	Marks
Products over reactants with appropriate brackets	1
Inclusion of correct indices	1
Total	**2**
$K=\frac{[NH_3]^2}{[N_2][H_2]^3}$ or $K=\frac{p(NH_3)^2}{p(N_2)p(H_2)^3}$	

(b) Use the following axes to sketch an energy profile diagram for the Haber process. Label the:

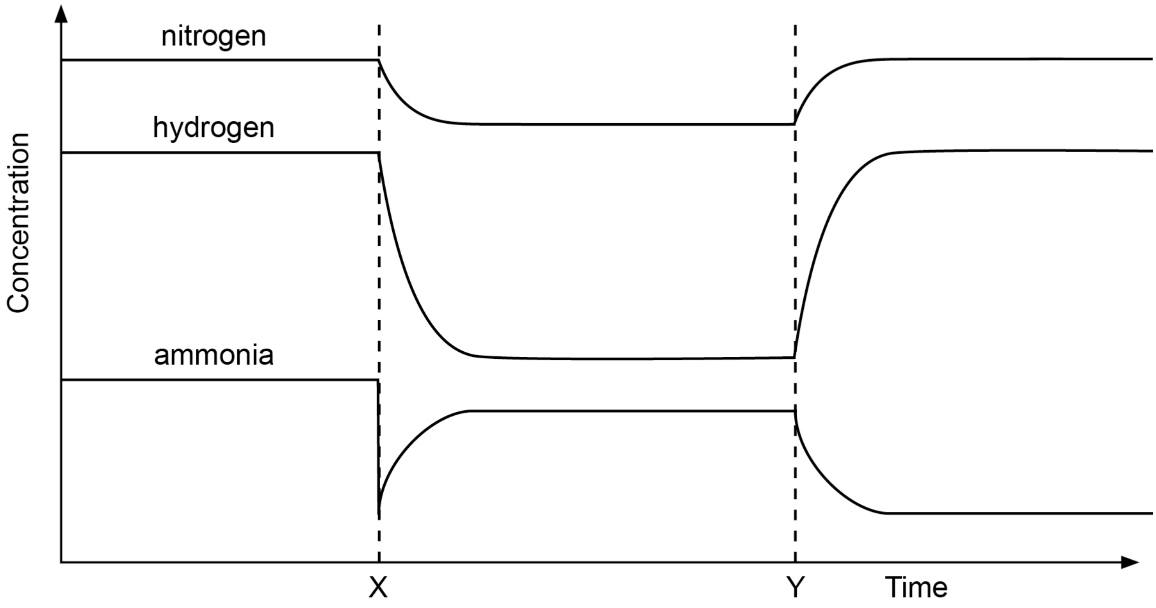
- axes
- products
- activation energy
- change in enthalpy. (4 marks)



Description	Marks
Labelling x-axis and y-axes, including units for y-axis	1
Peak goes up to 600 kJ and the activation energy (E_a) is labelled	1
The change in enthalpy is labelled and is equal to approximately -92 kJ	1
Products are labelled	1
Total	**4**

Question 32 (continued)

Some hydrogen, nitrogen and ammonia were sealed inside a reaction vessel and their concentrations were monitored for a period of time, as shown in the following graph.



(c) A change was made to the reaction system at time X. Identify this change and use collision theory to explain the shapes of the curves in the region X–Y. (5 marks)

Description	Marks
Ammonia was (instantaneously) removed from the system (at equilibrium/with the rate of the forward reaction equal to the rate of the reverse reaction).	1
(The reduced concentration of ammonia molecules) results in a lower frequency of collisions between ammonia molecules and as a result lowering the rate of the reverse reaction.	1
The rate of the forward reaction is now higher than the reverse reaction.	1
Which results in an increase in concentration of ammonia and a decrease in the concentrations of hydrogen and nitrogen.	1
This continues until the rates of forward and reverse reactions are equal; (establishing a new equilibrium) and the concentrations are then constant.	1
Total	**5**

(d) The temperature of the reaction system was increased at time Y. Show on the graph how this affected the concentrations of hydrogen, nitrogen and ammonia as the system returned to equilibrium. (3 marks)

Description	Marks
Curved lines showing direction of change for all three species.	1
Stoichiometric ratios correct.	1
All three reaching equilibrium at the same time.	1
Total	**3**

Question 33 **(8 marks)**

Ethanol (C_2H_5OH) dissolves readily in water, while decan-1-ol ($C_{10}H_{21}OH$) has very limited solubility. Explain, with the aid of labelled diagrams, why ethanol is able to dissolve in water, and decan-1-ol is not.

Description	Marks
A detailed, coherent response consisting of the majority of the points below: Energy response • In order for a solute to dissolve in a solvent the energy released in the formation of the intermolecular forces between the solute and solvent are sufficient to overcome the existing intermolecular forces between the solute molecules and the solvent molecules. • Both alcohols form dispersion forces and hydrogen bonds with water. • Ethanol and water both have hydrogen bonding as their predominant type of intermolecular force. • The energy required to disrupt the hydrogen bonds in the ethanol and water are comparable to the energy released during the formation of the hydrogen bonds between the ethanol and water molecules and so dissolution occurs. • The predominant type of intermolecular force in decan-1-ol is dispersion forces. • The energy released during the formation of dispersion forces with water and decan-1-ol is not sufficient to disrupt the dispersion forces between the decan-1-ol molecules and so dissolving does not occur. **or** Strength of attraction response • In order for a substance to dissolve, the strength of intermolecular forces formed must be sufficient to disrupt the intermolecular forces between the solute molecules and between the solvent molecules. • Both alcohols form dispersion forces and hydrogen bonds with water. • When ethanol dissolves in water, hydrogen bonds are their predominant forces of attraction between the water and the ethanol molecules. • The strength of the hydrogen bonds formed are sufficient to overcome the hydrogen bonds between the water molecules and the hydrogen bonds between the ethanol molecules and so dissolution occurs. • The predominant type of intermolecular force in decan-1-ol is dispersion forces. • The strength of the dispersion forces formed between decan-1-ol molecules and water is insufficient to disrupt the dispersion forces between the (much larger) decan-1-ol molecules and so dissolving does not occur.	1–6
Appropriate labelled diagrams showing interactions between solute and solvent, for example • Diagram showing the hydrogen bonding between the ethanol and water molecules. • Diagram showing the dispersion forces between decan-1-ol.	1–2
Total	**8**

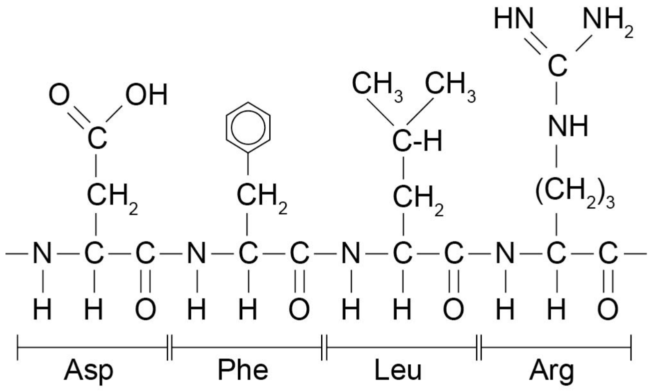
Section Three: Extended answer 40% (90 Marks)

Question 34 (13 marks)

Keratin 86 is a protein found in human fingernails. A small section of the amino acid sequence of Keratin 86 is shown below:

– Asp – Phe – Leu – Arg –

(a) Draw the full structural formula of this small section of Keratin 86. (3 marks)

Description	Marks
The four amino acids are correctly represented in the appropriate order	1
Peptide linkages are correctly drawn	1
Peptide chain not terminated at either end	1
Total	**3**
 	
Note: • Showing abbreviations of the amino acids under the structure is not required.	

The amino acid chains in Keratin 86 form α-helices, with two α-helices twisting around each other to form what is called a ‘coiled coil’ that is held together by disulfide bridges.

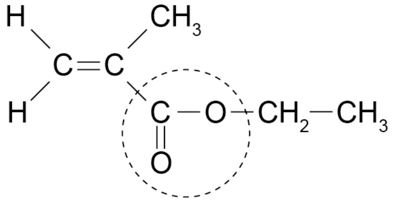
(b) Circle the protein structural level represented by an α-helix. (1 mark)

Description	Marks
secondary	1
Total	**1**

(c) What does the presence of disulfide bridges indicate about the primary structure of Keratin 86? (1 mark)

Description	Marks
(The amino acid) cysteine is present.	1
Total	**1**

Synthetic fingernails are a popular fashion accessory. They are made in industrial laboratories from polymers. A monomer that can be used to make a polymer suitable for synthetic fingernails is shown below.



(d) Name the circled functional group in this monomer. (1 mark)

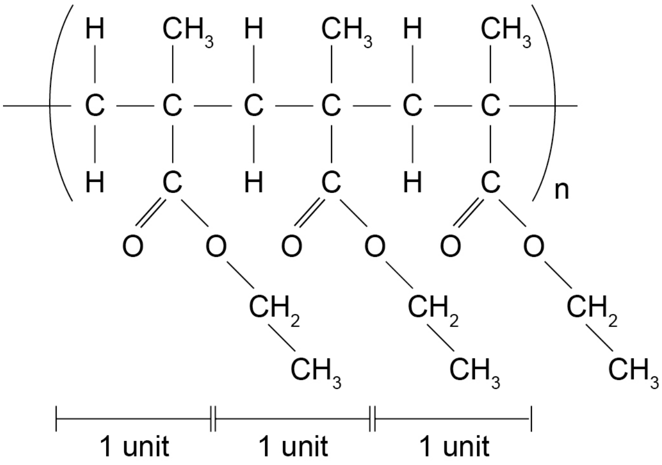
Description	Marks
ester	1
Total	**1**

(e) Give the IUPAC name of the alcohol needed to make this monomer. (1 mark)

Description	Marks
ethanol	1
Total	**1**

(f) Draw **three** repeating units of the polymer made from this monomer. (2 marks)

Description	Marks
The three monomers are correctly represented	1
Monomers are correctly linked	1
Total	**2**



Minor errors include:

- terminating either end of the chain
- missing or too many hydrogen atoms
- bond lines connecting to wrong atom (e.g. to a hydrogen instead of a carbon)

Note:

- 1 mark for minor error

Question 34 (continued)

The protein which makes natural fingernails, Keratin 86, is also a polymer.

(g) What type of polymerisation reaction produces Keratin 86 and what type produces synthetic fingernails? (2 marks)

Polymer	Type of polymerisation reaction	Marks
Keratin 86	condensation	1
Synthetic fingernail polymer	addition	1
	Total	**2**

(h) State **two** differences between the polymerisation reaction types identified in part (g). (2 marks)

Description	Marks
Any **two** relevant points. Answers could include: • Condensation polymerisation produces small molecules such as water, addition does not. • Addition polymerisation involves the conversion of a C=C double bond to a single bond, condensation does not. • Condensation polymerisation can result in the formation of, for example, polyamides or polyesters, addition does not. • Condensation polymerisation involves the reaction of monomers with different functional groups to form bonds in the polymer, addition does not. • Addition polymerisation produces a polymer which has the same empirical formula as its monomer, this is not the case in condensation polymerisation.	1–2
Total	**2**
Note: • Each difference needs to refer to both condensation and addition to be allocated the mark.	

Question 35 **(12 marks)**

The perchloric acid/acetic acid solution must be standardised before use and this can be done by titrating it with a solution made from a primary standard.

(a) Other than possessing a relatively high molar mass, state **two** characteristics required of a substance for it to be used as a primary standard. (2 marks)

Description	Marks
Any two relevant points. Answers could include: • available in very high purity • known purity • very low reactivity with CO_2 and/or O_2 • not deliquescent • not hygroscopic • predictable reactivity • (highly) soluble.	1–2
Total	**2**
Note: • For (highly) soluble, accept '(highly) soluble in water', even though these titrations are not performed in an aqueous medium.	

(b) Complete the following table by writing the name of the most suitable piece of equipment to use for each task. (3 marks)

Task	Piece of equipment to use	Marks
Making exactly 100.0 mL of nicotine-containing solution	volumetric flask	1
Measuring a 20.0 mL aliquot of the nicotine-containing solution	pipette	1
Adding the perchloric acid/acetic acid solution to the nicotine-containing solution	burette	1
	Total	**3**

(c) Use the chemist's titration data to identify the nicotine dosage of the patches in the unlabelled boxes. Show all of your working.

The molecular formula of nicotine is $C_{10}H_{14}N_2$ and the titration reaction is:

$$C_{10}H_{14}N_2 + 2\ CH_3COOH_2^+ \rightarrow C_{10}H_{16}N_2^{2+} + 2\ CH_3COOH$$ (7 marks)

Description	Marks
n(acid) in 15.11 mL = cV = 0.0483 × 0.01511 = 7.298×10^{-4} mol	1
n(nicotine) in 20.0 mL = $\frac{1}{2}$ × 0.000730 = 0.000365 mol	1
n(nicotine) in 100.0 mL = 0.000365 × 5 = 0.00182 mol	1
M(nicotine) = (10 × 12.01) + (14 × 1.008) + (2 × 14.01) = 162.232 g mol^{-1}	1
m(nicotine) in 100.0 mL = 162.232 × 0.00182 = 0.296 g	1
m(nicotine) in 1 patch = 0.296/14 = 0.0211 g	1
thus the boxes contain 21 mg patches	1
Total	**7**

Question 36 **(17 marks)**

Glycoluril is an organic compound composed of carbon, hydrogen, nitrogen and oxygen atoms.

(a) Determine the empirical formula of glycoluril. (12 marks)

Description	**Marks**
Carbon dioxide • $n(CO_2) = 2.85/44.01 = 0.06476$ mol CO_2 • $n(C) = 0.06476$ mol • $m(C) = 0.06476 \times 12.01 = 0.7777$ g	1
Water • $n(H_2O) = 0.874/18.016 = 0.04851$ mol H_2O • $n(H) = 2 \times 0.04851 = 0.09702$ mol of H • $m(H) = 0.09702 \times 1.008 = 0.09780$ g	1 1
Nitrogen • $n(H_2SO_4$, total$) = 1.35 \times 0.025 = 0.03375$ mol • $n(NaOH) = 0.186 \times 0.01540 = 0.002864$ mol • $n(H_2SO_4$ that reacted with NaOH$) = \frac{1}{2} \times 0.00286 = 0.001432$ mol • $n(H_2SO_4$ reacted with $NH_3) = 0.03375 - 0.001432 = 0.03232$ mol • $n(NH_3) = 2 \times 0.03232 = 0.06464$ mol = n(N from glycouril) • m(N from glycoluril sample) = $0.06464 \times 14.01 = 0.9056$ g	1–6
Oxygen • $2.30 - (0.7777 + 0.09780 + 0.9056) = 0.5189$ g • $n(O) = 0.5189/16.00 = 0.03243$ mol	1
<u>Mole ratio</u> C H N O Calculated moles 0.06476 0.09702 0.06464 0.03243 Divide all numbers for smallest figure 0.03243 Mole ratio 1.997 2.992 1.993 1.00 Simplified 2 3 2 1	1
Empirical formula is $C_2H_3N_2O$	1
Total	**12**
Note: % C in glycoluril = (0.778/2.3) × 100 = 33.81% % H in glycoluril = (0.0978/2.3) × 100 = 4.25% % N in glycoluril = (0.906/2.3) × 100 = 39.37% % O in glycoluril = (100 – 33.81 – 4.25 – 39.37) =22.57%	

(b) Another 2.30 g sample of glycoluril was vapourised at 242.0 kPa and 865.0 °C. The total volume of the resulting gas was 633.0 mL. Determine the molecular formula of glycoluril. (5 marks)

Description	**Marks**
T = 865.0 + 273.15 = 1138.15 K $n = PV/RT = 242.0 \times 0.633/8.314 \times 1138.15 = 0.01619$ mol	1
M (molecular) = 2.30/0.01619 = 142.081 g mol^{-1}	1
M (empirical) = 71.064 g mol^{-1}	1
Ratio of molecular to empirical: 142.081/71.064 = 1.999 = 2	1
Molecular formula of glycoluril is $2 \times C_2H_3N_2O = C_4H_6N_4O_2$	1
Total	**5**

Question 37 **(18 marks)**

A chemist was asked to develop a method of recycling used cathodes from a new type of lithium battery. The cathodes were a mixture of lithium cobalt oxide ($LiCoO_2$) and manganese (Mn). Each cathode contained 57.29 % cobalt by mass.

(a) (i) Which trial number(s) will allow the chemist to investigate the relationship between the sulfuric acid concentration and the amount of cobalt extracted? (1 mark)

Description	Marks
Trials 1, 2, 4 and 5	1
Total	**1**

(ii) Use collision theory to explain the effect of acid concentration on the rate at which the used cathodes dissolved. (3 marks)

Description	Marks
The higher the acid concentration the faster the used cathodes dissolved.	1
Using collision theory, the higher the H^+ concentration, the greater the frequency of collisions between H^+ ions and the used cathode components.	1
When there is a higher frequency of collisions occurring between the reactants, the rate of reaction (used cathode dissolution) is faster.	1
Total	**3**

(b) Do Fe^{2+} ions catalyse the dissolution of cobalt in sulfuric acid? Justify your answer. (3 marks)

Description	Marks
Yes, the Fe^{2+} catalyses the reaction.	1
Trials using Fe^{2+}dissolve more Co from the cathode in the time given (in trials 5 and 6).	1
Fe^{2+} is a catalyst because it was not consumed (in trials 3 and 6).	1
Total	**3**

(c) Would the used cathodes dissolve completely in Trial 2 assuming enough time was allowed? Support your answer with relevant calculations.

The dissolution reaction is:

$$2\ LiCoO_2(s) + Mn(s) + 8\ H^+(aq) \rightarrow 2\ Li^+(aq) + 2\ Co^{2+}(aq) + Mn^{2+}(aq) + 4\ H_2O(\ell)$$

(7 marks)

Description	Marks
m(Co in electrode) = 0.5729 × 531 = 304.21 g	1
n(Co) = 304.21/58.93 = 5.1622 mol	1
n(Co) = n($LiCoO_2$) = 5.1622 mol	1
m($LiCoO_2$) = 5.1622 x 97.87 = 505.2 g	1
m(Mn) = 531 – 505.2 = 25.78 g	1
n(Mn) = 25.78/54.94 = 0.4692 mol	1
n(Mn) < $\frac{1}{2}$ n($LiCoO_2$), therefore the cathodes will not dissolve completely.	1
Total	**7**

Question 37 (continued)

(d) Calculate the percentage, by mass, of lithium in a used cathode. Give your answer to the appropriate number of significant figures. (4 marks)

Description	**Marks**
n(Li) = n(Co) = 5.16 mol	1
m(Li) = 5.16 × 6.94 = 35.81 g	1
% Li in a spent electrode = 35.81/531 × 100 = 6.74%	1
% Li is given correct to 3 significant figures	1
Total	**4**
Note: If student correctly determines %Li from an incorrect value from part (c), still award full marks.	

Question 38 **(12 marks)**

Sulfuric acid is manufactured by the Contact process.

Use your understanding of collision theory and chemical equilibrium to discuss the reaction conditions for Steps 1 and 2 of the Contact process, given the aim is to produce the greatest yield in the shortest time. In your discussion, address economic concerns where appropriate.

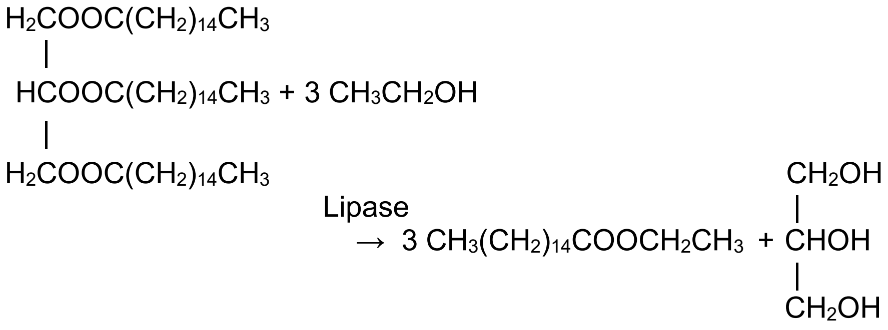
Description	Marks
Rates • High temperature increases the average kinetic energy of the particles, which means that the particles collide more frequently. • Also, more of these collisions will have energy higher than the activation energy, which means a greater proportion of collisions are successful, and the reaction rate increases. • The vanadium catalyst increases the rate of the forward reaction (and also the rate of the reverse reaction to an equal extent) as it provides an alternative pathway with a lower activation energy. • (Therefore, a greater proportion of the particles will have sufficient energy to react when they collide.) • High pressure (concentration) has more particles per unit volume and so there is a higher frequency of collisions, and the reaction rate increases. • As Step 1 is a combustion reaction, it essentially goes to completion at the high temperature (and does not require a catalyst or high pressure). • For Step 2, high temperature, high pressure and catalyst would favour high rate.	1–6
Equilibrium Only considered for Step 2 • High temperature favours the reverse reaction because it is endothermic, and this decreases the $SO_3(g)$ yield (which is not desired). • A low temperature decreases the rate of reaction (which is also not desired). • A high pressure favours the forward reaction because there are a greater number of moles of gas reactants, (increasing the $SO_3(g)$ yield which is desired).	1–3
Economics High pressures are costly (and dangerous).	1
Compromise • For Step 2, a compromise is required between the high temperature for rate and the low temperature for yield. • A compromise is also required between the cost of higher pressures and the pressure that allows a satisfactory yield and rate.	1–2
Total	**12**

Question 39 **(18 marks)**

The oil extracted from the seeds of a particular Australian tree contains tripalmitin.

(a) Demonstrate, by using a series of balanced reaction equations, how ethyl palmitate can be synthesised from tripalmitin. Your synthesis method **must** use ethene and lipase. You can also use water and any common laboratory acids.

Use condensed structural formulae to represent organic compounds. State symbols are only required for inorganic substances. (8 marks)

Description	Marks
Alcohol synthesis: $CH_2CH_2 + H_2O\,(g) \xrightarrow{H^+} CH_3CH_2OH$ • 1 mark for reactants • 1 mark for products • 1 mark for specifying a suitable catalyst (e.g. H_2SO_4/H_3PO_4) which can be written above the arrow or as a separate statement • 1 mark for correctly having H_2O in gas state	1–4
Biodiesel synthesis:  $\begin{array}{l} H_2COOC(CH_2)_{14}CH_3 \\ \quad \vert \\ HCOOC(CH_2)_{14}CH_3 + 3\ CH_3CH_2OH \\ \quad \vert \\ H_2COOC(CH_2)_{14}CH_3 \end{array} \xrightarrow{\text{Lipase}} 3\ CH_3(CH_2)_{14}COOCH_2CH_3 + \begin{array}{l} CH_2OH \\ \vert \\ CHOH \\ \vert \\ CH_2OH \end{array}$ • 1 mark for reactants • 1 mark for products • 1 mark for correct balancing • 1 mark for having lipase as the catalyst, written above the arrow or as a separate statement	1–4
Total	**8**

A chemist investigated the synthesis step involving lipase referred to in part (a). The results obtained by the chemist are shown in the following table:

Temperature of reaction system (°C)	**Biodiesel yield (%)**
20	65
30	78
35	85
40	88
50	91
55	92
60	85
65	75

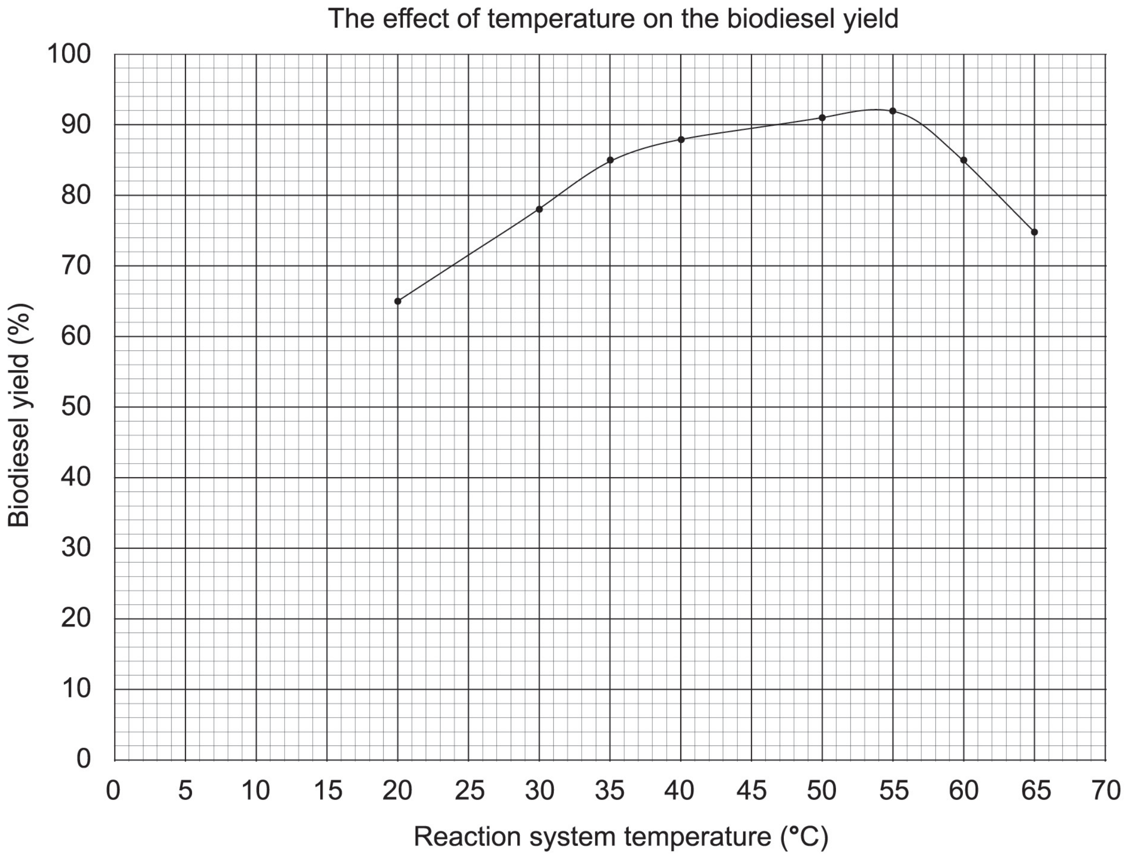
(b) Construct a question that the chemist might be trying to answer in this investigation.

(1 mark)

Description	**Marks**
A question recognising that the relationship between temperature and biodiesel yield is being investigated.	1
Total	**1**
Note: Any reasonable relevant question accepted. E.g. • What is the optimum temperature required to maximise the yield of biodiesel using lipase? • What is the effect of temperature on the yield of biodiesel? • Does temperature affect the yield of biodiesel?	

Question 39 (continued)

(c) Graph the data presented in the table on the following grid. (5 marks)



Description	Marks
Suitable title linking yield to temperature	1
Suitable scales on both axes	1
x-axis labelled as temperature (°C), y-axis labelled as biodiesel yield (%)	1
Plotting data correctly	1
Curve of best fit	1
Total	**5**
Note: • Must have correct identification of both axes and units to be awarded the mark.	

(d) Describe the relationship observed in the graph. (2 marks)

Description	Marks
The graph shows that the biodiesel yield increases (steadily) as the temperature increases, reaching a maximum at 55 °C.	1
The yield decreases at higher temperatures.	1
Total	**2**

(e) Explain how the use of lipase in the synthesis contributes to this relationship described in part (d). (2 marks)

Description	Marks
Lipase is an enzyme/protein.	1
Any one of • Enzymes/proteins are deactivated/denatured at higher temperatures (and lose their effectiveness hence the lower biodiesel yield at higher temperatures). • Lipase will not contribute to the relationship as a catalyst increase rate of forward and reverse reaction equally/does not affect yield.	1
Total	**2**

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