South Australian
Certificate of Education

1

Chemistry
2023

Question booklet 1

- Questions 1 to 4 (61 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 12 if you need more space
- Allow approximately 65 minutes

Examination information

Materials
- Question booklet 1
- Question booklet 2
- Periodic table and data sheet
- SACE registration number label

Instructions
- Use black or blue pen
- You may use a sharp dark pencil for diagrams and other representations
- Approved calculators may be used

Total time: 130 minutes
Total marks: 120

Attach your SACE registration number label here

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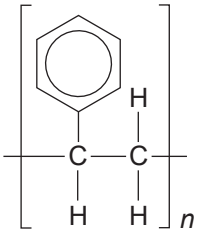
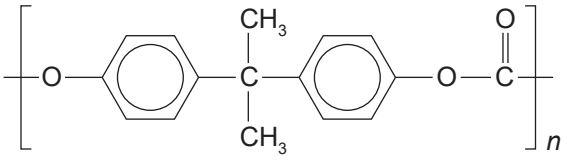
1. The sport of road cycling has been influenced by advances in materials science and analytical chemistry techniques.

(a) Bicycle helmets contain two types of thermoplastics. The interior is made of polystyrene while the exterior is made of polycarbonate. The structural formulae of the two thermoplastics are shown below.



polystyrene



polycarbonate

(i) Draw the structural formula of the monomer used to create polystyrene.

(2 marks)

(ii) Some physical properties of the two polymers are shown in the table below.

Polymer	*Melting temperature range* (°C)	*Density range* ($g\ L^{-1}$)	*Comparative hardness*
polystyrene	170–280	0.96–1.05	90
polycarbonate	280–320	1.20–1.22	120

With reference to the structures of polystyrene and polycarbonate, explain the difference in the physical properties of the two polymers.

(4 marks)

(b) Thin layer chromatography (TLC) is one technique used to detect whether a cyclist could be using performance-enhancing drugs.

The retardation factors (R_F) for some banned substances that could be found in the urine of cyclists are shown in the table below. The same stationary and mobile phases and conditions were used for all measurements. The stationary phase was more polar than the mobile phase.

Table of R_F values

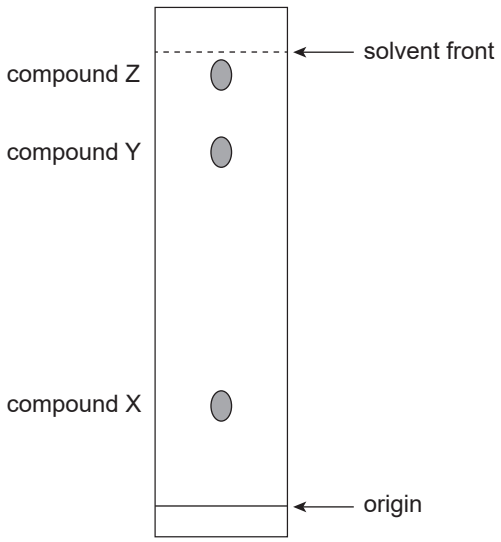
Banned substance	*Retardation factor, R_F*
acetazolamide	0.40
dextroamphetamine	0.58
stanozolol	0.95

(i) Explain whether stanozolol is more polar or less polar than acetazolamide.

(3 marks)

(ii) A cyclist's urine sample produced the following chromatogram using TLC with the same stationary and mobile phases and conditions as the table of R_F values above.

Explain which of the three banned substances in the Table of R_F values could be present in the cyclist's urine using evidence from the chromatogram.



(2 marks)

PLEASE TURN OVER

2. Australia has large mineral reserves from which metals, including nickel and lithium, can be extracted.

(a) Nickel can be extracted from its minerals using carbon reduction, but lithium can only be extracted from its minerals by electrolysis of a molten lithium mineral.

Explain why it is possible to extract nickel from its minerals using carbon reduction while lithium can only be extracted from its minerals by electrolysis of a molten lithium mineral.

_____

_____

_____

_____ (2 marks)

(b) Garnierite, $Ni_3Mg_3Si_4O_{10}(OH)_8$, is an important mineral containing nickel(II) ions, Ni^{2+}.

(i) Using subshell notation, write the electron configuration of Ni^{2+}.

_____ (2 marks)

(ii) Write the formula of the silicate anion in garnierite.

_____ (2 marks)

(c) Ni^{2+} is also found in sulfide minerals. Nickel is extracted from these minerals in a series of processes.

After concentration, the nickel(II) sulfide mineral, NiS, is heated in a furnace in the presence of oxygen-enriched air to produce nickel(II) oxide and the by-product sulfur dioxide.

(i) Write an equation for the reaction that occurs in the furnace.

(2 marks)

(ii) Explain what it means to call sulfur dioxide a by-product rather than a waste product.

_____

_____

_____

_____ (2 marks)

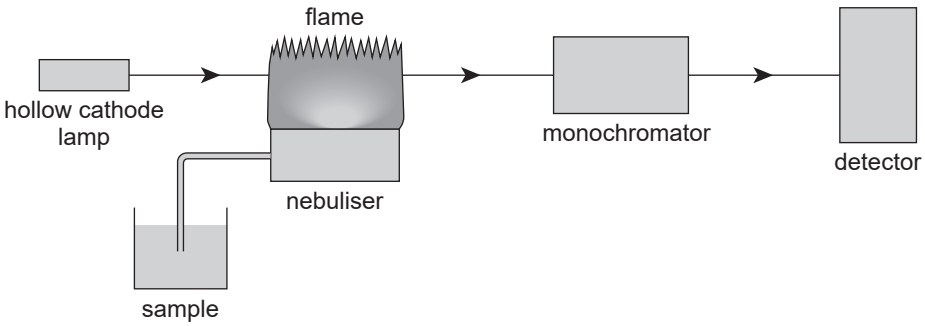
(d) Exposure to Ni^{2+} can cause health problems, so it is important that concentrations of Ni^{2+} in wastewater from nickel-extraction processes are monitored.

(i) Atomic absorption spectroscopy (AAS) can be used to measure the concentration of Ni^{2+} ions in wastewater.

(1) Explain why some wavelengths of radiation emitted and absorbed by Ni^{2+} are unique to nickel.

(3 marks)

(2) A simplified diagram of the components of an AAS apparatus is shown below.



Explain why the light that has passed through the flame must pass through a monochromator.

(2 marks)

Question 2 continues on page 6.

(ii) The wastewater from nickel extraction processes is often stored for decades in ponds called tailings ponds. A major concern with tailings ponds is the potential for leaks due to structural damage to the pond caused by age, earth movement, or extreme weather. Leaks allow toxic particles contained in the tailings ponds, such as Ni^{2+}, to escape into the surrounding environment.

Scientists in Indonesia have been investigating the use of certain bacteria to reduce the concentration of Ni^{2+} in wastewater stored in tailings ponds. This process is called bioremediation. The scientists found that adding a specific type of bacterium reduced the concentration of Ni^{2+} by 85%.

(1) With reference to the science as a human endeavour key concept of 'Application', explain how this investigation could benefit society.

_____

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_____ (3 marks)

(2) Suggest a possible 'Limitation' to this use of bioremediation.

_____

_____

_____ (1 mark)

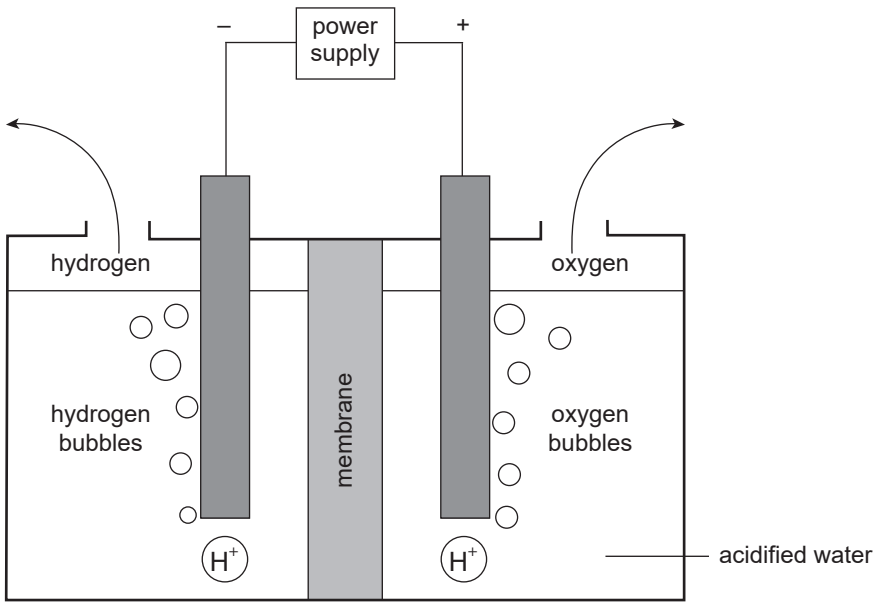
3. E-fuels are synthetic fuels that are manufactured from hydrogen and carbon dioxide gases. This carbon dioxide has been captured from the atmosphere or factory emissions. E-fuels are an alternative to fossil fuels and biofuels.

(a) Currently, most hydrogen gas is produced from steam and hydrocarbons sourced from fossil fuels. However, the hydrogen gas used in the manufacture of e-fuels is produced by electrolysis of water using renewable electricity sources.

(i) Describe *one* benefit of producing hydrogen from the electrolysis of water rather than from fossil fuels.

(2 marks)

(ii) A simplified diagram of an electrolytic cell used for the production of hydrogen is shown below.



(1) Write a half-equation for the reaction occurring at the cathode.

(2 marks)

(2) *On the diagram above*, draw an arrow indicating the direction of movement of one of the circled hydrogen ions in the electrolyte.

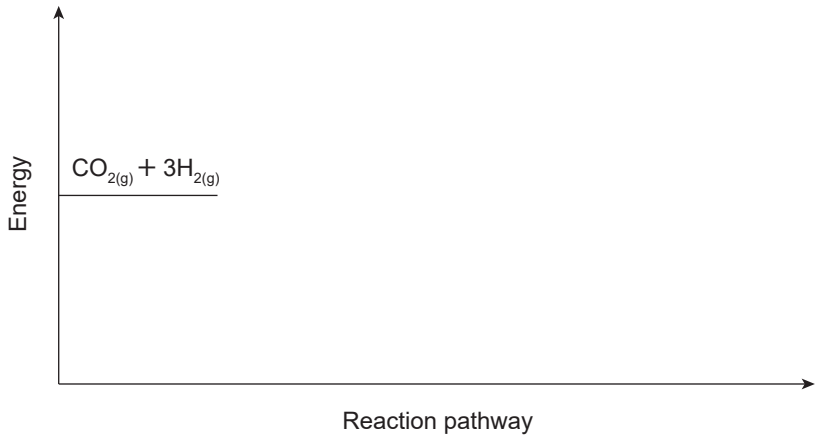
(1 mark)

(b) Methanol, CH_3OH, can be manufactured as an e-fuel.

The equation for the reaction between carbon dioxide and hydrogen to produce methanol is shown below.

$$CO_{2(g)} + 3H_{2(g)} \rightleftharpoons CH_3OH_{(g)} + H_2O_{(g)} \qquad \Delta H = -49.16 \text{ kJ mol}^{-1}$$

(i) *On the axes below*, draw an energy profile diagram for this reaction. Label the activation energy and the enthalpy change on your diagram.



(3 marks)

(ii) A series of trials were conducted at the same temperature to determine the equilibrium constant, K_c, for this reaction.

(1) Write the K_c expression for this reaction.

(2 marks)

(2) In one trial, the equilibrium concentrations of the gases were recorded, as shown in the table below.

Gas	CO_2	H_2	CH_3OH	H_2O
Equilibrium concentration (mol L^{-1})	0.294	0.118	0.00192	0.00192

Calculate the value of K_c.

(1 mark)

(3) State what your calculated K_c value in part (b)(ii)(2) indicates about the position of the equilibrium at this temperature.

_____

_____ (1 mark)

(iii) In the methanol production process, the CH_3OH and H_2O are removed from the equilibrium mixture as they form.

In terms of Le Châtelier's principle, explain how this removal helps maximise profit for the manufacturer of methanol.

_____

_____

_____

_____

_____

_____ (3 marks)

(iv) The manufacture of methanol e-fuel removes carbon dioxide from the atmosphere.

Explain whether or not the manufacture and subsequent combustion of methanol e-fuel will result in a decrease in the concentration of carbon dioxide in the atmosphere.

_____

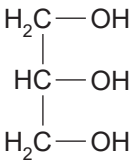
_____

_____

_____ (2 marks)

4. Cosmetics contain a variety of organic and inorganic compounds.

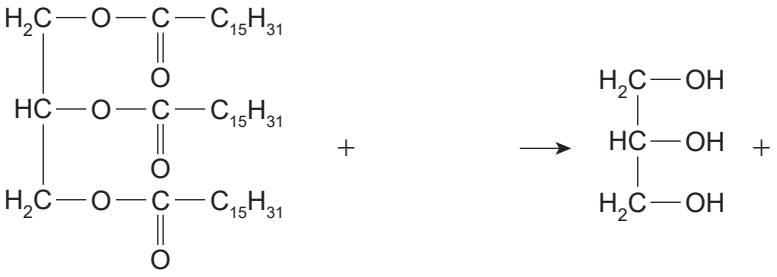
(a) Glycerol is a common organic component found in face creams. The structural formula of glycerol is shown below.



glycerol

(i) Glycerol is one product of the alkaline hydrolysis of triglycerides.

Complete and balance the equation below to illustrate the production of glycerol from the triglyceride shown.



triglyceride **glycerol**

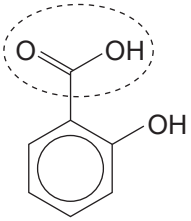
(2 marks)

(ii) Since air cannot be completely excluded from containers of face cream, glycerol may become oxidised during extended periods of storage.

Draw the structural formula of *one* oxidation product of glycerol.

(2 marks)

(b) Salicylic acid is an organic compound added to face creams to prevent blemishes on the skin. The structural formula of salicylic acid is shown below.



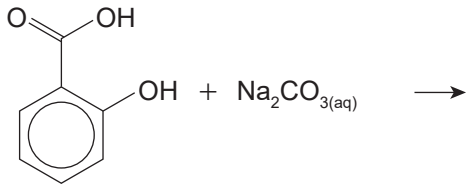
salicylic acid

(i) Name the functional group indicated by the dashed oval in the diagram.

_____ (1 mark)

(ii) Salicylic acid has low solubility in water. To convert it into a water-soluble salt, it is reacted with sodium carbonate solution, $Na_2CO_{3(aq)}$.

(1) Complete and balance the equation for the conversion below.



(2 marks)

(2) Explain why the salt produced is more soluble in water than the original salicylic acid.

(3 marks)

(c) Some cosmetics contain minerals that are layered silicates and aluminosilicates. One such mineral contains adsorbed magnesium cations.

Explain what is likely to happen to the magnesium content of the mineral when a person wearing such a cosmetic swims underwater in the sea (highly saline water).

(4 marks)

You may write on this page if you need more space to finish your answers to any of the questions in this question booklet. Make sure to label each answer carefully (e.g. 1(a)(ii) continued).

South Australian
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Chemistry
2023

Question booklet 2

- Questions 5 to 8 (59 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 14 if you need more space
- Allow approximately 65 minutes

2

Copy the information from your SACE label here

SEQ	FIGURES	CHECK LETTER	BIN

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AUSTRALIA

5. Amino acids can be used in water-soluble fertilisers that are applied to soil to promote plant growth.

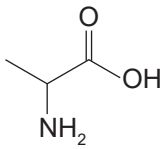
(a) State why nutrients for plants must be applied to soil in a water-soluble form.

_____

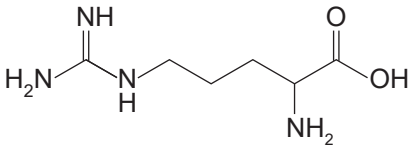
_____ (1 mark)

(b) Amino acids can be separated by ion exchange chromatography.

The molecular structures of the amino acids alanine and arginine are shown below.



alanine



arginine

The pH of a mixture containing alanine and arginine was adjusted to 1.45.

(i) Calculate the hydrogen ion concentration in a solution of pH 1.45.

(2 marks)

(ii) Draw the structural formula of alanine as it would exist in this low pH solution.

(2 marks)

(iii) State whether the sites on the ion exchange resin used to separate this mixture of alanine and arginine would be positively charged or negatively charged.

_____ (1 mark)

(c) The use of amino acids in water-soluble fertilisers can lead to a decrease in the use of synthetic fertilisers. Synthetic fertilisers increase crop productivity, but higher doses of these chemicals are associated with high nitrous oxide, N_2O, emissions. N_2O is a powerful greenhouse gas with an effect 300 times that of CO_2.

Synthetic fertilisers can also contribute to excess nitrogen-containing nutrient run-off that enters water bodies. Researchers have found that the use of water-soluble amino acid fertilisers on growing plants improves nitrogen uptake from the soil and decreases this run-off.

Discuss *two* positive environmental outcomes of the use of these water-soluble amino acid fertilisers.

(6 marks)

6. Brandy is an alcoholic drink made from a process involving the fermentation of a mixture of mashed fruit followed by distillation.

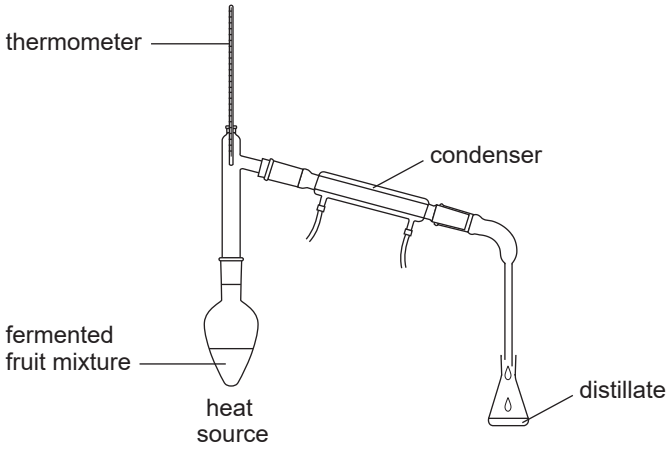
(a) In the first stage of the process, ethanol is produced by the fermentation of glucose in a fruit mixture.

Write an equation for the fermentation of glucose.

(2 marks)

(b) In the second stage of the process, the liquid from the fermented fruit mixture undergoes thermal distillation.

The diagram below shows apparatus that may be used in a laboratory for the thermal distillation process.



The boiling point of ethanol is 78°C and the boiling point of water is 100°C.

Explain how the use of the apparatus shown in the diagram results in a higher concentration of ethanol in the distillate than in the original liquid from the fermented fruit mixture.

(3 marks)

(c) After distillation, the concentration of ethanol present in a distillate was determined by titration, using the following steps.

Step 1 A 20.00 mL sample of distillate containing an unknown concentration of ethanol was diluted to 100.0 mL in a volumetric flask.

Step 2 A 5.00 mL volume of the diluted ethanol solution was acidified using sulfuric acid.

Step 3 25.00 mL of a solution containing dichromate ions, $Cr_2O_7^{2-}$, of concentration 0.249 mol L^{-1}, was added to the acidified ethanol solution from step 2 and allowed to react until all ethanol had been completely oxidised. Excess $Cr_2O_7^{2-}$ ions remained.

Step 4 A titration was performed with a solution containing iron(II) ions, Fe^{2+}, of concentration 0.344 mol L^{-1} and a suitable indicator, to determine the number of moles of excess $Cr_2O_7^{2-}$ from step 3.

(i) Calculate the number of moles of Fe^{2+} that reacted in step 4 if the titre was 20.73 mL. Express your answer to the appropriate number of significant figures.

(3 marks)

(ii) The equation for the reaction that occurred in step 4 is:

$$Cr_2O_7^{2-}{}_{(aq)} + 6Fe^{2+}{}_{(aq)} + 14H^+{}_{(aq)} \longrightarrow 2Cr^{3+}{}_{(aq)} + 6Fe^{3+}{}_{(aq)} + 7H_2O$$

Calculate the number of moles of excess $Cr_2O_7^{2-}$ that remained after step 3.

(1 mark)

(iii) Calculate the number of moles of $Cr_2O_7^{2-}$ that were added to the ethanol solution at the beginning of step 3.

(2 marks)

(iv) Hence find the number of moles of $Cr_2O_7^{2-}$ that reacted with the ethanol.

(1 mark)

(v) The equation for the reaction that occurred between ethanol and $Cr_2O_7^{2-}$ is:

$$2Cr_2O_7^{2-}{}_{(aq)} + 3C_2H_5OH_{(aq)} + 16H^+{}_{(aq)} \longrightarrow 4Cr^{3+}{}_{(aq)} + 3CH_3COOH_{(aq)} + 11H_2O_{(l)}$$

Show that the number of moles of ethanol present in the 5.00 mL diluted sample was 7.55×10^{-3}.

(1 mark)

(vi) Calculate the concentration of ethanol (in mol L^{-1}) in the original undiluted 20.00 mL sample.

(2 marks)

(vii) Express the concentration you calculated in part (c)(vi) as %w/v of ethanol.

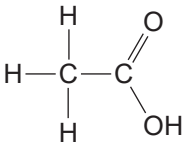
(3 marks)

(viii) Prior to distillation, there are substances other than ethanol present in the fermentation mixture that may react with the acidified dichromate solution.

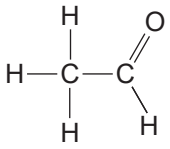
If the distillate is contaminated with a compound that reacts with acidified dichromate solution, explain whether the volume of iron(II) solution used in the titration in step 4 would be increased or decreased.

(3 marks)

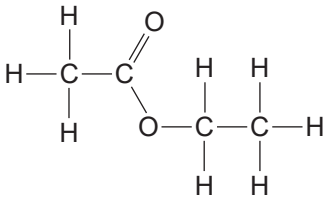
(ix) Molecules **A**, **B**, and **C**, shown below, are commonly found in fermentation mixtures.



molecule A



molecule B



molecule C

(1) Give the systematic name of molecule **C**.

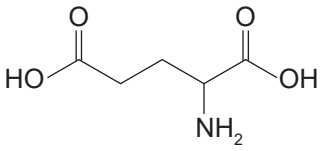
_____ (2 marks)

(2) Identify which of the molecules **A**, **B**, or **C** would react with acidified dichromate solution.

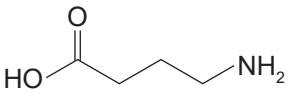
_____ (1 mark)

7. Gamma-aminobutyric acid (GABA) is a chemical produced in the brain. It is also found naturally in various foods. GABA plays an important part in calming the central nervous system.

(a) In the brain, GABA is synthesised from glutamate. The structural formulae of glutamate and GABA are shown below.



glutamate



GABA

(i) Write the molecular formula for glutamate.

(2 marks)

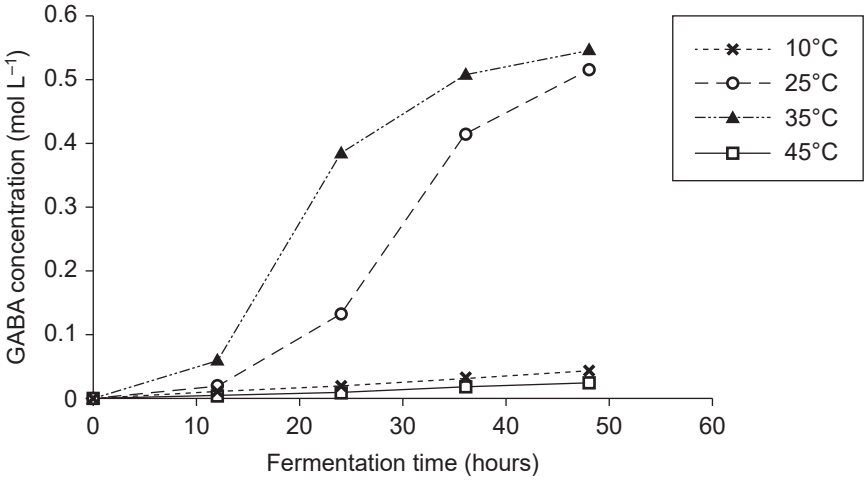
(ii) GABA synthesis in the brain is catalysed by a particular enzyme.

State the effect of this enzyme on the overall activation energy of the chemical reaction that converts glutamate to GABA.

_____ (1 mark)

Question 7 continues on page 10.

(b) Taking GABA supplements may help reduce stress. Pharmaceutical researchers have found that GABA can be synthesised from glutamate by microbes. They conducted an investigation of GABA synthesis by microbes at various temperatures. The results are shown in the graph below.



Source: adapted from Li, H., Qui, T. Huang, G., et al 2010, 'Production of gamma-aminobutyric acid by Lactobacillis brevis NCL912 using fed-batch fermentation', Microbial Cell Factories 9, 85.

(i) State the dependent variable for the investigation.

_____ (1 mark)

(ii) Suggest a suitable hypothesis for the investigation.

_____

_____ (1 mark)

(iii) In terms of collision theory, explain the effect of increasing the reaction temperature from 10°C to 35°C.

_____

_____

_____

_____

_____

_____ (3 marks)

(iv) State a possible reason for the trial at 45°C producing very little GABA.

_____

_____ (1 mark)

(v) State the feature of the graph at 25°C that indicates that the rate of reaction was greatest during time interval 24–36 hours.

_____

_____ (1 mark)

8. The transparency of some materials allows them to be used in windows, skylights, and other architectural applications.

(a) Polymethylmethacrylate (PMMA) is a rigid, almost 100% transparent, thermoplastic material used to construct fish tanks. PMMA is usually made from fossil fuel resources, but recently there has been a focus on producing PMMA from biomass feedstock.

(i) Describe *one* possible **disadvantage** of producing PMMA from biomass feedstock rather than fossil fuel resources.

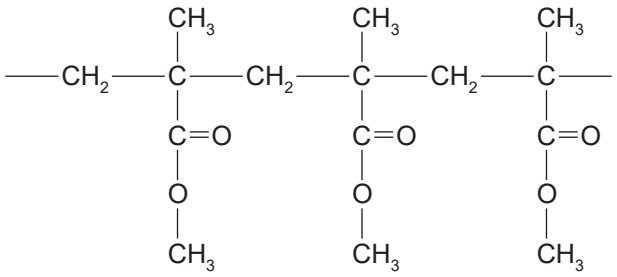
_____

_____

_____

_____ (2 marks)

(ii) The structural formula of a section of PMMA polymer is shown below.



(1) *On the diagram above*, draw brackets around one repeating unit of PMMA.

(1 mark)

(2) State the type of polymerisation used to produce PMMA.

_____ (1 mark)

(iii) With reference to its structure, explain why PMMA is not biodegradable.

_____

_____

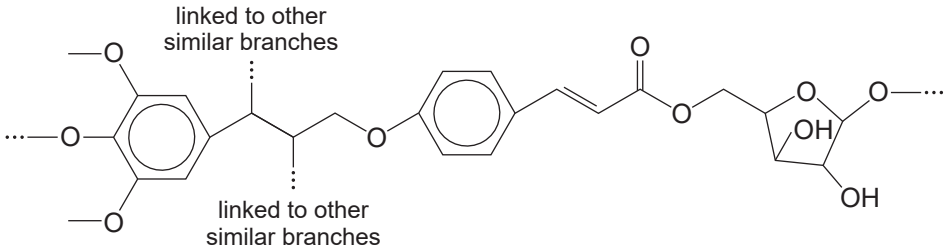
_____

_____ (2 marks)

(b) An alternative to PMMA is a composite material known as transparent wood. This composite material is up to 90% transparent, biodegradable, and shatterproof. These properties make it ideal for use as windows in buildings.

(i) The colour and lack of transparency of wood is largely due to lignocellulose. Boiling wood with sodium hydroxide solution, $NaOH_{(aq)}$, breaks down the complex structure of lignocellulose. The structure of a small segment of lignocellulose is shown below.

On the structure of lignocellulose below, circle the functional group that would react with $NaOH_{(aq)}$ on boiling.



(1 mark)

Source: adapted from Modenbach, A., Nolees, S., 2014, 'Effects of Sodium Hydroxide Pretreatment on Structural Components of Biomass', *Biosystems and Agricultural Engineering Faculty Publications*, 84.

(ii) In a later step, the wood is soaked in molten biodegradable polymers to produce a composite 'transparent wood' material.

Explain why windows made from transparent wood are difficult to recycle.

(2 marks)

(iii) The wood source for the manufacture of transparent wood is balsa, which is a fast-growing plantation tree. The cellulose in this wood, combined with the biodegradable polymer, makes transparent wood more durable and less dense than glass. Transparent wood can withstand much greater impacts than glass and it bends or stretches on impact rather than breaking easily. It can also be cut to size using existing industrial equipment.

Explain how the innovation of transparent wood is an example of science as a human endeavour.

(4 marks)

You may write on this page if you need more space to finish your answers to any of the questions in this question booklet. Make sure to label each answer carefully (e.g. 8(b)(iii) continued).

Chemistry data sheet

Metal activity

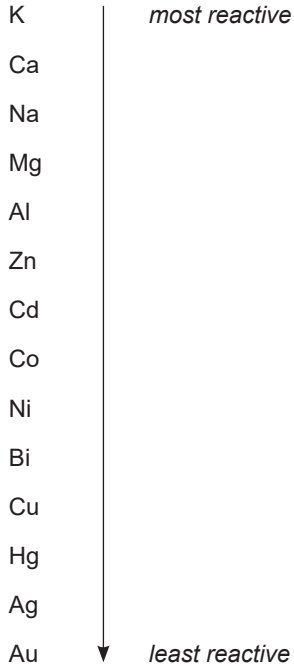


Table of SI prefixes

SI prefix	*Symbol*	*Value*
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Symbols of common quantities

amount of substance	n
mass	m
molar concentration	c
change in enthalpy	ΔH
molar mass	M
volume	V
heat energy	Q
specific heat capacity	c
temperature	T

Mathematical relationships

$$n = \frac{m}{M}$$

$$c = \frac{n}{V}$$

$$Q = mc\Delta T$$

$$\Delta H = \frac{Q}{n}$$

$$\text{pH} = -\log\left[\text{H}^{+}\right]$$

Periodic table of the elements

1 H hydrogen 1.008																	2 He helium 4.003
3 Li lithium 6.941	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31											13 Al aluminium 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.06	17 Cl chlorine 35.45	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.90	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.70	29 Cu copper 63.55	30 Zn zinc 65.38	31 Ga gallium 69.72	32 Ge germanium 72.59	33 As arsenic 74.92	34 Se selenium 78.96	35 Br bromine 79.90	36 Kr krypton 83.80
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.94	43 Tc technetium (97)	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57[1] La lanthanum 138.9	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium (223)	88 Ra radium (226)	89[2] Ac actinium (227)	104 Rf rutherfordium (267)	105 Db dubnium (268)	106 Sg seaborgium (271)	107 Bh bohrium (272)	108 Hs hassium (270)	109 Mt meitnerium (276)	110 Ds darmstadtium (281)	111 Rg roentgenium (280)	112 Cn copernicium (285)	113 Nh nihonium (284)	114 Fl flerovium (289)	115 Mc moscovium (288)	116 Lv livermorium (293)	117 Ts tennessine (294)	118 Og oganesson (294)

[1]lanthanide series	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0	71 Lu lutetium 175.0
[2]actinide series	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium (237)	94 Pu plutonium (244)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (258)	102 No nobelium (259)	103 Lr lawrencium (262)