Please check the examination details below before entering your candidate information

Candidate surname: StemUp Model Solution

Other names:

Pearson Edexcel Level 3 GCE

Centre Number

Candidate Number

Time 1 hour 45 minutes

Paper reference **9CH0/02**

Chemistry

Advanced

PAPER 2: Advanced Organic and Physical Chemistry

Candidates must have: Scientific calculator
Data Booklet
Ruler

Total Marks

Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*
- Show all your working in calculations and include units where appropriate.

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an asterisk (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Check your answers if you have time at the end.
- Good luck with your examination.

Turn over ▶

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Answer ALL questions.

Some questions must be answered with a cross in a box ☒.
If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 What is the total number of **ions** in 26.4 g of ammonium sulfate, $(NH_4)_2SO_4$?

[Molar mass of $(NH_4)_2SO_4$ = 132 g mol^{-1} Avogadro constant = 6.0×10^{23} mol^{-1}]

☐ **A** 4.0×10^{22}

☐ **B** 1.2×10^{23}

☐ **C** 2.4×10^{23}

☒ **D** 3.6×10^{23}

(Total for Question 1 = 1 mark)

2 The equation for the complete combustion of butane is

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$$

What is the minimum volume of oxygen, at room temperature and pressure (r.t.p.), needed for the complete combustion of 0.200 mol of butane?

[Molar volume of a gas at r.t.p. = 24.0 dm^3 mol^{-1}]

☐ **A** 4.8 dm^3

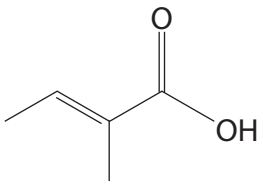
☐ **B** 9.6 dm^3

☒ **C** 31.2 dm^3

☐ **D** 62.4 dm^3

(Total for Question 2 = 1 mark)

3 What is the systematic name for tiglic acid?



tiglic acid

☒ **A** *E*-2-methylbut-2-enoic acid

☐ **B** *Z*-2-methylbut-2-enoic acid

☐ **C** *E*-3-methylbut-2-enoic acid

☐ **D** *Z*-3-methylbut-2-enoic acid

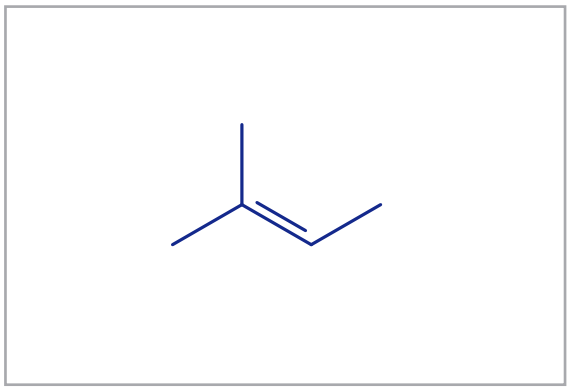
(Total for Question 3 = 1 mark)

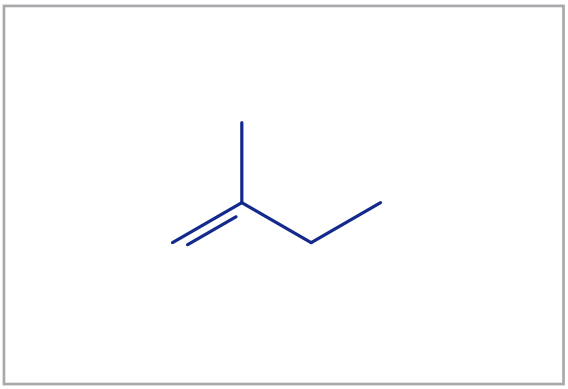
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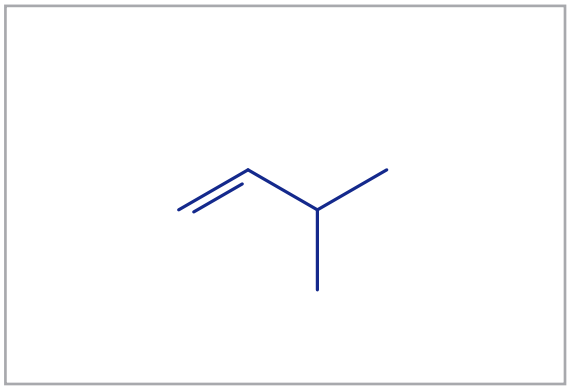
4 This question is about alkenes with the molecular formula C_5H_{10}.

(a) Draw the **skeletal** formulae of three **branched** chain alkenes with the molecular formula C_5H_{10}.

(3)







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(b) Which of these compounds would form pent-2-ene **only**, when reacted with concentrated phosphoric acid, H_3PO_4?

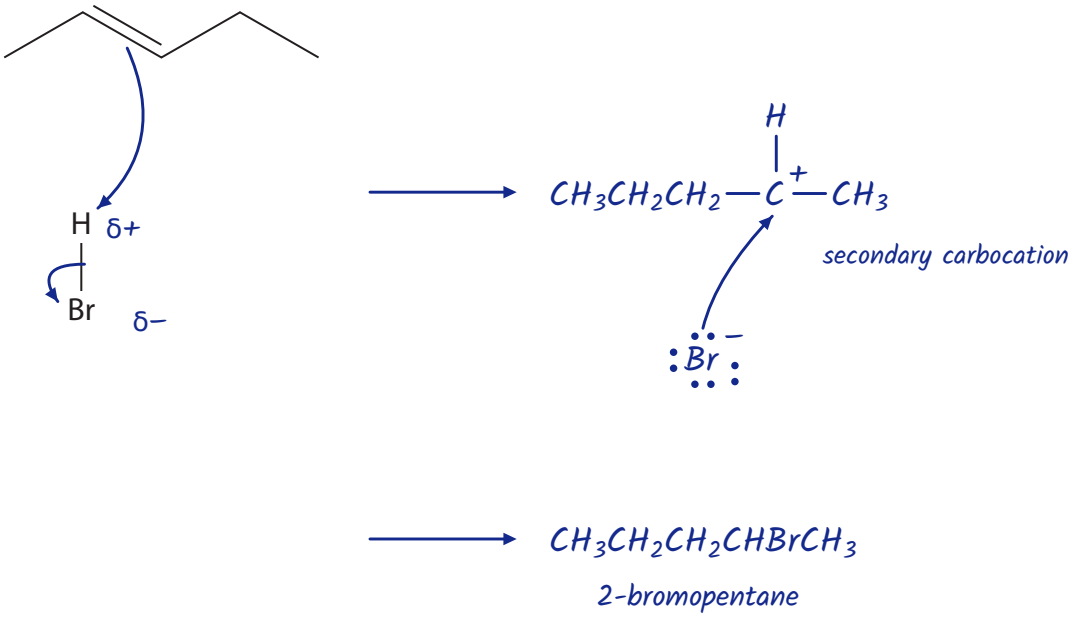
(1)

- ☒ **A** $CH_3CH(OH)CH(CH_3)_2$
- ☒ **B** $CH_2(OH)CH_2CH_2CH_2CH_3$
- ☒ **C** $CH_3CH_2CH_2CH(OH)CH_3$
- ☒ **D** $CH_3CH_2CH(OH)CH_2CH_3$

(c) Pent-2-ene reacts with hydrogen bromide, HBr, to form two bromoalkanes.

Complete the diagram to show the mechanism for the formation of 2-bromopentane in this reaction.
Include curly arrows, and relevant lone pairs and dipoles.

(4)



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(d) A sample of pent-1-ene, with a mass of 1.33 g, is warmed to 60 °C in a sealed container. The volume of the container is 500 cm^3.

Calculate the pressure inside the container.
Include units and give your answer to an appropriate number of significant figures.

[Gas constant (R) = 8.31 J mol^{-1} K^{-1}]

(4)

M_r of pent-1-ene, C_5H_{10} = (5 × 12.0) + (10 × 1.0) = 70.0

n = 1.33 ÷ 70.0 = 0.0190 mol

V = 500 cm^3 = 500 × 10^{-6} m^3 = 5.00 × 10^{-4} m^3

T = 60 + 273 = 333 K

$pV = nRT$ so $p = nRT \div V$

p = (0.0190 × 8.31 × 333) ÷ 5.00 × 10^{-4}

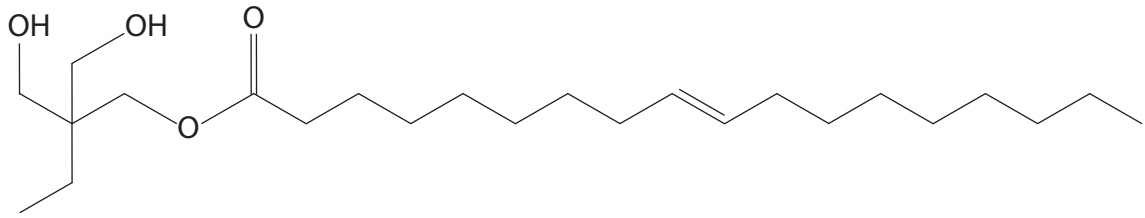
= 105 155 Pa

Pressure = 1.05 × 10^5 Pa (3 s.f.)

(Total for Question 4 = 12 marks)

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5 Compound **X** is a component of synthetic oils used as lubricants, for instance in the gearboxes of ships.



compound **X**

(a) Name the **three** functional groups present in compound **X**.

(2)

Alcohol (hydroxyl, –OH groups: a diol)

Ester

Alkene (C=C)

(b) The effectiveness of this synthetic oil is much reduced if it is contaminated with water.

Give, in terms of a chemical reaction, a possible reason for this.

(1)

The ester group reacts with the water in a hydrolysis reaction, so compound X is broken down into a carboxylic acid and an alcohol (the diol/triol).

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(c) An alternative to synthetic oil is known as mineral oil and consists solely of hydrocarbons separated from crude oil.

(i) What is the name of the process used to separate different hydrocarbons from crude oil?

(1)

- ☒ **A** cracking
- ☒ **B** reforming
- ☒ **C** fractional distillation
- ☒ **D** heating under reflux

(ii) Explain why compound **X** is likely to have a higher boiling temperature than hydrocarbons of a similar molecular mass and shape.

A detailed description of how the intermolecular forces arise is not required.

(2)

Compound X has O–H groups, so it can form hydrogen bonds between its molecules, whereas hydrocarbons only have London forces.

Hydrogen bonds are stronger than London forces, so more energy is needed to break the intermolecular forces (to vaporise compound X), so its boiling temperature is higher.

(Total for Question 5 = 6 marks)

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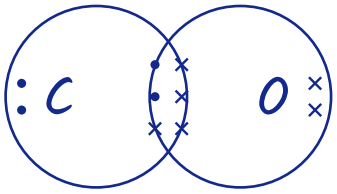
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6 This question is about carbon monoxide, CO, which is a toxic and colourless gas used widely in the chemical industry.

(a) Draw a dot-and-cross diagram of a molecule of carbon monoxide.

Use dots (•) for the carbon electrons and crosses (×) for the oxygen electrons.

(2)



· carbon electron × oxygen electron

triple bond: two shared pairs and one dative pair (both electrons from O)

(b) Carbon monoxide can be made by the thermal decomposition of sodium ethanedioate.

$$Na_2C_2O_4 \rightarrow Na_2CO_3 + CO$$

Calculate the atom economy, by mass, for the production of carbon monoxide in this reaction.

(2)

$M_r\ Na_2C_2O_4 = (2 \times 23.0) + (2 \times 12.0) + (4 \times 16.0) = 134.0$

$M_r\ CO = 28.0$ $M_r\ Na_2CO_3 = 106.0$

Atom economy = (mass of desired product ÷ total mass of products) × 100

= 28.0 ÷ (28.0 + 106.0) × 100 = 28.0 ÷ 134.0 × 100

= 20.896 %

Atom economy = 20.9 %

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(c) Carbon monoxide can also be made by the thermal decomposition of ethanal, CH_3CHO, in the gas phase.

$$CH_3CHO(g) \rightarrow CH_4(g) + CO(g)$$

This reaction was carried out at two different temperatures, and all other variables were kept constant.

Temperature / K	Rate / mol dm^{-3} s^{-1}	1/Temperature (1/T) / K^{-1}	ln rate
700	0.0108	1.43×10^{-3}	−4.53
850	4.90	1.18×10^{-3}	1.59

(i) Complete the data in the table.

(1)

(ii) Calculate the activation energy, E_a, for the reaction without plotting a graph. Include a sign and units in your answer.

The Arrhenius equation may be written as

$$\ln \text{ rate} = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant} \qquad [R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}]$$

(3)

Gradient = Δ(ln rate) ÷ Δ(1/T) = $-E_a/R$

Δ(ln rate) = 1.59 − (−4.53) = 6.12

Δ(1/T) = $1.18 \times 10^{-3} - 1.43 \times 10^{-3} = -2.5 \times 10^{-4}$ K^{-1}

Gradient = 6.12 ÷ (-2.5×10^{-4}) = −24 480 K

$-E_a/R = -24\,480$ so $E_a = 24\,480 \times 8.31$

$E_a = +203\,429$ J mol^{-1}

$E_a = +203$ kJ mol^{-1}

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(d) Haemoglobin (Hb) found in red blood cells reacts almost irreversibly with carbon monoxide.
Initial rate experiments were carried out to investigate the effect of the concentrations of Hb and CO on the rate of this reaction.

Experiment	[Hb] / mol dm^{-3}	[CO] / mol dm^{-3}	Rate / mol dm^{-3} s^{-1}
1	2.09×10^{-6}	1.40×10^{-6}	8.20×10^{-7}
2	4.18×10^{-6}	1.40×10^{-6}	1.64×10^{-6}
3	3.26×10^{-6}	2.80×10^{-6}	2.56×10^{-6}

(i) Deduce the order of reaction with respect to haemoglobin.

(1)

First order (1): from Exp 1 to 2, [Hb] doubles, [CO] constant, rate doubles.

(ii) Determine the order with respect to carbon monoxide using your answer to (d)(i) and the data in the table.
Justify your answer.

(2)

First order (1) with respect to carbon monoxide.

From experiment 1 to 3, [Hb] increases by a factor of 3.26 ÷ 2.09 = 1.56, so this alone (first order) would increase the rate by a factor of 1.56.

[CO] doubles and the rate increases by a factor of $2.56 \times 10^{-6} \div 8.20 \times 10^{-7} = 3.12$ = 1.56 × 2, so doubling [CO] doubles the rate.

(iii) Write the rate equation for this reaction using your answers to (d)(i) and (d)(ii).

(1)

rate = k[Hb][CO]

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(iv) Calculate the rate constant, *k*, for the reaction, using the data from Experiment 1 and the rate equation from (d)(iii).
Include units in your answer.

(3)

k = rate ÷ ([Hb][CO])

$k = 8.20 \times 10^{-7} \div (2.09 \times 10^{-6} \times 1.40 \times 10^{-6})$

$= 280\ 246$

units: $mol\ dm^{-3}\ s^{-1} \div (mol\ dm^{-3})^2 = dm^3\ mol^{-1}\ s^{-1}$

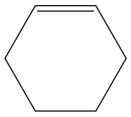
$k = 2.80 \times 10^5\ dm^3\ mol^{-1}\ s^{-1}$

(Total for Question 6 = 15 marks)

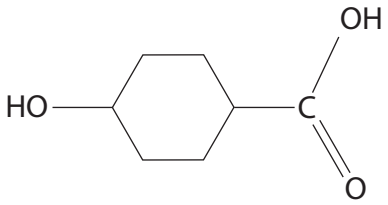
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***7** This question is about polymers.

(a) Compare and contrast how each of these monomers forms a polymer.



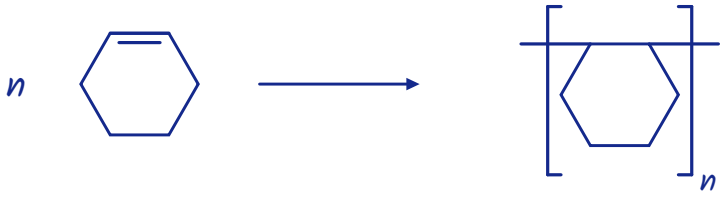
cyclohexene



4-hydroxycyclohexanecarboxylic acid

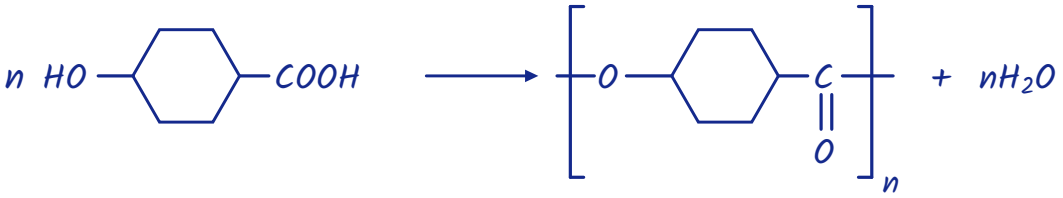
Include equations, showing the formation of a single repeat unit for each polymer.

(6)



addition polymerisation

condensation polymerisation (ester link)



Similarity: in both cases many monomer molecules join together by covalent bonds to form a long-chain polymer, and each polymer is made from a single type of monomer.

Cyclohexene is unsaturated: it has a C=C double bond, so it forms an addition polymer. The π bond in the C=C breaks and the monomers add on to each other, forming a saturated polymer, poly(cyclohexene), as shown in the first equation.

Because this is an addition reaction, the polymer is the only product, so there are no additional products and the atom economy is 100%. Only one functional group (the C=C) is needed.

4-hydroxycyclohexanecarboxylic acid has two different functional groups on the same molecule, an alcohol (–OH) group and a carboxylic acid (–COOH) group, so it forms a

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condensation polymer (a polyester).

The –OH group of one monomer reacts with the –COOH group of the next monomer to form an ester link (–COO–), and a small molecule, water, is also formed (eliminated) for each link made, as shown in the second equation.

So, unlike the addition polymerisation of cyclohexene, the condensation polymerisation gives two products, the polymer and water, so its atom economy is less than 100%.

As a result, the backbone of poly(cyclohexene) contains only C–C bonds, whereas the polyester has ester links in its backbone, which can be hydrolysed, so the polyester is biodegradable but poly(cyclohexene) is not.

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(b) Give three ways in which waste polymers can be utilised to improve their sustainability.

(3)

Recycling: waste polymers are sorted, melted down and re-moulded into new products (re-use).

Incineration to release energy, which is used to generate electricity (use as a fuel).

Use as a feedstock (e.g. for cracking): break the polymers down into monomers or smaller molecules to make new polymers and chemicals.

(Total for Question 7 = 9 marks)

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8 This question is about a dicarboxylic acid **Y** which is present in some citrus fruits. **Y** contains only the elements carbon, hydrogen and oxygen.

(a) A sample of **Y** with a mass of 1.98 g was burned completely in excess oxygen. The reaction formed 2.51 g of carbon dioxide, CO_2, and 0.69 g of water, H_2O.

Use these data to calculate the empirical formula of **Y**.

(4)

Mass of C = 2.51 × (12.0 ÷ 44.0) = 0.68455 g

Mass of H = 0.69 × (2.0 ÷ 18.0) = 0.076667 g

Mass of O = 1.98 − 0.68455 − 0.076667 = 1.21878 g

Moles of C = 0.68455 ÷ 12.0 = 0.05705 mol

Moles of H = 0.076667 ÷ 1.0 = 0.076667 mol

Moles of O = 1.21878 ÷ 16.0 = 0.076174 mol

Divide by smallest (0.05705): C : H : O = 1 : 1.34 : 1.34

× 3: C : H : O = 3 : 4 : 4

Empirical formula = $C_3H_4O_4$

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(b) A solution was prepared using 4.34 g of the dicarboxylic acid **Y** made up to a volume of 250 cm^3 with distilled water.

A 25.0 cm^3 sample of this solution was then titrated using sodium hydroxide solution, NaOH(aq), of concentration 0.320 mol dm^{-3}.

The mean titre of sodium hydroxide solution was 26.10 cm^3.

Calculate the molar mass of **Y** using the titration data, and hence deduce its structure. You must show your working.

(5)

Moles of NaOH = (26.10 ÷ 1000) × 0.320 = 8.352×10^{-3} mol

Y is a dicarboxylic acid, so 1 mol Y reacts with 2 mol NaOH

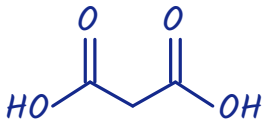
Moles of Y in 25.0 cm^3 = $8.352 \times 10^{-3} \div 2 = 4.176 \times 10^{-3}$ mol

Moles of Y in 250 cm^3 = $4.176 \times 10^{-3} \times (250 \div 25.0) = 4.176 \times 10^{-2}$ mol

Molar mass of Y = $4.34 \div 4.176 \times 10^{-2} = 103.9 = 104$ g mol^{-1}

M_r of $C_3H_4O_4$ = 36.0 + 4.0 + 64.0 = 104, so molecular formula = $C_3H_4O_4$

Structure of Y: HOOC–CH_2–COOH (propanedioic acid)



(c) Which of these is used to convert a dicarboxylic acid into a diol?

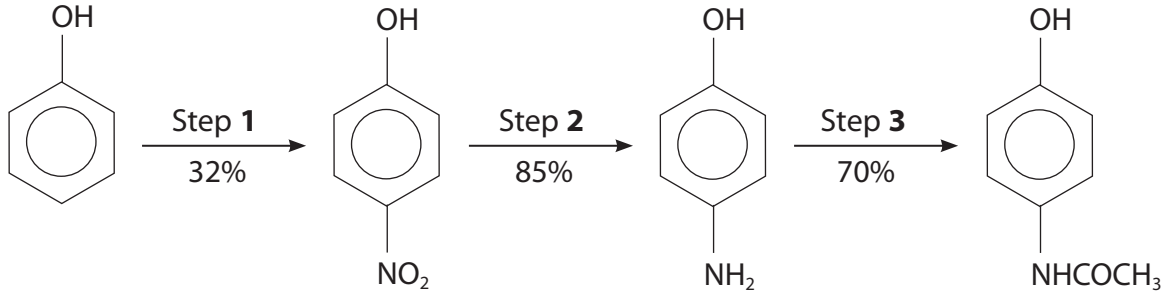
(1)

- ☒ **A** $LiAlH_4$ and ether
- ☐ **B** $KMnO_4$ and H_2SO_4
- ☐ **C** Sn and HCl
- ☐ **D** $Na_2Cr_2O_7$ and H_2SO_4

(Total for Question 8 = 10 marks)

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9 The painkiller paracetamol can be synthesised from phenol in three steps.
The percentage yield for each step is shown.

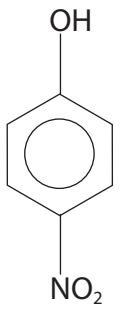
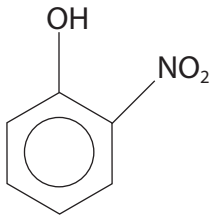


phenol paracetamol

(a) In Step **1** another product also forms. The two products can be distinguished using their ^{13}C NMR spectra.

Complete the table to show the number of peaks in each ^{13}C NMR spectrum.

(2)

Product		
Number of peaks in the ^{13}C NMR spectrum	4	6

(b) Calculate the minimum mass of phenol needed to synthesise 1.00 kg of paracetamol.
[M_r values: paracetamol = 151.0 phenol = 94.0]

(3)

Overall yield = 0.32 × 0.85 × 0.70 = 0.1904 = 19.04 %

Moles of paracetamol = 1000 g ÷ 151.0 = 6.6225 mol

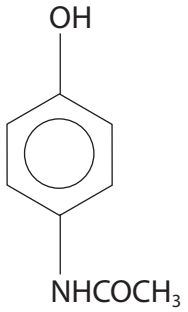
Mass of phenol (100% yield) = 6.6225 × 94.0 = 622.52 g

Mass of phenol needed = 622.52 × (100 ÷ 19.04) = 3269.5 g

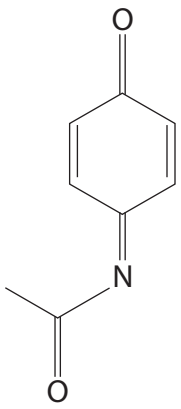
Minimum mass of phenol = 3.27 kg

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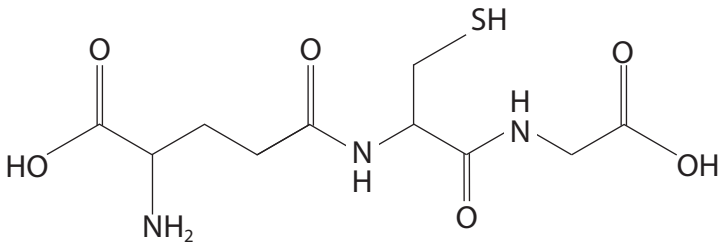
(c) When metabolised in the body, paracetamol forms a toxic compound **Z**.
This is then removed in the liver by a reaction with the tripeptide glutathione.



paracetamol



compound **Z**



glutathione

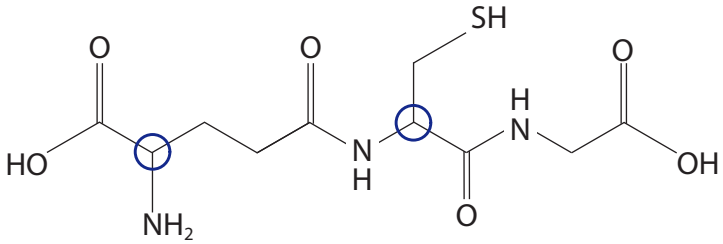
(i) The conversion of paracetamol to compound **Z** is

(1)

- ☒ **A** addition
- ☒ **B** hydrolysis
- ☒ **C** oxidation
- ☒ **D** reduction

(ii) Draw a circle around each of the chiral carbon atoms in glutathione.

(1)

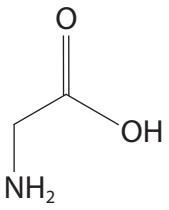


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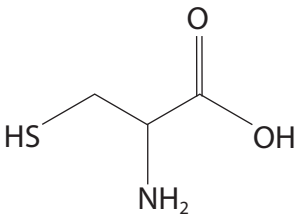
(iii) Glutathione is formed from glycine and two other amino acids.

Which two amino acids combine with glycine to form glutathione?

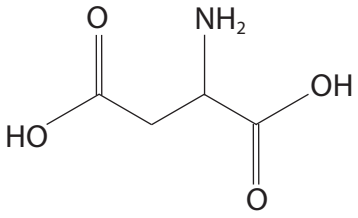
(1)



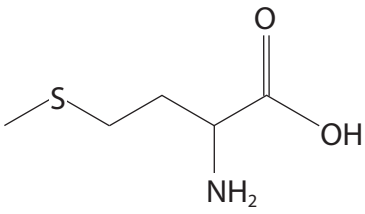
glycine



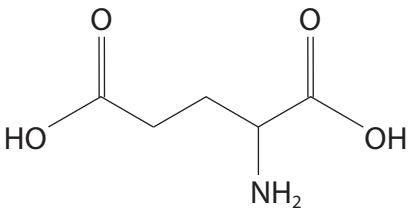
cysteine



aspartic acid



methionine



glutamic acid

- ☒ **A** aspartic acid and cysteine
- ☒ **B** glutamic acid and cysteine
- ☒ **C** glutamic acid and methionine
- ☒ **D** aspartic acid and methionine

(d) Explain why amino acids such as glycine are crystalline solids at room temperature.

(2)

Amino acids exist as zwitterions: the NH_2 group gains H^+ to form NH_3^+ and the COOH group loses H^+ to form COO^-.

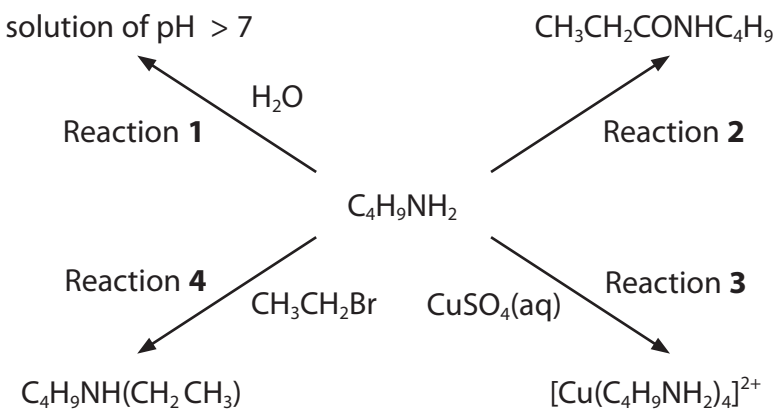
So there are strong ionic bonds (electrostatic attractions) between oppositely charged groups on neighbouring zwitterions in a lattice, which need a lot of energy to break.

(Total for Question 9 = 10 marks)

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10 This question is about the amines butylamine, $C_4H_9NH_2$, and phenylamine, $C_6H_5NH_2$.

The reaction scheme shows some reactions of butylamine, a primary amine.



(a) (i) Write the equation for Reaction **1** to show why the pH of the solution is greater than 7. State symbols are not required.

(1)

$C_4H_9NH_2 + H_2O \rightleftharpoons C_4H_9NH_3^+ + OH^-$

(ii) Explain why phenylamine is a weaker base than butylamine.

(3)

Both have a lone pair of electrons on the nitrogen atom, which accepts a proton (H^+).

In phenylamine the lone pair on nitrogen interacts with the π electrons of the benzene ring; it is delocalised into the ring.

So the electron density on N is lower and the lone pair is less available, so phenylamine is less able to accept a proton. In butylamine the butyl group pushes electrons towards the lone pair on N, so it is more able to accept a proton.

(b) Give the name and structural formula of the compound needed to react with butylamine in Reaction **2**.

(2)

Name propanoyl chloride

Structural formula CH_3CH_2COCl

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(c) What is seen when excess butylamine is used in Reaction **3**?

(1)

- ☒ **A** blue solution
- ☐ **B** blue precipitate
- ☐ **C** yellow solution
- ☐ **D** yellow precipitate

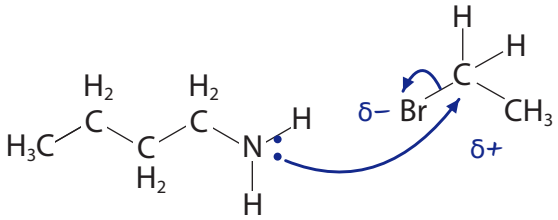
(d) (i) What is the type and mechanism of the reaction in Reaction **4**?

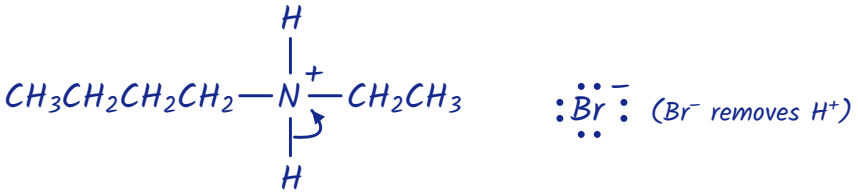
(1)

- ☐ **A** electrophilic addition
- ☐ **B** electrophilic substitution
- ☐ **C** nucleophilic addition
- ☒ **D** nucleophilic substitution

(ii) Complete the diagram to show the mechanism for Reaction **4**.
Include curly arrows, and relevant lone pairs and dipoles.

(4)







(Total for Question 10 = 12 marks)

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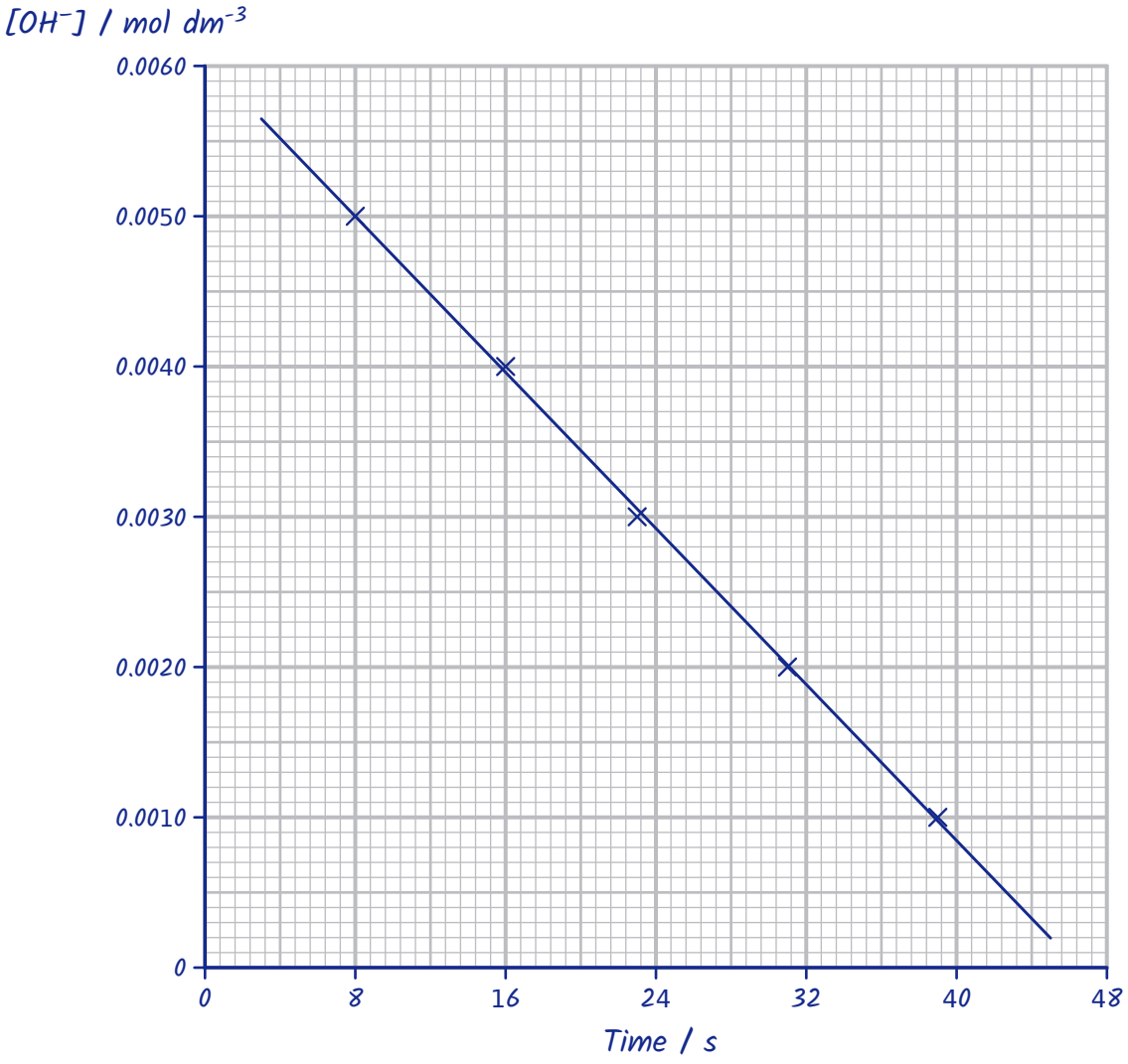
11 A series of experiments was carried out to determine the kinetics of the reaction between a chloroalkane, RCl, and potassium hydroxide in aqueous solution.
A large excess of the chloroalkane was used.

The data obtained are shown.

$[OH^-]$ / mol dm^{-3}	Time / s
0.00100	39
0.00200	31
0.00300	23
0.00400	16
0.00500	8

(a) Plot a graph of the concentration of the hydroxide ions against time.

(2)



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(b) State the order with respect to hydroxide ions.
Justify your answer by reference to your graph in (a).

(2)

Zero order with respect to hydroxide ions.

The graph of $[OH^-]$ against time is a straight line (constant gradient), so the rate of reaction is constant and independent of the concentration of hydroxide ions.

(c) Deduce the type of mechanism occurring.
Justify your answer.

(2)

The mechanism is S_N1 (unimolecular nucleophilic substitution).

There is only one reactant, the chloroalkane, in the rate-determining step; the hydroxide ions do not affect the rate, so they are not involved in the slow step. The C–Cl bond breaks first to form a carbocation, which then reacts quickly with OH^-.

(d) Give the classification of the chloroalkane in this reaction.

(1)

The chloroalkane is tertiary.

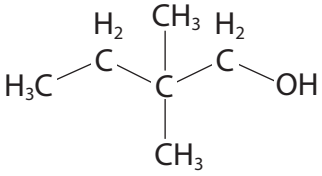
(Total for Question 11 = 7 marks)

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12 The alcohol 2,2-dimethylbutan-1-ol has the structure



Devise a reaction scheme for a synthesis of this alcohol starting from 2-bromo-2-methylbutane.
Include in your answer all reagents and conditions and the structures of any intermediate compounds.

(6)

Start: $CH_3CH_2C(CH_3)_2Br$ (2-bromo-2-methylbutane)

Step 1: react with magnesium (Mg) in dry ether (heat under reflux) to form the Grignard reagent:

$CH_3CH_2C(CH_3)_2MgBr$ i.e. $CH_3CH_2C(MgBr)(CH_3)CH_3$

Step 2: react the Grignard reagent with methanal, HCHO, in dry ether:

$CH_3CH_2C(CH_3)_2CH_2OMgBr$

Step 3: hydrolyse with dilute acid (e.g. dilute HCl, $H^+(aq)$):

$CH_3CH_2C(CH_3)_2CH_2OH$ (2,2-dimethylbutan-1-ol)

(Total for Question 12 = 6 marks)

TOTAL FOR PAPER = 90 MARKS

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The Periodic Table of Elements

1 (1)	2 (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	3 (13)	4 (14)	5 (15)	6 (16)	7 (17)	0 (8) (18)
																	4.0 **He** helium 2
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12											27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	95.9 **Mo** molybdenum 42	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La*** lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111							

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

1.0 **H** hydrogen 1

Elements with atomic numbers 112-116 have been reported but not fully authenticated

140 **Ce** cerium 58	141 **Pr** praseodymium 59	144 **Nd** neodymium 60	[147] **Pm** promethium 61	150 **Sm** samarium 62	152 **Eu** europium 63	157 **Gd** gadolinium 64	159 **Tb** terbium 65	163 **Dy** dysprosium 66	165 **Ho** holmium 67	167 **Er** erbium 68	169 **Tm** thulium 69	173 **Yb** ytterbium 70	175 **Lu** lutetium 71
232 **Th** thorium 90	[231] **Pa** protactinium 91	238 **U** uranium 92	[237] **Np** neptunium 93	[242] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[245] **Bk** berkelium 97	[251] **Cf** californium 98	[254] **Es** einsteinium 99	[253] **Fm** fermium 100	[256] **Md** mendelevium 101	[254] **No** nobelium 102	[257] **Lr** lawrencium 103

* Lanthanide series

* Actinide series

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