Please check the examination details below before entering your candidate information

Candidate surname	Other names
StemUp Model Solution	

Centre Number | Candidate Number

Pearson Edexcel Level 3 GCE

Time 1 hour 45 minutes

Paper reference **9CH0/02**

Chemistry

Advanced

PAPER 2: Advanced Organic and Physical Chemistry

You must have:
Scientific calculator, Data Booklet, ruler

Total Marks

Instructions

- Use **black** ink or 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.*

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.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

Turn over ▶

©2022 Pearson Education Ltd.
Q:1/1/1/1/1/1/

P 6 7 0 9 4 R A 0 1 2 4

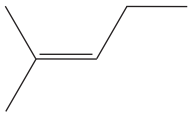
Pearson

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 This is a question about polymers.

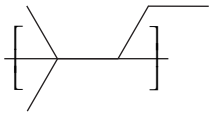
(a) An addition polymer is formed from 2-methylpent-2-ene.



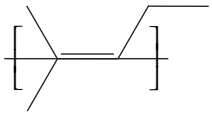
What is the repeat unit for poly(2-methylpent-2-ene)?

(1)

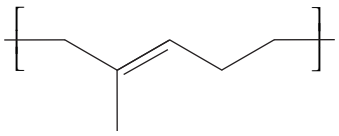
☒ **A**



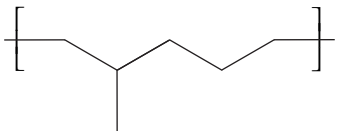
☐ **B**



☐ **C**



☐ **D**



(b) Which is **not** a use of waste poly(alkenes)?

(1)

☐ **A** feedstock for cracking

☒ **B** generation of biodegradable materials

☐ **C** incineration to release energy

☐ **D** make new materials by recycling

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

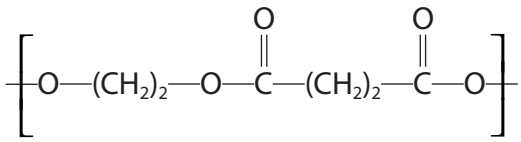
DO NOT WRITE IN THIS AREA

(c) A condensation polymer can be made from ethane-1,2-diol and butanedioic acid.

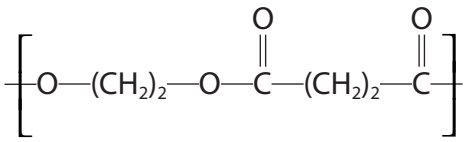
Which is the repeat unit for this polymer?

(1)

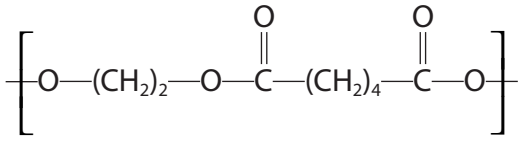
☒ **A**



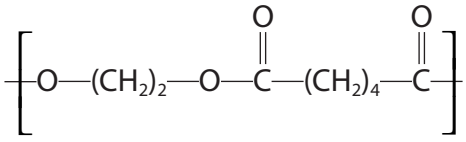
☒ **B**



☒ **C**



☒ **D**



(d) Which approach used by chemists would **not** contribute to a more sustainable use of materials over the life cycle of a polymer?

(1)

☒ **A** make more efficient use of energy

☒ **B** make more efficient use of resources

☒ **C** use catalysts for a faster reaction rate

☒ **D** use a higher temperature for a faster reaction rate

(Total for Question 1 = 4 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

2 This is a question about hydrocarbons.

(a) State what is meant by the term **hydrocarbon**.

(1)

A compound containing hydrogen and carbon atoms only.

(b) Explain why 2,2-dimethylpropane has a much lower boiling temperature than its isomer pentane.
Detailed descriptions of the forces involved are not required.

(2)

2,2-dimethylpropane is branched, so its molecules have a smaller surface area and fewer points of contact (they cannot pack as closely together) than the straight-chain pentane molecules.

So there are fewer (weaker) London forces between its molecules, which need less energy to overcome, giving a much lower boiling temperature.

(c) The **heterolytic** bond fission of a sigma (σ) bond in an alkane would produce

(1)

- ☒ **A** only carbocations
- ☒ **B** only free radicals
- ☒ **C** free radicals and ions
- ☒ **D** ions

(Total for Question 2 = 4 marks)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

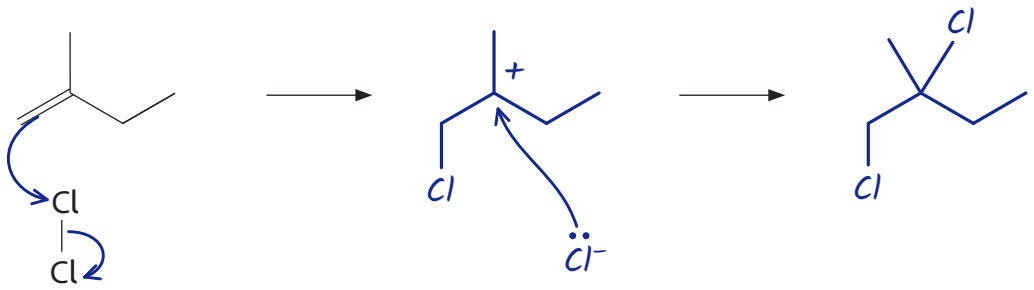
DO NOT WRITE IN THIS AREA

3 This is a question about dihalogenoalkanes.

(a) Dihalogenoalkanes are formed when alkenes react with halogens.

(i) Complete the mechanism for the production of a dihalogenoalkane from 2-methylbut-1-ene and chlorine.
Include curly arrows and any relevant lone pairs.

(3)

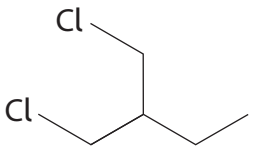


(ii) Give the name of the dihalogenoalkane produced.

(1)

1,2-dichloro-2-methylbutane

(b) What is the classification of the dihalogenoalkane shown?



(1)

- ☒ **A** primary
- ☐ **B** secondary
- ☐ **C** tertiary
- ☐ **D** primary and secondary

(Total for Question 3 = 5 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

4 This question is about nitrogen and some nitrogen compounds.

(a) A study of one brand of crisps found that each packet contained 0.420 g of nitrogen gas at a pressure of 120 kPa and a temperature of 20 °C.

(i) Calculate the volume of nitrogen gas, in **cm^3**, in one packet of crisps.

[$R = 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$]

(4)

$n(N_2) = 0.420 \div 28.0 = 0.0150\ mol$

$p = 120\ kPa = 120\ 000\ Pa \qquad T = 20 + 273 = 293\ K$

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

$V = (0.0150 \times 8.31 \times 293) \div 120\ 000$

$V = 3.04 \times 10^{-4}\ m^3$

$V = 3.04 \times 10^{-4} \times 10^6\ cm^3$

$volume = 304\ cm^3$

(ii) Give a possible reason why nitrogen gas and not air is used in packets of crisps.

(1)

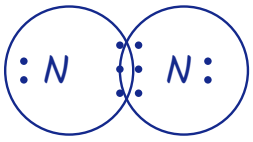
Nitrogen is unreactive, so it prevents oxidation of the crisps by the oxygen in air, keeping the crisps fresh.

(b) Draw dot-and-cross diagrams for a molecule of nitrogen gas and for the nitride ion, N^{3-}, in sodium nitride, Na_3N.

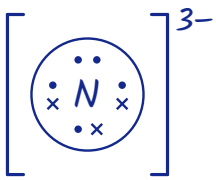
Use dots (•) for nitrogen electrons and crosses (**X**) for electrons from sodium.

(2)

Nitrogen molecule



Nitride ion



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

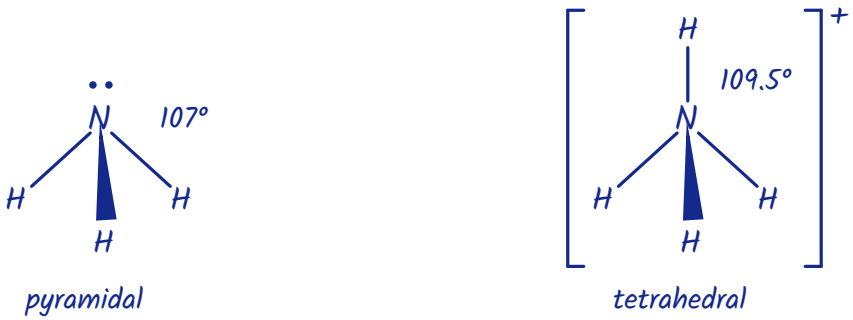
DO NOT WRITE IN THIS AREA

(c) Ammonia accepts a proton to form an ammonium ion.

$$NH_3 + H^+ \rightarrow NH_4^+$$

Explain why the ammonia molecule and the ammonium ion have different shapes and different bond angles.

(4)



NH_3 has three bond pairs and one lone pair, so it is (trigonal) pyramidal with a bond angle of 107°. NH_4^+ has four bond pairs and no lone pair, so it is tetrahedral, 109.5°. Electron pairs repel to be as far apart as possible, and the lone pair repels more than the bonded pairs, so it pushes the N–H bonds in NH_3 closer together.

(d) Butylamine, $C_4H_9NH_2$, reacts with ethanoyl chloride.

$$2C_4H_9NH_2 + CH_3COCl \rightarrow C_4H_9NHCOCH_3 + C_4H_9NH_3^+Cl^-$$

Explain how this equation illustrates that butylamine acts as a nucleophile and as a base.

(4)

A nucleophile is an electron pair donor: the nitrogen of the amine group in butylamine donates its lone pair of electrons and attacks the $C^{\delta+}$ atom of the C=O in ethanoyl chloride, forming the amide $C_4H_9NHCOCH_3$.

This reaction also produces hydrogen chloride, HCl.

A base is a proton acceptor: the second butylamine molecule accepts a proton (H^+) from the HCl, forming the salt $C_4H_9NH_3^+Cl^-$, so butylamine also acts as a base.

(Total for Question 4 = 15 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

5 Ice has a density of 0.92 g cm^{-3} and water has a density of 1.00 g cm^{-3}.

(a) About 200 cm^3 of water and 200 cm^3 of cooking oil were placed in a large beaker and two layers formed. The cooking oil formed the upper layer.

An ice cube made from water with a water-soluble blue food dye was added.

Initially the ice cube floated on top of the cooking oil but on melting the blue-coloured water sank into the bottom layer of water.

Give a possible value for the density of the cooking oil. Justify your answer.

(2)

A possible density is 0.96 g cm^{-3} (between 0.92 and 1.00 g cm^{-3}).

The oil forms a layer above the water, so it is less dense than water (1.00 g cm^{-3}),

but the ice floats on the oil, so the oil is more dense than ice (0.92 g cm^{-3}).

(b) Calculate how many **more** molecules there are in 5.00 cm^3 of water compared to 5.00 cm^3 of ice.

(3)

mass of water = 5.00 × 1.00 = 5.00 g *mass of ice = 5.00 × 0.92 = 4.60 g*

n(water) = 5.00 ÷ 18.0 = 0.27778 mol

n(ice) = 4.60 ÷ 18.0 = 0.25556 mol

difference = 0.27778 − 0.25556 = 0.022222 mol

extra molecules = 0.022222 × 6.02 × 10^{23}

= 1.34 × 10^{22} more molecules

(Total for Question 5 = 5 marks)

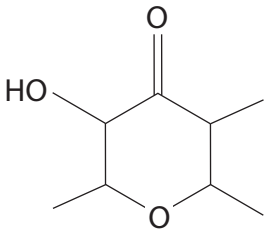
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

6 Aldehydes and ketones are carbonyl compounds.

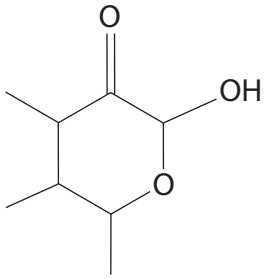
(a) Which of these compounds does **not** contain a ketone functional group?

(1)

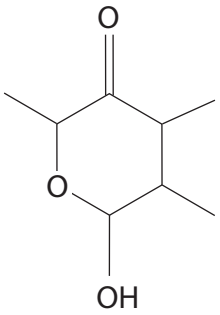
☒ **A**



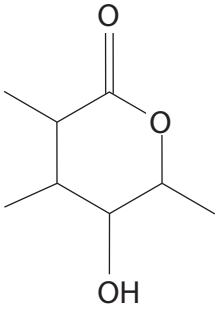
☒ **B**



☒ **C**



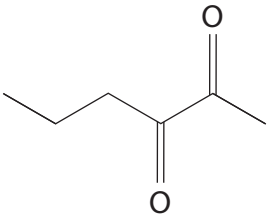
☒ **D**



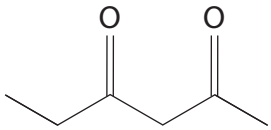
(b) Which of these compounds has both an aldehyde functional group **and** a ketone functional group?

(1)

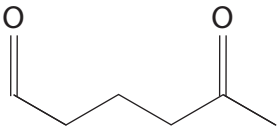
☒ **A**



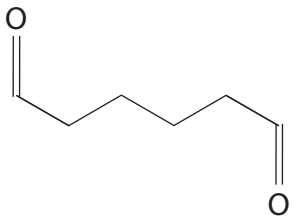
☒ **B**



☒ **C**



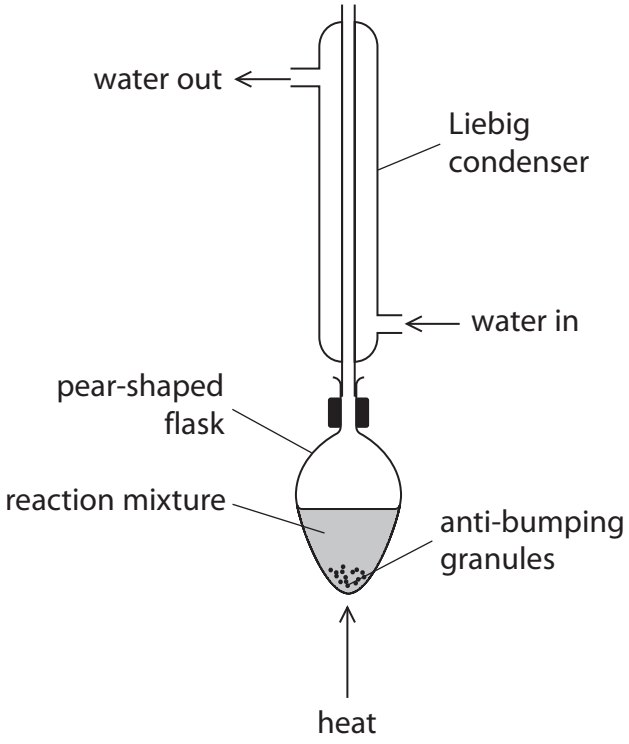
☒ **D**



DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(c) Propanal can be produced from the oxidation of propan-1-ol.

(i) A student assembled the apparatus shown for this oxidation.



Explain why the use of this apparatus would give a very low yield of propanal.

(2)

The apparatus is set up for heating under reflux, so the propanal is condensed back into the pear-shaped flask and is not distilled off (removed) from the oxidising agent. So the propanal is further oxidised to propanoic acid.

(ii) The oxidising agent is acidified $Na_2Cr_2O_7$.

State the oxidation number of chromium in $Na_2Cr_2O_7$.

(1)

+6 (VI)

(iii) Complete the ionic half-equation for the oxidation of propan-1-ol.

(1)

$$CH_3CH_2CH_2OH \rightarrow CH_3CH_2CHO + \underline{2}\ H^+ + \underline{2}\ e^-$$

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(iv) State how the use of anti-bumping granules gives smoother boiling.

(1)

They provide a rough surface with nucleation sites where many small bubbles form, so large bubbles do not form (prevents superheating).

(v) Another student used the correct apparatus for this oxidation.
1.50 g of propan-1-ol produced 0.609 g of propanal.

Calculate the percentage yield of propanal by mass.

(3)

n(propan-1-ol) = 1.50 ÷ 60.0 = 0.0250 mol

1 : 1 ratio, so maximum n(propanal) = 0.0250 mol

maximum mass of propanal = 0.0250 × 58.0 = 1.45 g

percentage yield = (0.609 ÷ 1.45) × 100

percentage yield = 42.0 %

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(d) The table contains data on propanone and ethanoic acid.

Substance	Molar mass / g mol^{-1}	Boiling temperature / °C	Solubility in water
Propanone	58	56	completely miscible
Ethanoic acid	60	118	completely miscible

(i) Explain, by reference to the data and any intermolecular forces involved, the difference in the boiling temperatures.

(4)

Propanone and ethanoic acid have similar molar masses (58 and 60 g mol^{-1}), so they have a similar number of electrons and so similar London forces.

Both molecules are polar (C=O), so both have permanent dipole-dipole forces between their molecules.

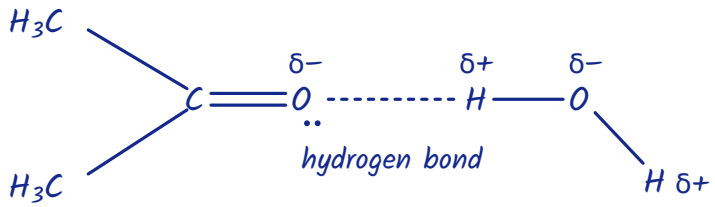
Only ethanoic acid has an O–H group, so only ethanoic acid forms (intermolecular) hydrogen bonds between its molecules.

Hydrogen bonds are stronger, so more energy is needed to break the hydrogen bonds between ethanoic acid molecules, giving it a much higher boiling temperature (118 °C compared with 56 °C).

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(ii) Explain, with the aid of a diagram, why propanone is completely miscible with water.

(2)



Propanone forms hydrogen bonds with water: a lone pair on the δ− oxygen of the C=O group forms a hydrogen bond with a δ+ hydrogen atom of a water molecule, as shown in the diagram.

So propanone molecules can mix fully with water molecules.

(Total for Question 6 = 16 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

7 Organic compounds containing nitrogen include amides, amines, amino acids and nitriles.

(a) Propylamine, $CH_3CH_2CH_2NH_2$, may be formed from either a nitrile or a halogenoalkane.

(i) Give the reagent and essential condition for the formation of propylamine from a nitrile.
Include an equation for the reaction.

(2)

Reagent and condition: $LiAlH_4$ in dry ether (then dilute acid)

$CH_3CH_2CN + 4[H] \rightarrow CH_3CH_2CH_2NH_2$

(ii) Give the reagent and essential conditions for the formation of propylamine from a halogenoalkane.
Include an equation for the reaction.

(3)

Reagent: excess ammonia dissolved in ethanol (ethanolic NH_3)

Conditions: heat, in a sealed tube (under pressure)

$CH_3CH_2CH_2Br + 2NH_3 \rightarrow CH_3CH_2CH_2NH_2 + NH_4Br$

(b) A compound produced a peak due to an N—H stretching vibration in its infrared spectrum with a wavenumber of 3220 cm^{-1}.

This compound could be

(1)

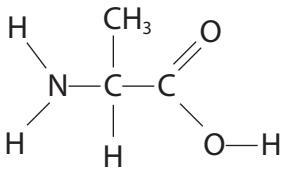
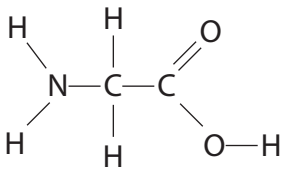
- ☒ **A** an amide
- ☐ **B** an amine
- ☐ **C** either an amide or an amine
- ☐ **D** neither an amide nor an amine

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

*(c) Alanine and glycine are amino acids.

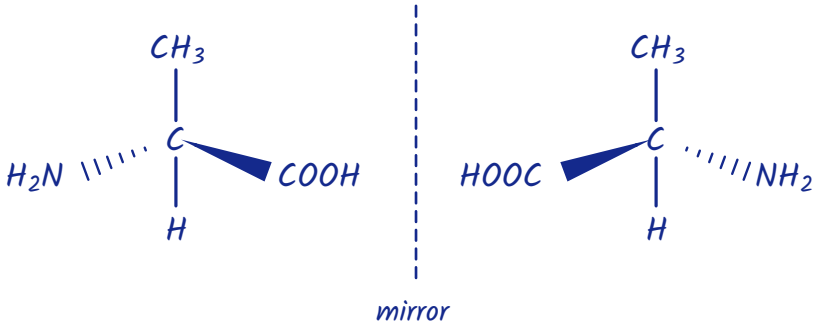
Amino acid	Structure
alanine	
glycine	

Compare and contrast the structures, optical activity and reactions with acids and bases of alanine and glycine.

Include diagrams, structures and equations to illustrate your answer.

(6)

The two enantiomers of alanine (non-superimposable mirror images):



Similarities: alanine and glycine are both 2-amino acids (α-amino acids), with an NH_2 group and a COOH group bonded to the same carbon atom.

Both exist as zwitterions in the solid and in solution, because the acidic COOH group donates a proton to the basic NH_2 group: glycine is $H_3N^+CH_2COO^-$ and alanine is $H_3N^+CH(CH_3)COO^-$.

Difference in structure: alanine has a CH_3 side chain where glycine has an H atom.

Optical activity: in alanine the central carbon is bonded to four different groups (H, CH_3, NH_2 and COOH), so it is a chiral centre (asymmetric carbon). So alanine exists as two enantiomers, which are non-superimposable mirror images, as drawn above.

Therefore a solution of one enantiomer of alanine rotates the plane of polarisation of

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

plane-polarised light, so alanine is optically active.

Glycine has two H atoms on the central carbon, so it has no chiral centre, so it does not rotate the plane of plane-polarised light and is not optically active.

Reactions with acids and bases: both are amphoteric and react in the same way, because the side chain (CH_3 or H) does not react.

With an acid, the COO^- group accepts a proton:

$H_3N^+CH_2COO^- + H^+ \rightarrow H_3N^+CH_2COOH$

$H_3N^+CH(CH_3)COO^- + H^+ \rightarrow H_3N^+CH(CH_3)COOH$

With a base, the NH_3^+ group donates a proton:

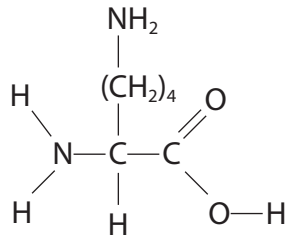
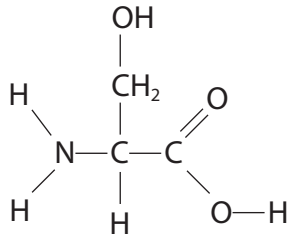
$H_3N^+CH_2COO^- + OH^- \rightarrow H_2NCH_2COO^- + H_2O$

$H_3N^+CH(CH_3)COO^- + OH^- \rightarrow H_2NCH(CH_3)COO^- + H_2O$

So the two amino acids differ only in their optical activity, while their acid and base reactions are the same.

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(d) Lysine and serine are two more amino acids.

Amino acid	Structure of amino acid
lysine	
serine	

Explain the difference in the volumes of 0.010 mol dm^{-3} hydrochloric acid required to completely react with separate 10.0 cm^3 samples of aqueous lysine and of aqueous serine, both of concentration 0.010 mol dm^{-3}.

(2)

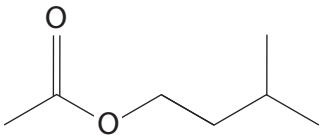
Lysine requires twice the volume of hydrochloric acid: 20.0 cm^3 compared with 10.0 cm^3 for serine.

This is because lysine has two basic amine (NH_2) groups, so each lysine molecule accepts two protons, whereas serine has only one NH_2 group so accepts one proton (its OH group is not basic).

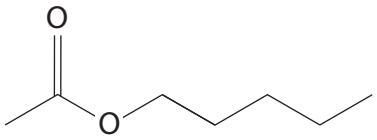
(Total for Question 7 = 14 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

8 Esters have many uses due to their characteristic aromas and often have common names. For example, isoamyl acetate is referred to as banana oil and amyl acetate has a scent similar to apples.



isoamyl acetate



amyl acetate

(a) What is the number of peaks in a ^{13}C NMR spectrum of isoamyl acetate and of amyl acetate?

(1)

		isoamyl acetate	amyl acetate
☐	**A**	5	6
☐	**B**	6	6
☒	**C**	6	7
☐	**D**	7	7

(b) State the molecular formula of amyl acetate.

(1)

$C_7H_{14}O_2$

(c) Deduce the structural formula of the carboxylic acid that could be used to form both isoamyl acetate and amyl acetate.

(1)

CH_3COOH

(d) Deduce the **name** of the alcohol that forms isoamyl acetate.

(1)

3-methylbutan-1-ol

(e) Give the systematic name for amyl acetate.

(1)

pentyl ethanoate

DO NOT WRITE IN THIS AREA

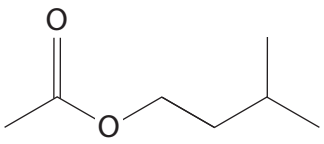
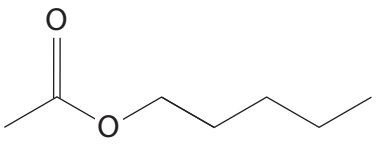
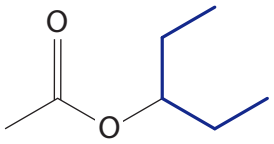
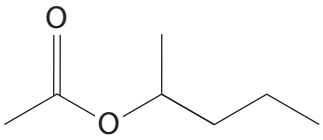
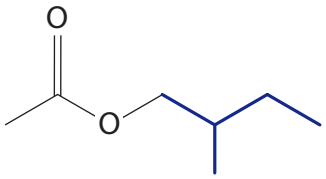
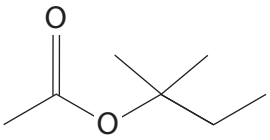
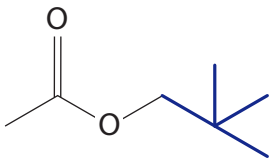
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

(f) The carboxylic acid used to make isoamyl acetate and amyl acetate can also be used to make six further ester isomers. The structures of two of these esters, **A** and **B**, are shown.

(i) Complete the **skeletal** formulae of **three** of the remaining esters. Names are **not** required.

(3)

 isoamyl acetate	 amyl acetate	
 ester **A**		
 ester **B**		

(ii) Write an equation to show the formation of ester **A** from an acyl chloride and an alcohol.

(2)

$CH_3COCl + CH_3CH(OH)CH_2CH_2CH_3$

$\rightarrow CH_3COOCH(CH_3)CH_2CH_2CH_3 + HCl$

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

(g) Esters can be hydrolysed by heating under reflux with aqueous acid or alkali.

Compare and contrast these two methods of hydrolysis for amyl acetate.

(4)

Similarity: both methods break the ester bond and both produce the same alcohol, pentan-1-ol.

Acid: $CH_3COOC_5H_{11} + H_2O \rightleftharpoons CH_3COOH + C_5H_{11}OH$

Acid hydrolysis is reversible (an equilibrium), so it does not go to completion, and it produces the carboxylic acid, ethanoic acid. The acid (H^+) is a catalyst, so it is not used up.

Alkali: $CH_3COOC_5H_{11} + OH^- \rightarrow CH_3COO^- + C_5H_{11}OH$

Alkaline hydrolysis is irreversible, so it goes to completion, and it produces the carboxylate ion (ethanoate, e.g. sodium ethanoate with NaOH). The alkali is a reactant, so it is used up.

(Total for Question 8 = 14 marks)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

9 At high temperatures, ethanal decomposes to form methane and carbon monoxide. The reaction is second order with respect to ethanal and second order overall.

$$CH_3CHO \rightarrow CH_4 + CO$$

(a) Write the rate equation for this reaction.

(1)

rate = k[CH₃CHO]²

(b) Deduce the units of the rate constant given that the units of rate are mol dm^{-3} s^{-1}.

(1)

units of k = mol dm⁻³ s⁻¹ ÷ (mol dm⁻³)²

= dm³ mol⁻¹ s⁻¹

(c) The table shows the concentration of ethanal in a sample at different times.

Time / s	Concentration of ethanal / mol dm^{-3}
0	0.72
420	0.36
1260	0.18

Calculate average values for the rate of reaction between 0 and 420 seconds and between 420 and 1260 seconds.
Give your answers to an appropriate number of significant figures.

(2)

rate = (0.72 − 0.36) ÷ (420 − 0) = 8.57 × 10⁻⁴

0 s – 420 s *8.6 × 10⁻⁴ mol dm⁻³ s⁻¹*

rate = (0.36 − 0.18) ÷ (1260 − 420) = 2.14 × 10⁻⁴

420 s – 1260 s *2.1 × 10⁻⁴ mol dm⁻³ s⁻¹*

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA

(d) Explain why the data given and your answers in (c) show that the reaction is **neither** zero order **nor** first order.

(2)

Not zero order, because the rate is not constant: the rate between 420 and 1260 s is lower than the rate between 0 and 420 s.

Not first order, because the half-life is not constant: the concentration halves (0.72 to 0.36) in 420 s, but halving again (0.36 to 0.18) takes 840 s. Also when the concentration halves the rate falls to a quarter, not a half.

(e) The rate constant for the reaction was determined at five temperatures. The results are given in the table.

Temperature (T) / K	1/ Temperature ($1/T$) / K^{-1}	Rate constant (k) / units in (b)	$\ln k$
700	1.43×10^{-3}	0.011	–4.51
730	1.37×10^{-3}	0.035	–3.35
760	1.32×10^{-3}	0.105	–2.25
790	*1.27×10^{-3}*	0.343	*–1.07*
810	1.23×10^{-3}	0.787	–0.24

Determine the activation energy, E_a, in kJ mol^{-1}, by completing the data in the table and plotting a graph of $\ln k$ against $1/T$.

You should include the value of the gradient of the line and its units.

The Arrhenius equation can be expressed as $\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$

(7)

gradient = $-4.00 \div (0.187 \times 10^{-3}) = -2.14 \times 10^4$ K (graph opposite)

gradient = $-E_a \div R$ so $E_a = -\text{gradient} \times R$

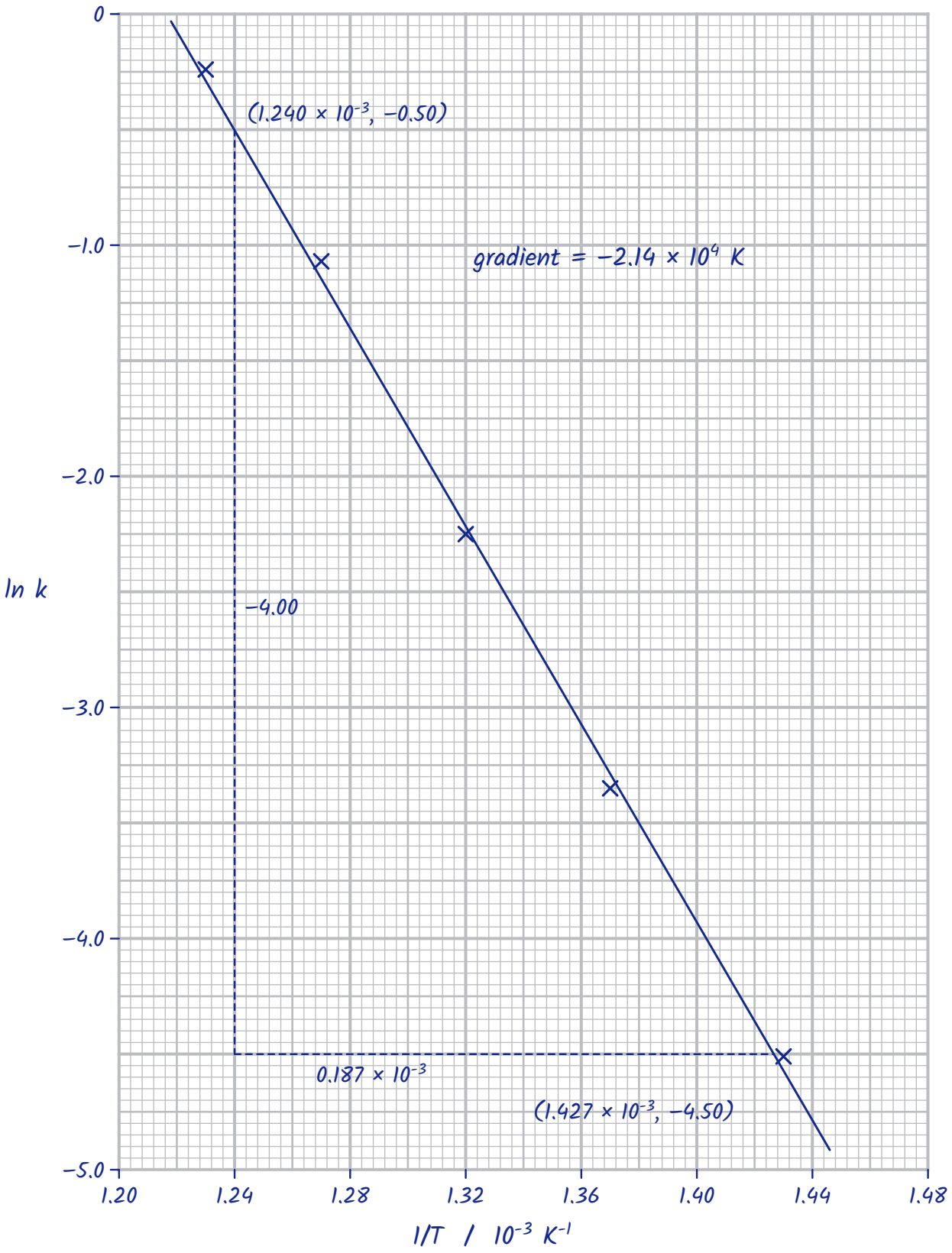
$E_a = 2.14 \times 10^4 \times 8.31 = 1.78 \times 10^5$ J mol^{-1}

$E_a = +178$ kJ mol^{-1}

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



Total for Question 9 = 13 marks)

TOTAL FOR PAPER = 90 MARKS

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8)
							1.0 H hydrogen 1										(18) 4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									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	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(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							

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

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA