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

Monday 16 June 2025

Morning (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.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **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 how 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 ▶

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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 This question is about mass spectrometry.

(a) Which molecule would **not** give a molecular ion peak with $m/z = 74$?

(1)

☐ **A** C_2H_5COOH

☐ **B** CHOCOOH

☒ **C** $CH_2(OH)COOH$

☐ **D** CH_3COOCH_3

(b) The fragmentation pattern in a mass spectrum can be used to distinguish between structural isomers.

Which m/z peak would be present in the mass spectrum of propanal, CH_3CH_2CHO, but **not** in the mass spectrum of propanone, CH_3COCH_3?

(1)

☐ **A** 15

☒ **B** 29

☐ **C** 43

☐ **D** 59

(Total for Question 1 = 2 marks)

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2 Intermolecular forces affect the physical properties of compounds.

(a) Which of these isomers, with the formula C_8H_{18}, will have the **lowest** boiling temperature?

(1)

- ☒ **A** $(CH_3)_2CHCH_2C(CH_3)_3$
- ☒ **B** $(CH_3)_2CHCH_2CH(CH_3)CH_2CH_3$
- ☒ **C** $CH_3CH_2CH_2C(CH_3)_2CH_2CH_3$
- ☒ **D** $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

(b) Pentan-1-ol and hexane have the same number of electrons but pentan-1-ol is much less volatile than hexane.

Explain this difference in volatility.

(2)

Pentan-1-ol has hydrogen bonds between its molecules (because of the O–H group), whereas hexane only has London forces.

Hydrogen bonds are stronger than London forces, so more energy is needed to break the intermolecular forces in pentan-1-ol, so it is less volatile.

(c) Iodine is a solid at room temperature but on gentle heating it vaporises.

What bonds or forces are being broken?

(1)

- ☒ **A** covalent bonds
- ☒ **B** ionic bonds
- ☒ **C** London forces
- ☒ **D** permanent dipole-dipole forces

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(d) The boiling temperature of boron trichloride is 13 °C while that of phosphorus trichloride is 76 °C.

Explain, in terms of the shapes of the molecules, why phosphorus trichloride has a much higher boiling temperature, although both compounds have polar bonds.

Do not consider differences in London forces.

(4)

Boron trichloride has a trigonal planar shape (bond angle 120°), so it is symmetrical.

Phosphorus trichloride has a (trigonal) pyramidal shape, because of the lone pair on phosphorus.

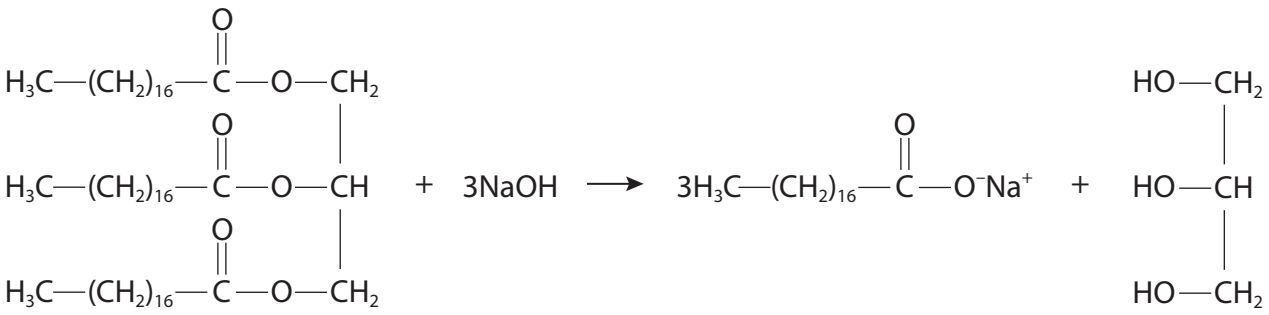
In boron trichloride the bond dipoles cancel, so the molecule has no overall dipole (it is non-polar). In phosphorus trichloride the dipoles do not cancel, so it is a polar molecule with an overall dipole.

So phosphorus trichloride has permanent dipole-dipole forces between its molecules, which need more energy to overcome, so its boiling temperature is higher.

(Total for Question 2 = 8 marks)

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3 Sodium stearate is a constituent of soap and can be made from the hydrolysis of stearin as shown.



stearin | sodium stearate | glycerol

(a) What is the atom economy, by mass, for the production of sodium stearate in this reaction?

Substance	stearin	sodium hydroxide	sodium stearate	glycerol
Molar mass / g mol^{-1}	890	40	306	92

(1)

- ☒ **A** 32.9 %
- ☒ **B** 34.4 %
- ☒ **C** 90.9 %
- ☒ **D** 98.7 %

(b) What is the IUPAC name for glycerol?

(1)

- ☒ **A** 1,2,3-trihydroxypropane
- ☒ **B** propanetriol
- ☒ **C** 2,3-dihydroxypropan-1-ol
- ☒ **D** propane-1,2,3-triol

(Total for Question 3 = 2 marks)

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4 Covalent bonds can break by either heterolytic fission or homolytic fission.

(a) The reaction of butane and chlorine involves homolytic bond fission of the chlorine molecule, using ultraviolet radiation.

(i) The energy of ultraviolet radiation can be calculated using the formula shown.

$$\text{Energy of one photon} = \frac{h \times c}{\lambda}$$

Planck constant, $h = 6.626 \times 10^{-34}$ J s
Speed of light, $c = 3.00 \times 10^{8}$ m s^{-1}
Avogadro constant, $L = 6.02 \times 10^{23}$ mol^{-1}
Wavelength, λ in metres

The mean C—H bond energy is 413 kJ mol^{-1} compared to 243 kJ mol^{-1} for the Cl—Cl bond.

Show, by calculation, that ultraviolet radiation, with the wavelength 315 nm, can break the Cl—Cl bond but not the C—H bond.

(4)

λ = 315 nm = 315 × 10^{-9} m = 3.15 × 10^{-7} m

Energy of one photon = (6.626 × 10^{-34} × 3.00 × 10^{8}) ÷ 3.15 × 10^{-7}

= 6.3105 × 10^{-19} J

Energy per mole of photons = 6.3105 × 10^{-19} × 6.02 × 10^{23}

= 379 890 J mol^{-1} = 379.9 kJ mol^{-1}

379.9 kJ mol^{-1} > 243 kJ mol^{-1}, so the UV radiation has enough energy to break the Cl–Cl bond.

379.9 kJ mol^{-1} < 413 kJ mol^{-1}, so it does not have enough energy to break the C–H bond.

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(ii) In the reaction of chlorine with butane, the propagation stage produces two different butyl radicals.

Write the structural formulae of these two radicals.

(2)

$CH_3CH_2CH_2CH_2\bullet$

primary butyl radical

$CH_3CH\bullet CH_2CH_3$

secondary butyl radical

(iii) The reaction of chlorine with butane produces 2-chlorobutane (72%) and 1-chlorobutane (28%).

Explain, by application of your knowledge of the stability of carbocations, why there is a higher yield of 2-chlorobutane.

(2)

1-chlorobutane forms from the primary butyl radical and 2-chlorobutane forms from the secondary butyl radical (the radicals shown in (ii)).

The secondary radical is more stable, as it has two electron-releasing alkyl groups (positive inductive effect) instead of one.

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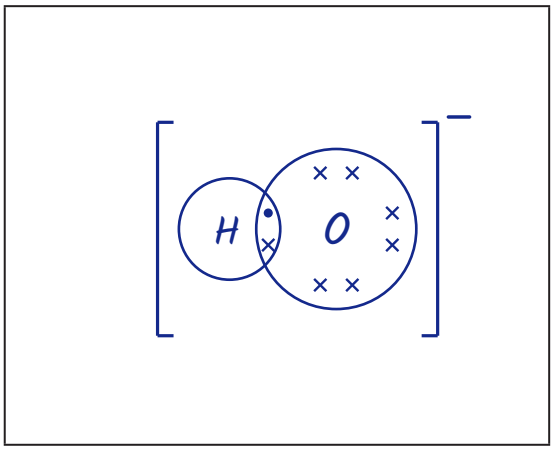
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(b) Water molecules can undergo either heterolytic fission to form a hydroxide ion or homolytic fission to form a hydroxyl radical.

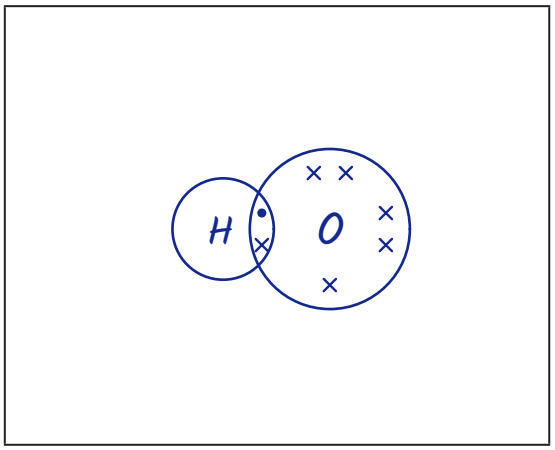
Draw dot-and-cross diagrams of these two species.

Use crosses (×) for oxygen electrons and dots (●) for hydrogen electrons.

(2)



hydroxide ion



hydroxyl radical

(c) Which process does **not** involve heterolytic fission?

(1)

☒ **A** the formation of the cyanide nucleophile from KCN

☐ **B** the formation of propanenitrile from bromoethane

☐ **C** hydroxide ion attack on bromopropane in ethanol

☐ **D** aqueous silver nitrate in ethanol reacting with iodoethane

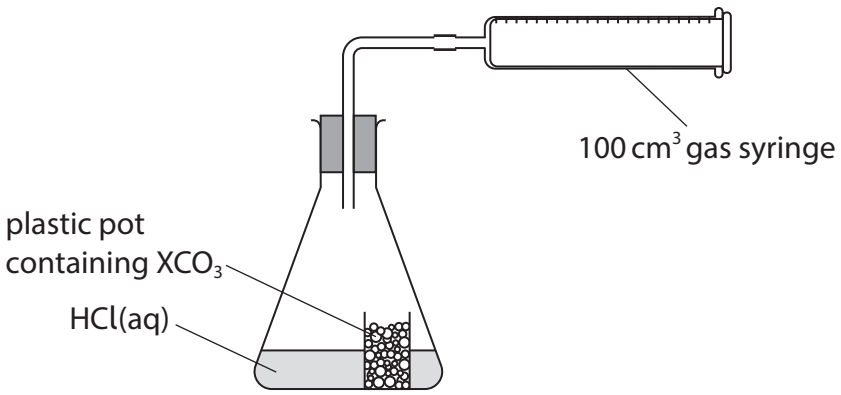
(Total for Question 4 = 11 marks)

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5 The kinetics of the reactions of hydrochloric acid with metal carbonates were investigated using the apparatus shown.



The equation for the reaction is shown.

$$XCO_3(s) + 2HCl(aq) \rightarrow XCl_2(aq) + CO_2(g) + H_2O(l)$$

(a) One student used 0.355 g of calcium carbonate.

Calculate the minimum volume, in **cm³**, of 0.100 mol dm^{-3} hydrochloric acid that would completely react with this mass of calcium carbonate.
Give your answer to an appropriate number of significant figures.

[Calcium carbonate molar mass = 100.1 g mol^{-1}]

(4)

Moles of $CaCO_3$ = 0.355 ÷ 100.1 = 3.5465×10^{-3} mol

1 mol $CaCO_3$ reacts with 2 mol HCl

Moles of HCl = $2 \times 3.5465 \times 10^{-3} = 7.0929 \times 10^{-3}$ mol

Volume of HCl = $7.0929 \times 10^{-3} \div 0.100 = 0.070929$ dm^3

= $0.070929 \times 1000 = 70.929$ cm^3

Minimum volume = 70.9 cm^3 (3 s.f.)

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(b) State why powdered metal carbonate reacts faster than large lumps.

(1)

Powder has a greater surface area, so more particles are exposed to the acid and there are more frequent collisions.

(c) A second student used 4.19×10^{-3} mol of magnesium carbonate and suggested heating up the apparatus to speed up the rate of reaction.

(i) If the use of heat means that the carbon dioxide gas is at a temperature of 74.0 °C, then the apparatus shown would **not** give a measurable result.

Justify this comment by calculating the volume of carbon dioxide gas at this temperature using the ideal gas equation.

Assume that the pressure remains at 100 kPa throughout the experiment.

(4)

$p = 100\ kPa = 1.00 \times 10^5\ Pa$ $\quad T = 74.0 + 273 = 347.0\ K$

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

$V = (4.19 \times 10^{-3} \times 8.31 \times 347.0) \div 1.00 \times 10^5$

$= 1.21 \times 10^{-4}\ m^3 = 1.21 \times 10^{-4} \times 10^6 = 121\ cm^3$

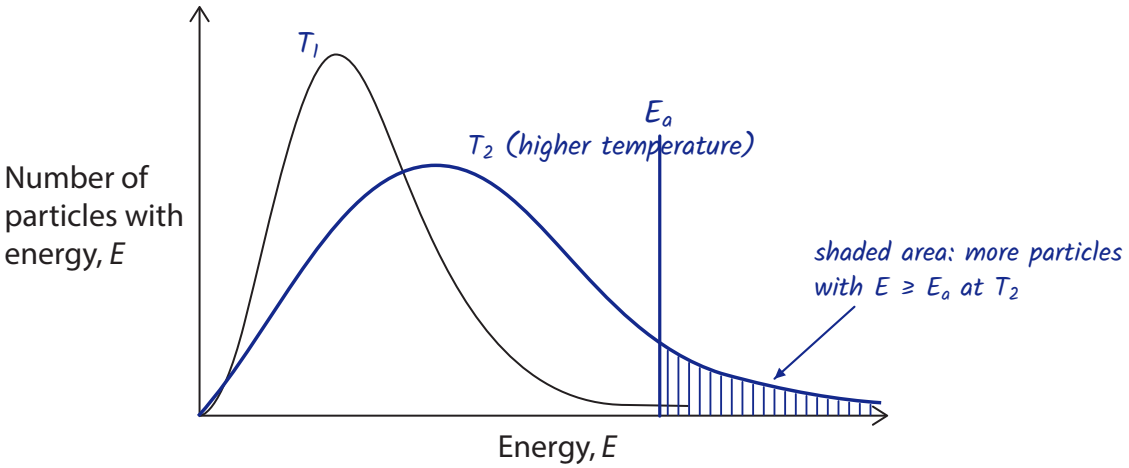
$121\ cm^3$ is greater than the $100\ cm^3$ capacity of the gas syringe, so the volume of CO_2 would exceed the syringe and could not be measured.

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(ii) The student suggested that the Maxwell–Boltzmann distribution of molecular energies for a reaction mixture at a particular temperature is shown in a graph.

Explain, by adding another line to the graph **and** by annotating the graph, how heating the reaction mixture results in a faster reaction rate.

(3)

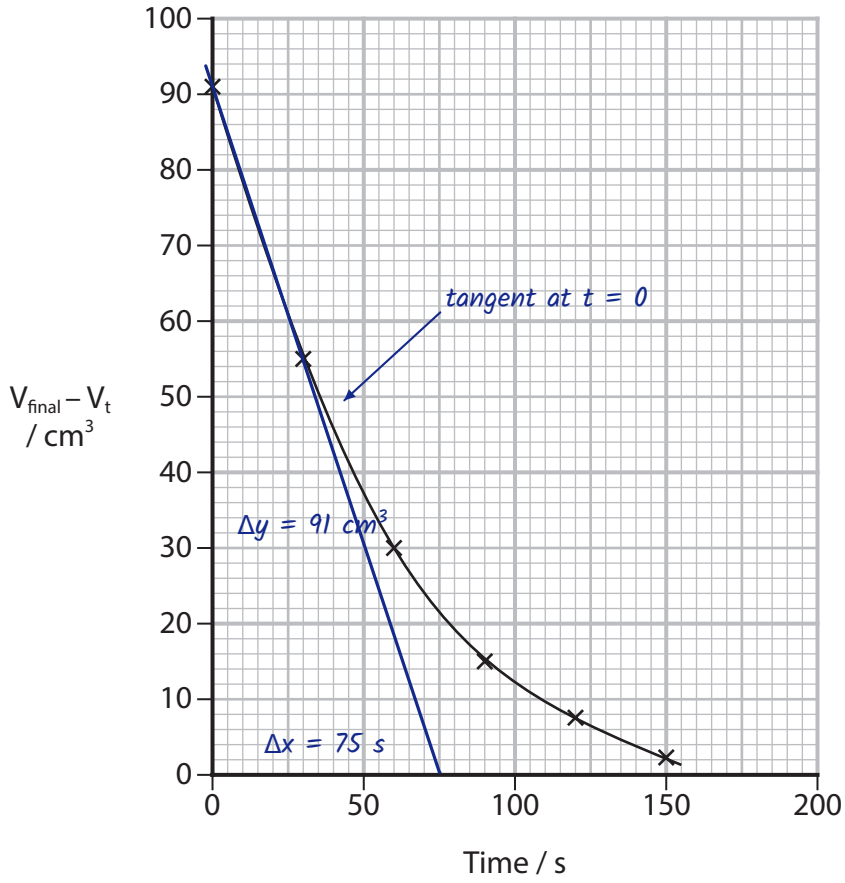


At the higher temperature the curve is flatter and the peak is lower and shifted to higher energy (the area under the curve stays the same).

A greater proportion of particles have energy greater than or equal to the activation energy (shaded area), so more collisions are successful per second and the rate is faster.

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(d) A third student, in order to obtain the rate of reaction, measured the volume of gas produced at various times and used their data to plot the graph shown.



Determine the initial rate of this reaction.
You **must** show your working on the graph.
Include units in your answer.

(2)

Initial rate = gradient of the tangent at t = 0

= 91 cm^3 ÷ 75 s

Initial rate = 1.21 cm^3 s^{-1}

(Total for Question 5 = 14 marks)

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6 This question is about benzaldehyde and some related compounds.

*(a) Benzaldehyde (C_6H_5CHO) can be distinguished from phenylethanone ($C_6H_5COCH_3$) and benzoic acid (C_6H_5COOH) using **chemical** tests.

Describe a series of **chemical** tests which could be used to distinguish each of these compounds, giving the relevant tests and their positive results.

Do **not** use tests which give positive results for more than one of these compounds.

Detailed information of the laboratory equipment is not required.

(6)

Benzaldehyde: add Tollens' reagent (ammoniacal silver nitrate) to a sample of each compound and warm in a water bath.

Only benzaldehyde gives a silver mirror, because it is an aldehyde and is oxidised to benzoic acid. Phenylethanone is a ketone and benzoic acid is a carboxylic acid, so neither can be oxidised and there is no change.

Phenylethanone: add iodine in sodium hydroxide solution (alkaline iodine) to a fresh sample of each compound and warm.

Only phenylethanone gives a pale yellow precipitate (of triiodomethane, iodoform), because it contains the $CH_3C{=}O$ (methyl ketone) group. Benzaldehyde and benzoic acid do not contain this group, so no precipitate forms.

Benzoic acid: add sodium hydrogencarbonate solution to a fresh sample of each compound.

Only benzoic acid gives effervescence (fizzing), because it is a carboxylic acid and is acidic enough to react to release carbon dioxide gas, which turns limewater milky.

Benzaldehyde and phenylethanone are not acidic, so no bubbles are seen.

So each compound gives a positive result in only one test, and the three compounds can be distinguished.

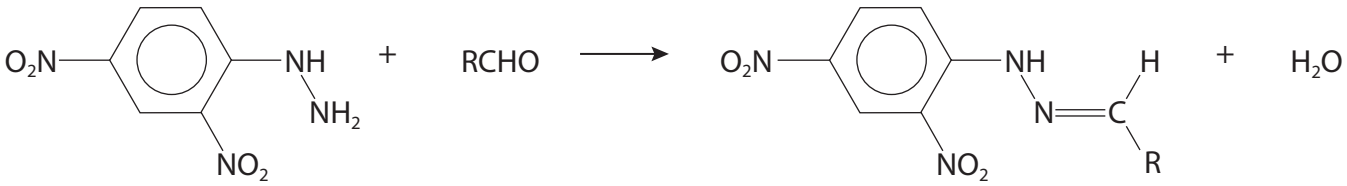
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(b) The reaction of 2,4-dinitrophenylhydrazine (2,4-DNPH) with a general aldehyde, RCHO, is shown.



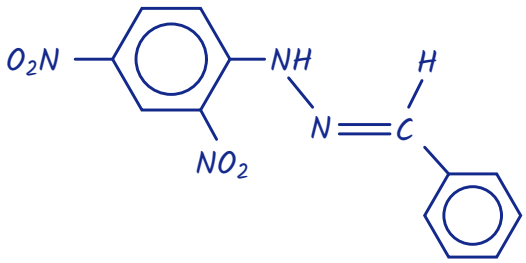
(i) What is this type of reaction?

(1)

- ☒ **A** addition
- ☒ **B** condensation
- ☒ **C** hydrolysis
- ☒ **D** polymerisation

(ii) Draw the structure of the organic product of the reaction of 2,4-DNPH with benzaldehyde.

(1)



(Total for Question 6 = 8 marks)

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7 This question is about amines.

(a) Aliphatic amines may be prepared from halogenoalkanes or from nitriles.

Assess these two methods for the preparation of butylamine.
Consider the reagents, the conditions needed, atom economy and the type of reaction.
Include equations.

(7)

From the halogenoalkane: $CH_3CH_2CH_2CH_2Br + 2NH_3 \rightarrow CH_3CH_2CH_2CH_2NH_2 + NH_4Br$

Reagent and conditions: excess (concentrated) ammonia in ethanol (alcoholic solvent), heated in a sealed tube under pressure.

This is nucleophilic substitution. The atom economy is low because NH_4Br is also formed. Also the butylamine can react further with more halogenoalkane, so secondary and tertiary amines and a quaternary ammonium salt are also produced, giving a mixture and a low yield. Heating in a sealed tube is also difficult in practice.

From the nitrile: $CH_3CH_2CH_2CN + 4[H] \rightarrow CH_3CH_2CH_2CH_2NH_2$

Reagent and conditions: $LiAlH_4$ in dry ether, or hydrogen gas with a nickel catalyst: $CH_3CH_2CH_2CN + 2H_2 \rightarrow CH_3CH_2CH_2CH_2NH_2$

This is reduction (hydrogenation). Butylamine is the only product, so the atom economy is greater (100% with hydrogen) and there are no further substitution products, although water must be excluded when using $LiAlH_4$.

So the nitrile method is better, giving a purer product with a higher atom economy, but the nitrile has one carbon fewer, so it must be made first, e.g. from 1-bromopropane and KCN.

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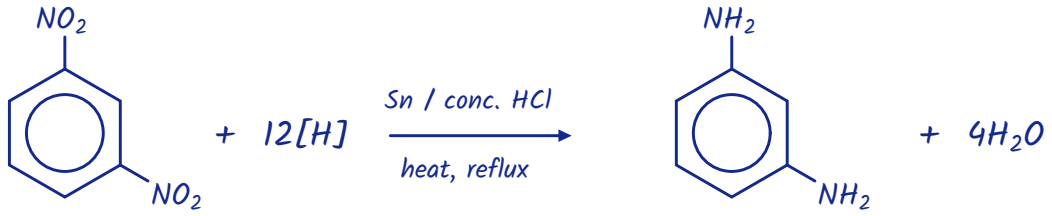
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(b) Preparation of the aromatic amine, benzene-1,3-diamine, requires different conditions.

(i) Write an equation for the preparation of benzene-1,3-diamine from the corresponding dinitro-compound and include necessary conditions.

(3)



Conditions *tin and concentrated HCl, heat under reflux*

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(ii) Explain the factors affecting the basicity of benzene-1,3-diamine and propane-1,3-diamine.

Include reference to information given in the table.

Substance	pK_{b1}
benzene-1,3-diamine	8.89
propane-1,3-diamine	3.83

K_{b1} is the equilibrium constant for the first protonation reaction.

The equation is shown.

$$RNH_2 + H_2O \rightleftharpoons RNH_3^+ + OH^-$$

(4)

A base is a proton (H^+) acceptor: the lone pair of electrons on a nitrogen atom accepts a proton.

Propane-1,3-diamine has the lower pK_{b1} (3.83), so it has the larger K_{b1} and is the stronger base. Benzene-1,3-diamine has the higher pK_{b1} (8.89), so it is the weaker base.

In benzene-1,3-diamine the lone pair of electrons on each nitrogen is delocalised with the π system (ring of delocalised electrons) of the benzene ring.

So the lone pair on nitrogen is less available to accept a proton, so benzene-1,3-diamine is a weaker base.

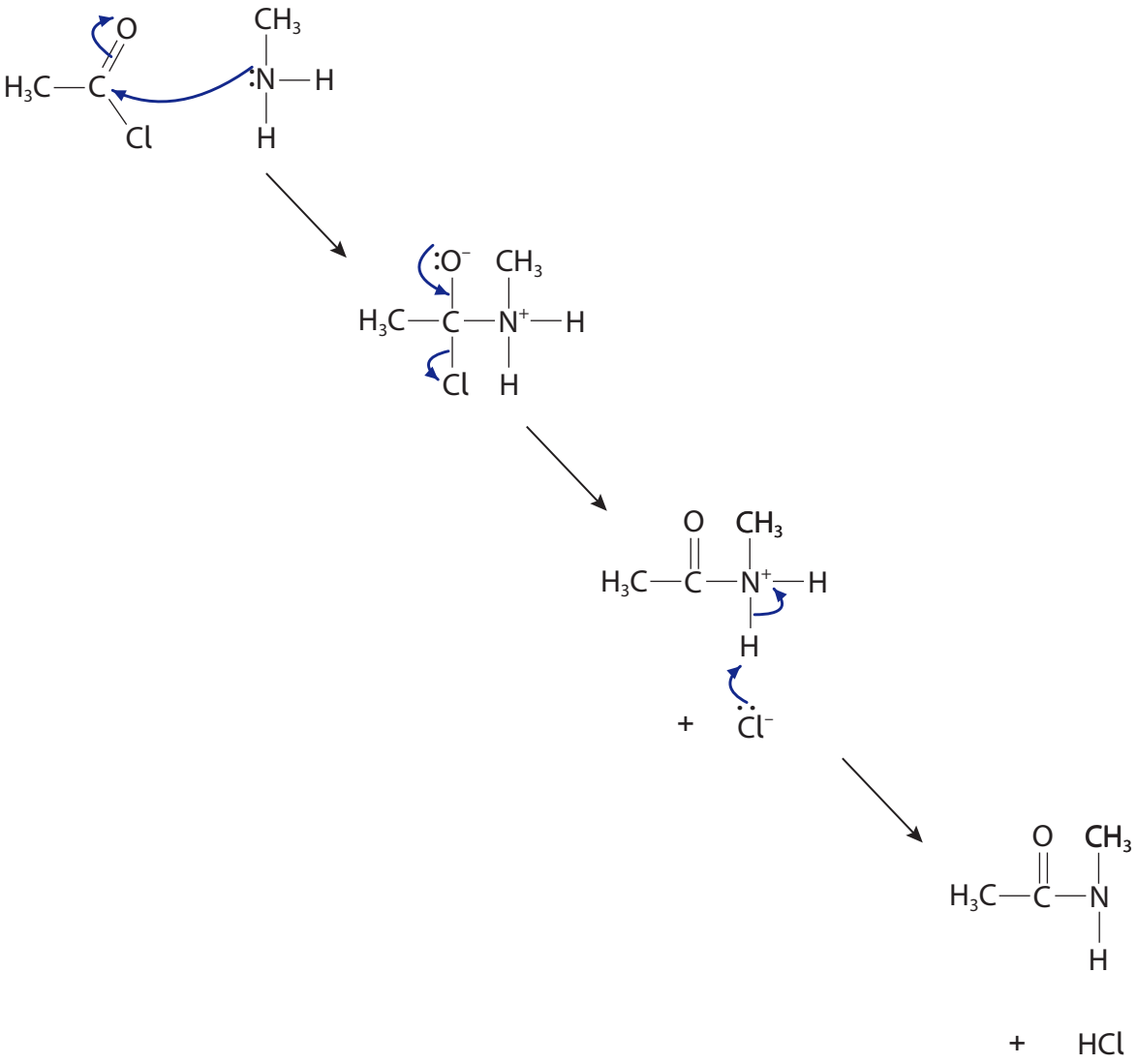
In propane-1,3-diamine the alkyl groups are electron releasing (positive inductive effect), increasing the electron density on nitrogen, so the lone pair is more available to accept a proton.

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(c) Methylamine reacts with ethanoyl chloride to produce an amide.
An incomplete outline of the mechanism is shown.

Add curly arrows to show the movement of the electrons in the mechanism.

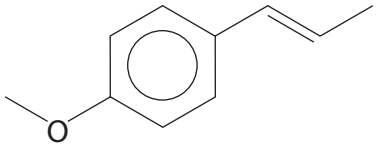
(3)



(Total for Question 7 = 17 marks)

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8 The flavour of aniseed and liquorice is mainly due to anethole, which has the structure shown.



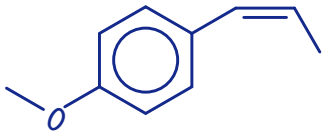
(a) Give the molecular formula of anethole.

(1)

$C_{10}H_{12}O$

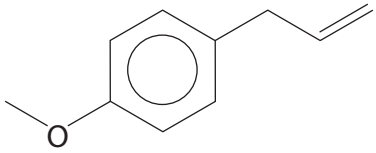
(b) Draw the stereoisomer of anethole.

(1)



cis isomer

(c) A structural isomer of anethole is estragole, which has the structure shown.



Give a reason why anethole shows stereoisomerism but estragole does **not**.

(1)

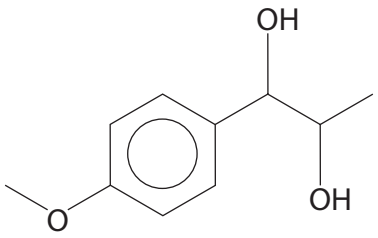
In anethole each carbon atom of the C=C bond is bonded to two different groups (H and CH_3; H and the ring). In estragole one carbon of the C=C bond is bonded to two identical H atoms.

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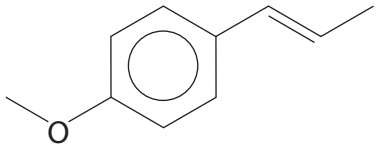
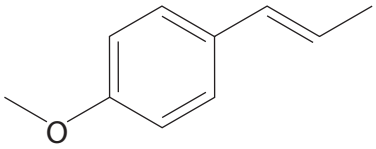
(d) What is the reagent required to convert anethole to the diol shown?



(1)

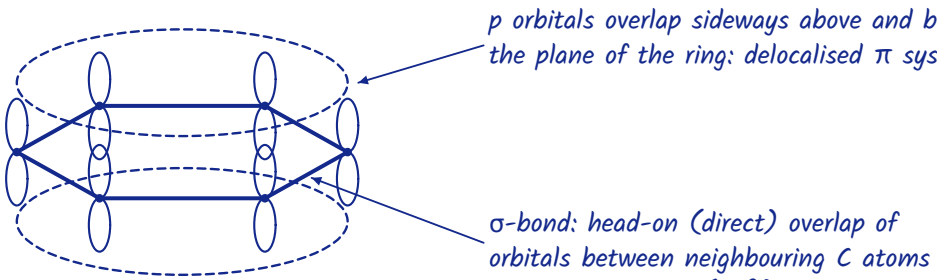
- ☒ **A** acidified potassium manganate(VII)
- ☐ **B** aqueous sodium hydroxide
- ☐ **C** ethanolic potassium hydroxide
- ☐ **D** steam with an acid catalyst

(e) The structure of anethole can be drawn with a delocalised model of the benzene ring or with the Kekulé benzene ring structure as shown.

delocalised model	Kekulé structure
	

(i) Describe how the orbitals of carbon atoms overlap to form the σ-bonds and the π-bonds in the delocalised model of the benzene ring.
You may include a labelled diagram in your answer.

(3)



σ-bonds form by head-on (direct) overlap of orbitals (sp^2) from neighbouring carbon atoms.

Each carbon has one p orbital at right angles to the ring; adjacent p orbitals overlap sideways above and below the plane of the ring.

This forms a delocalised π system (ring) of six electrons.

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(ii) Explain why the delocalised model of the benzene ring is the preferred representation rather than the Kekulé cyclic triene.
Refer to **one** physical and **one** thermodynamic measurement in your answer.

(4)

Thermodynamic: ΔH of hydrogenation for the Kekulé structure would be three times that of cyclohexene, −360 kJ mol^{-1}, more exothermic than the measured −208 kJ mol^{-1} for benzene.

So the delocalised model is more (energetically) stable, by about 152 kJ mol^{-1}.

Physical: X-ray diffraction shows that in the Kekulé structure the C=C and C–C bonds would have different lengths,

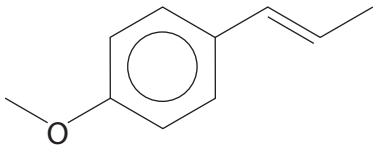
but in the delocalised model (and real benzene) all the carbon-carbon bond lengths are equal, a regular hexagon.

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(f) Anethole is also present in some alcoholic drinks such as the Greek liquor, ouzo.

The anethole is responsible for the so-called 'ouzo effect'. This effect is the transparent ouzo liquor turning milky when water is added.
The addition of water causes the anethole to form oily droplets which result in a stable milky emulsion.

Deduce the solubility of anethole in ethanol and in water from the 'ouzo effect'. Justify your answer with reference to the anethole structure shown, but detailed descriptions of intermolecular forces are not required.



anethole

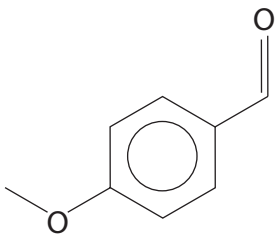
(3)

Anethole is soluble in ethanol, as the ouzo (anethole in ethanol) is transparent.

Anethole is insoluble (only slightly soluble) in water, as adding water makes it separate as oily droplets.

Anethole is mostly non-polar (benzene ring and hydrocarbon chain, no O–H group), so its structure is more similar to ethanol, which has a non-polar ethyl group. Anethole forms stronger London forces with the ethyl part of ethanol than with water, and hydrogen bonds with water much less readily.

(g) A derivative of anethole is anisaldehyde, which has the structure shown.



What is the number of peaks in the ^{13}C NMR spectrum of anisaldehyde?

(1)

- ☐ **A** 5
- ☒ **B** 6
- ☐ **C** 7
- ☐ **D** 8

(Total for Question 8 = 15 marks)

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9 Halogenoalkanes are hydrolysed to form alcohols.

(a) The rate constant for the reaction of 1-bromopropane with aqueous sodium hydroxide was determined at five temperatures.
Some of the results are given in the table.

Temperature (T) / K	1/Temperature ($1/T$) / K^{-1}	Rate constant (k) / $dm^3\,mol^{-1}\,s^{-1}$	ln k
298	3.36×10^{-3}	1.36×10^{-4}	–8.9
304	3.29×10^{-3}	2.25×10^{-4}	–8.4
308	3.25×10^{-3}	3.04×10^{-4}	–8.1
318	3.14×10^{-3}	6.76×10^{-4}	–7.3
328	3.06×10^{-3}	1.23×10^{-3}	–6.7

(i) Complete the table of data.

(2)

(ii) Plot a graph of ln k against $1/T$ and use it to determine the activation energy, E_a, for this reaction in $kJ\,mol^{-1}$.

You must show your working on the graph and include the value of the gradient of the line and its units.

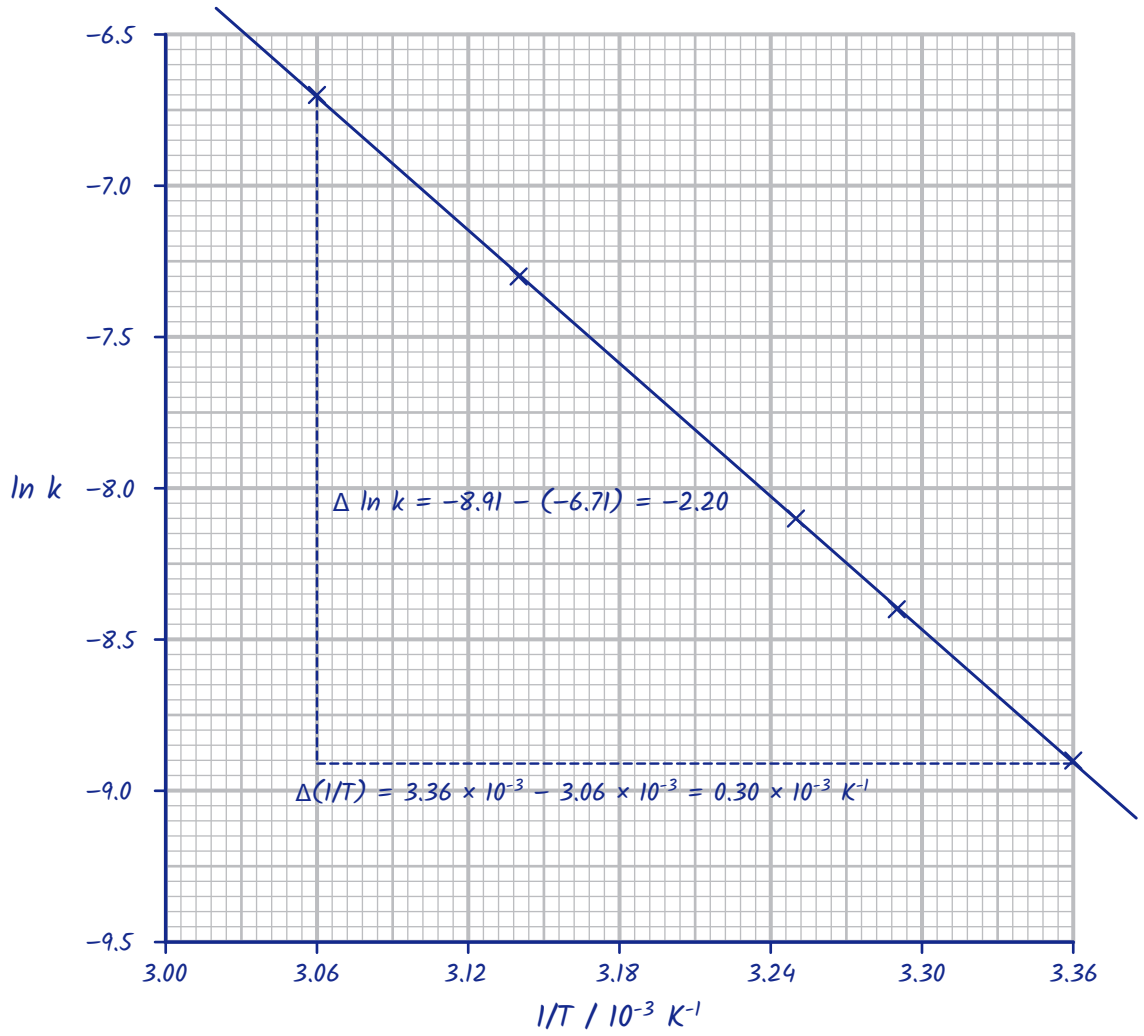
The Arrhenius equation can be expressed as

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

(5)

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gradient = $-2.20 \div 0.30 \times 10^{-3} = -7330$ K

gradient = $-E_a/R$ so E_a = −gradient × R

$E_a = 7330 \times 8.31 = 60\,900$ J mol^{-1}

$E_a = 60.9$ kJ mol^{-1}

Gradient ..... -7.33×10^3 K .....

Activation energy ..... +60.9 kJ mol^{-1} .....

(iii) The rate constant for the reaction of 1-bromopropane with aqueous potassium hydroxide has the units of $dm^3\,mol^{-1}\,s^{-1}$.

Explain why it can be deduced that the reaction is second order overall. Assume that the units of the rate of reaction are $mol\,dm^{-3}\,s^{-1}$.

(2)

rate = k[A]^n, so [concentration]^n = rate ÷ k = mol dm^{-3} s^{-1} ÷ dm^3 mol^{-1} s^{-1} = mol^2 dm^{-6}

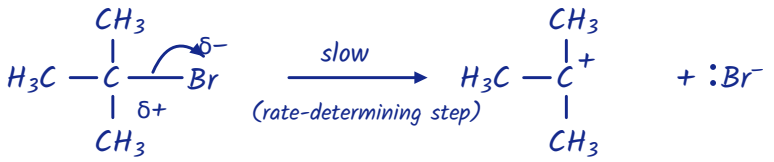
mol^2 dm^{-6} is the units of concentration squared, (mol dm^{-3})^2, so the reaction is second order overall.

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(b) The rate of reaction for the hydrolysis of 2-bromo-2-methylpropane by aqueous hydroxide ions is independent of the concentration of hydroxide ions.

(i) Draw the S_N1 reaction mechanism for this hydrolysis.
Include curly arrows and any relevant dipoles and lone pairs of electrons.

(3)





(ii) State how your mechanism is consistent with the rate of reaction being independent of hydroxide ion concentration.

(1)

The slow (rate-determining) step is step 1, breaking of the C–Br bond to form the carbocation. Hydroxide ions do not appear in step 1, so the rate does not depend on $[OH^-]$.

(Total for Question 9 = 13 marks)

TOTAL FOR PAPER = 90 MARKS

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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

* Lanthanide series	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
* Actinide series	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

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