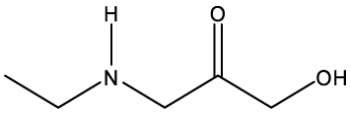
1. The skeletal formula of an organic molecule is shown below.



Which of the following statements is / are correct?

1: The molecule contains an amine group.

2: The molecule contains a carboxylic acid group.

3: The molecule contains an amide group.

A. 1, 2 and 3
B. Only 1 and 2
C. Only 2 and 3
D. Only 1

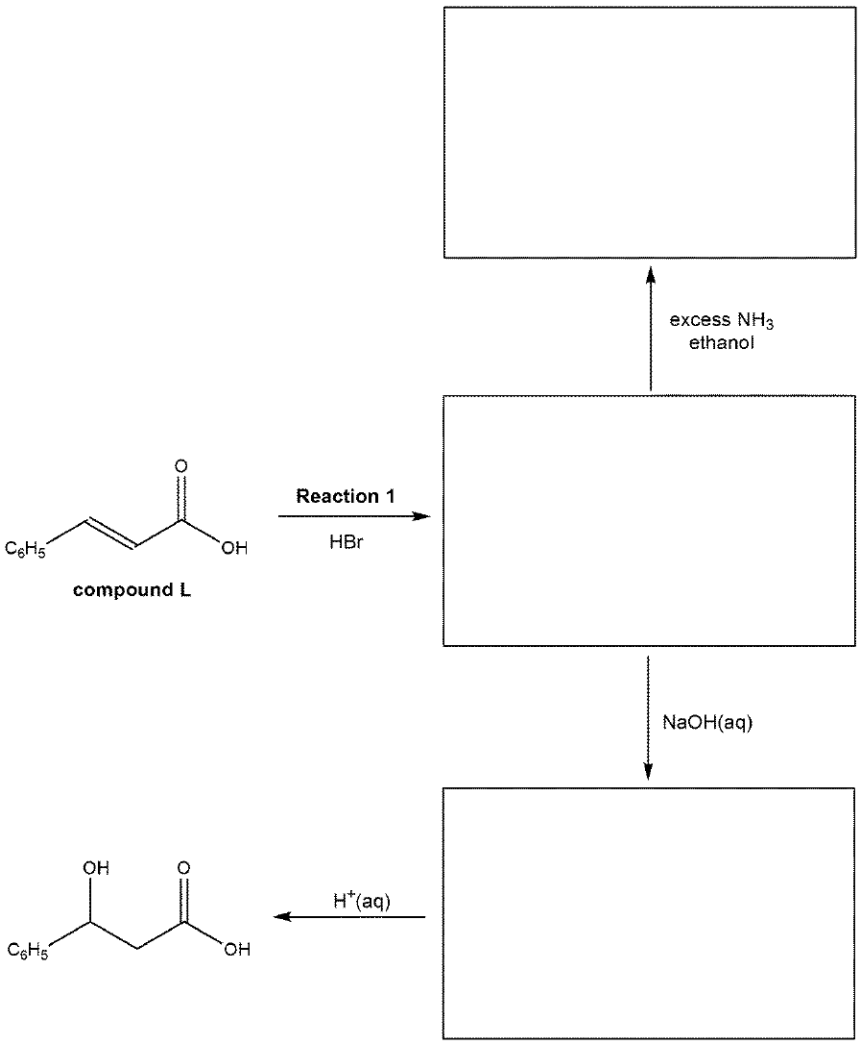
Your answer ☐

[1]

2(a). This question is about the reactions of compounds with more than one functional group.

A chemist investigates some reactions of compound **L**, as shown in the flowchart below.

Complete the flowchart by showing the missing organic structures in the boxes.



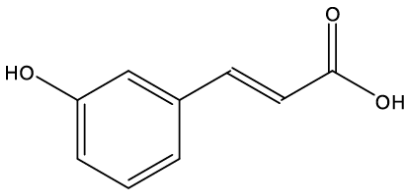
[3]

(b). Outline the mechanism that occurs in **Reaction 1**.

Include curly arrows, relevant dipoles and the name of the mechanism.

name of mechanism ..... **[4]**

(c). The chemist synthesises compound **M**, which can undergo both addition and condensation polymerisation.



compound M

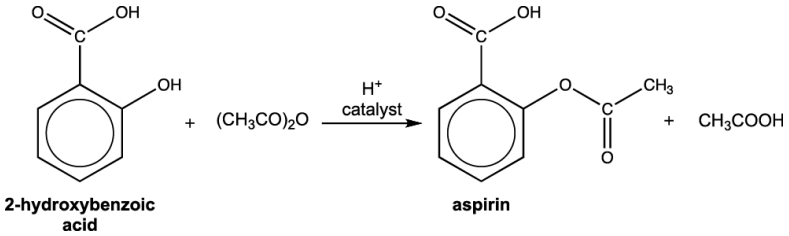
i. Draw the repeat unit of the **addition** polymer formed from compound **M**.

[1]

ii. Draw **two** repeat units of the **condensation** polymer formed from compound **M**.

[2]

3(a). * Aspirin can be made by refluxing 2-hydroxybenzoic acid with ethanoic anhydride, $(CH_3CO)_2O$, in the presence of a concentrated acid catalyst.



2-hydroxybenzoic acid **aspirin**

- Aspirin is much more soluble in hot water than in cold water.
- The percentage yield of aspirin from this method is 90.0%.

Outline a plan to prepare 8.10 g of pure aspirin.

In your answer, include the mass of 2-hydroxybenzoic acid needed and the purification steps from the hot reaction mixture.

[6]

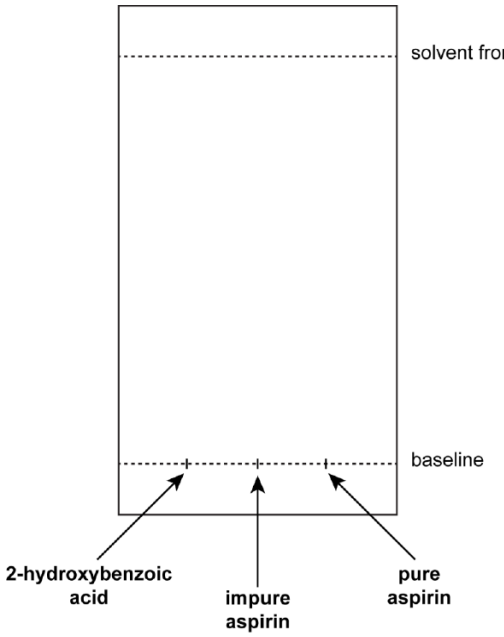
(b). The R_f values and melting point ranges of 2-hydroxybenzoic acid and pure aspirin are shown in the table.

Compound	R_f	Melting point range / °C
2-Hydroxybenzoic acid	0.30	158–161
Pure aspirin	0.75	138–140

i. A student analyses the purity of their impure aspirin by thin-layer chromatography (TLC).

From the results the student concludes that the impure aspirin is contaminated with a small amount of unreacted 2-hydroxybenzoic acid.

Draw spots on the chromatogram below to show how the student arrived at this conclusion.

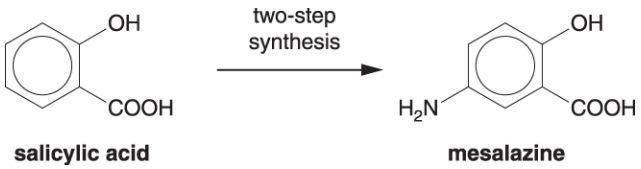


[2]

ii. Predict the melting point range of the impure aspirin.

[1]

4. Mesalazine is a drug that can be synthesised from salicylic acid in two steps.



salicylic acid **mesalazine**

i. Suggest a **two-step** synthesis to prepare mesalazine from salicylic acid.

For **each** step
- state the reagents used,
- write a chemical equation.

[4]

ii. Mesalazine reacts with acids to form salts.

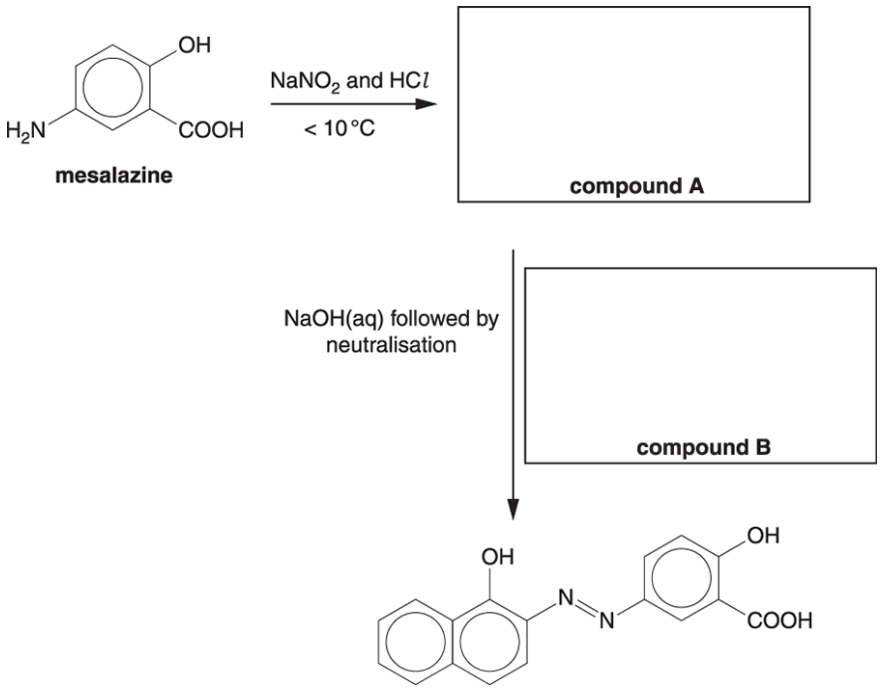
Explain how mesalazine is able to react with acids.

[1]

iii. Mesalazine reacts in another two-stage process as shown below.

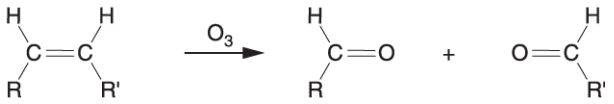
In the boxes, draw the structures of organic compounds **A** and **B**.

[2]



5. 'Ozonolysis' is a technique used in organic chemistry to break open a C=C double bond.

During ozonolysis, an alkene reacts with ozone, O_3. The products are carbonyl compounds, as shown below.



i. Draw the structures of the products you would expect from the complete ozonolysis of the following alkenes.

- pent-2-ene

- hexa-2,4-diene

[3]

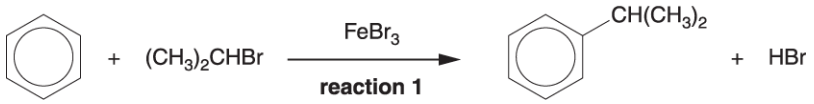
ii. In another ozonolysis reaction, organic compound **G** reacted to form **only** hexane-1,6-dial.

Compound **G** has six carbon atoms.

Draw the structure of compound **G**.

[1]

6(a). Benzene can react with halogenoalkanes in the same way as with bromine, as shown in **reaction 1** below.

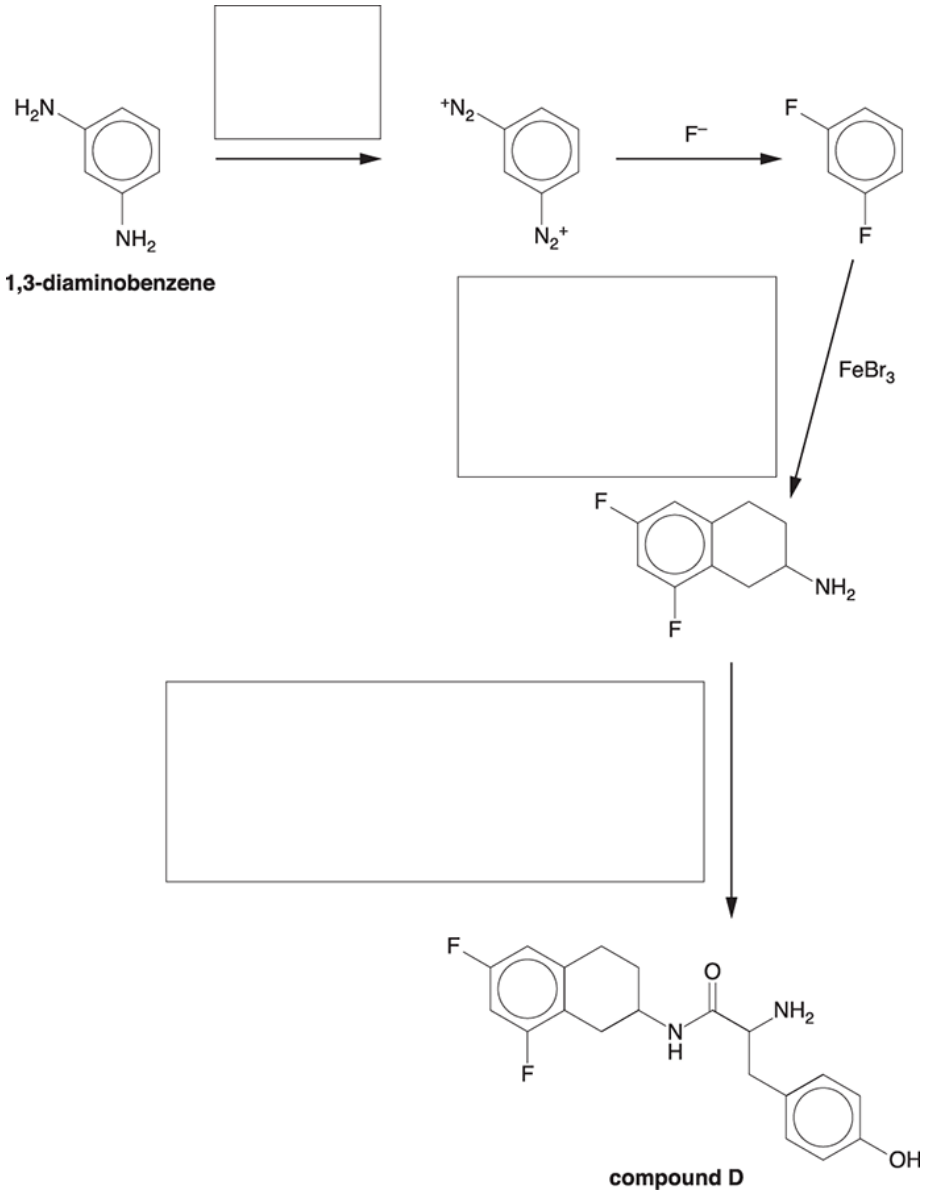


Write an equation to show the formation of the electrophile that reacts with benzene in **reaction 1**.

[1]

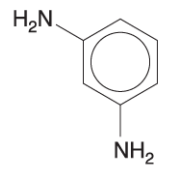
(b). The types of reaction shown in the previous questions can be used to synthesise compound **D**, as shown in the flowchart below.

i. Complete the boxes below to suggest formulae for the reactants involved in the synthesis of compound **D**.
Give structures for organic compounds.

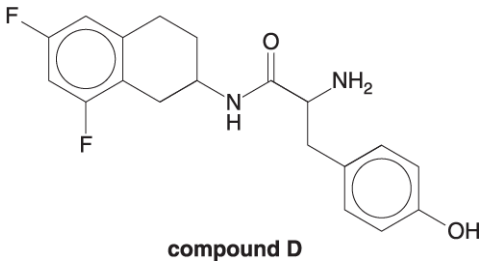


[3]

ii. In a synthesis of compound **D** from 1,3-diaminobenzene shown in the flowchart, 1.73 g of compound **D** was prepared. These structures have been repeated below:



1,3-diaminobenzene



compound D

The overall percentage yield of compound **D** was 40.0%.

M_r of compound **D** = 346.0

Calculate the mass of 1,3-diaminobenzene needed for this synthesis.

mass = ... g **[3]**

iii. Compound **D** has been developed for possible use as a drug to treat heart conditions. When compound **D**, prepared in this synthesis, was given to patients, only 25% of the dose was effective in treating their heart conditions.

Explain why only 25% of the dose was effective. Suggest how the synthesis of compound **D** might be changed to make the dose more effective.

[3]

7(a). A chemistry teacher carries out an experiment to synthesise 2-aminopropan-1-ol, $CH_3CH(NH_2)CH_2OH$.

The teacher asks a university chemistry department to test the 2-aminopropan-1-ol using proton NMR spectroscopy and mass spectrometry.

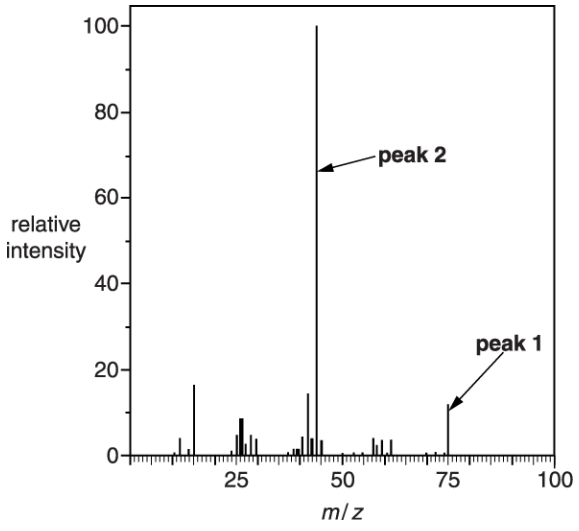
i. For the ^1H NMR analysis, the sample was dissolved in D_2O.

Complete the table to predict the ^1H NMR spectrum of $CH_3CH(NH_2)CH_2OH$ after dissolving in D_2O.

^1H NMR spectrum for $CH_3CH(NH_2)CH_2OH$, dissolved in D_2O		
Chemical shift, δ/ ppm	**Relative peak area**	**Splitting pattern**

[3]

ii. The mass spectrum for $CH_3CH(NH_2)CH_2OH$ is shown below.



Give the formulae for the species responsible for **peak 1** and **peak 2** in the mass spectrum.

peak 1

peak 2

[2]

(b). The teacher synthesises 2-aminopropan-1-ol, $CH_3CH(NH_2)CH_2OH$, from 2-chloropropan-1-ol, CH_3CHC/CH_2OH.

i. State the reagents and conditions required for this synthesis.

[1]

ii. The sample prepared by the teacher from 2-chloropropan-1-ol is not pure. It also contains compound **D**.

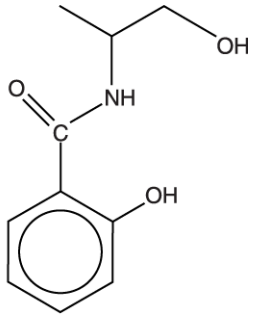
Compound **D** has a molecular formula of $C_6H_{15}NO_2$.

Suggest the structure of compound **D**.

Compound **D**

[1]

(c). In a separate experiment, the chemistry teacher prepares compound **E** from 2-aminopropan-1-ol.



compound E

i. One of the functional groups in compound **E** is a phenol.

Name the other functional groups in compound **E**.

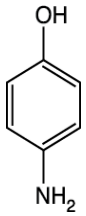
_____

[1]

ii. Draw the structures of the **two** organic products formed when compound **E** is heated under reflux with dilute hydrochloric acid.

[2]

8. The compound shown below can be prepared from phenol.



Which reagent(s) is/are required?

A Concentrated NH_3

B Dilute NH_3

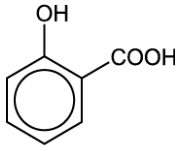
C Dilute HNO_3 and then concentrated HCl/ /Sn

D Dilute HNO_3 and then $NaBH_4$

Your answer ☐

[1]

9. 'Oil of wintergreen' is used to relieve aching muscles and can be prepared by reacting salicylic acid with methanol.



salicylic acid

i. Suggest the structure of oil of wintergreen and the conditions needed to prepare oil of wintergreen from salicylic acid.

Structure

Conditions ..... **[1]**

ii.

iii. After its preparation, oil of wintergreen can be purified by distillation.

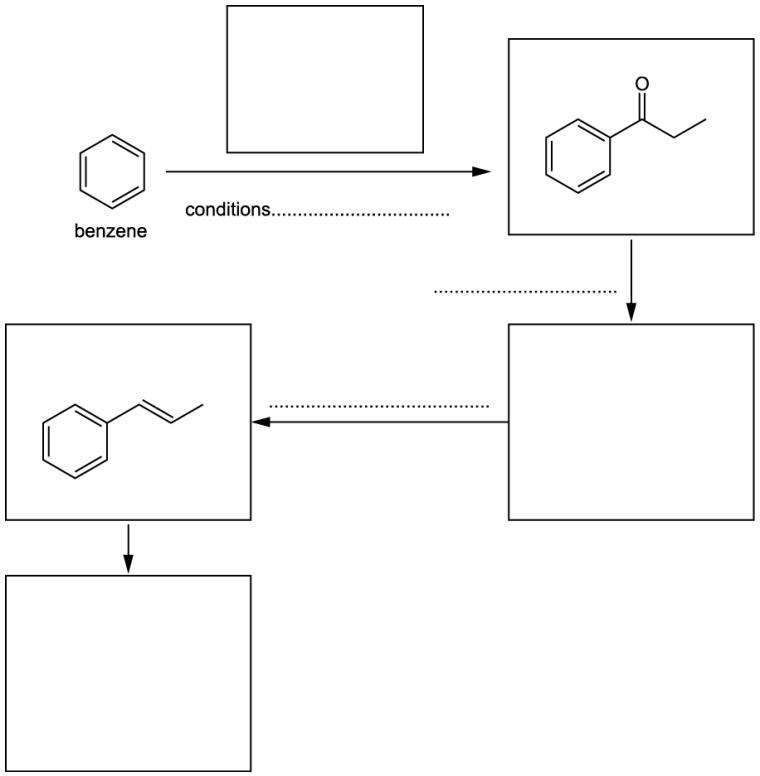
Draw a **labelled** diagram showing how the apparatus is set up for distillation.

[2]

10(a). This question is about the synthesis of a polymer.

The flowchart below shows the synthesis of polymer **I** starting from benzene.

Draw the structures of the missing compounds in the boxes and add the missing reagents on the dotted lines.



repeat unit of polymer **I**

[6]

(b). Polymer **I** cannot be disposed of in landfill sites as it is not biodegradable.

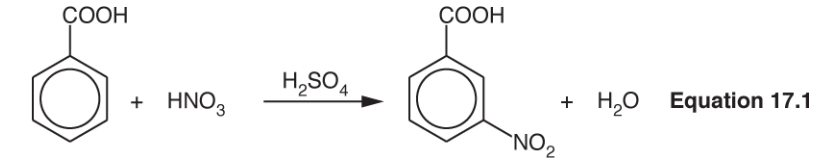
Suggest **one** way of processing waste polymer **I** other than landfill and recycling.

[1]

11(a). This question is about the chemistry of aromatic compounds.

Benzoic acid can be nitrated by concentrated nitric acid in the presence of concentrated sulfuric acid as a catalyst, as shown in **Equation 17.1**.

The organic product of this reaction is 3-nitrobenzoic acid.



Equation 17.1

benzoic acid **3-nitrobenzoic acid**

i. Outline the mechanism for this nitration of benzoic acid.

Show how H_2SO_4 behaves as a catalyst.

[5]

ii. A chemist carries out the reaction in **Equation 17.1** using 4.97 g of benzoic acid.

The chemist obtains 3-nitrobenzoic acid as an impure solid.

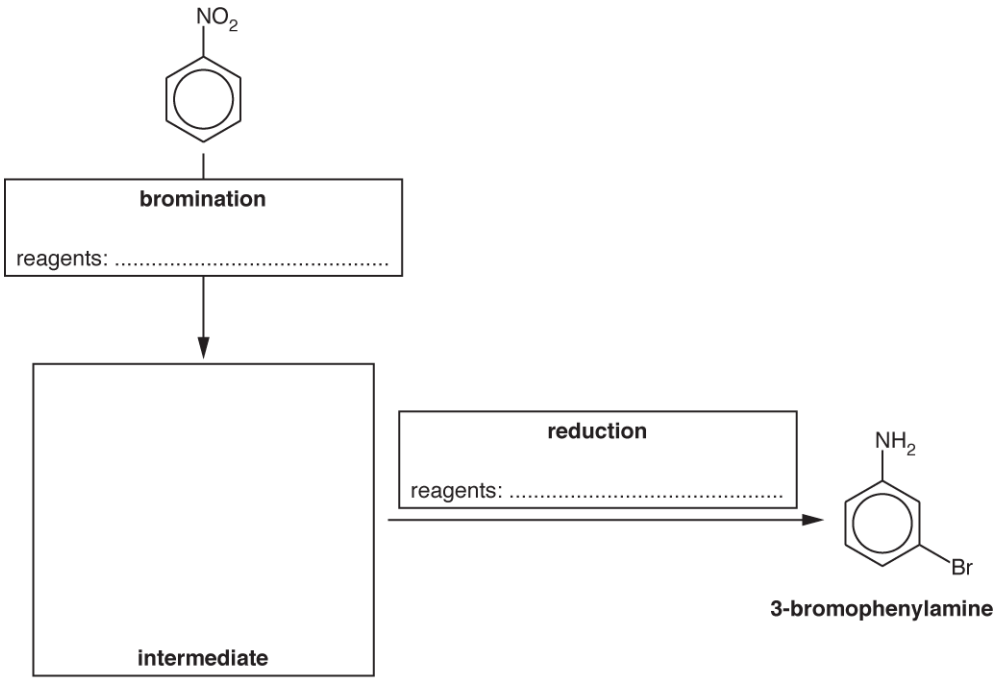
The chemist purifies the solid to obtain 4.85 g of 3-nitrobenzoic acid.

Describe a method to obtain a pure sample of 3-nitrobenzoic acid from the impure solid, determine the percentage yield and check its purity.

[6]

(b). A student synthesises 3-bromophenylamine, shown below, starting from nitrobenzene.

i. Complete the flowchart showing the structure of the intermediate and the **formulae** of the reagents for each stage.



[3]

ii. Another student attempts the same synthesis but carries out reduction **before** bromination. The student was surprised to find that two structural isomers of 3-bromophenylamine had been formed instead of the desired organic product.

Explain this result and suggest the structures of the two isomers that formed.

Explanation

Structures

[3]

12. This question is about organic compounds containing nitrogen.

Sodium cyanide, NaCN, can be reacted with many organic compounds to increase the length of a carbon chain.

i. 1-Chloropropane, $CH_3CH_2CH_2Cl$, reacts with ethanolic sodium cyanide by nucleophilic substitution.

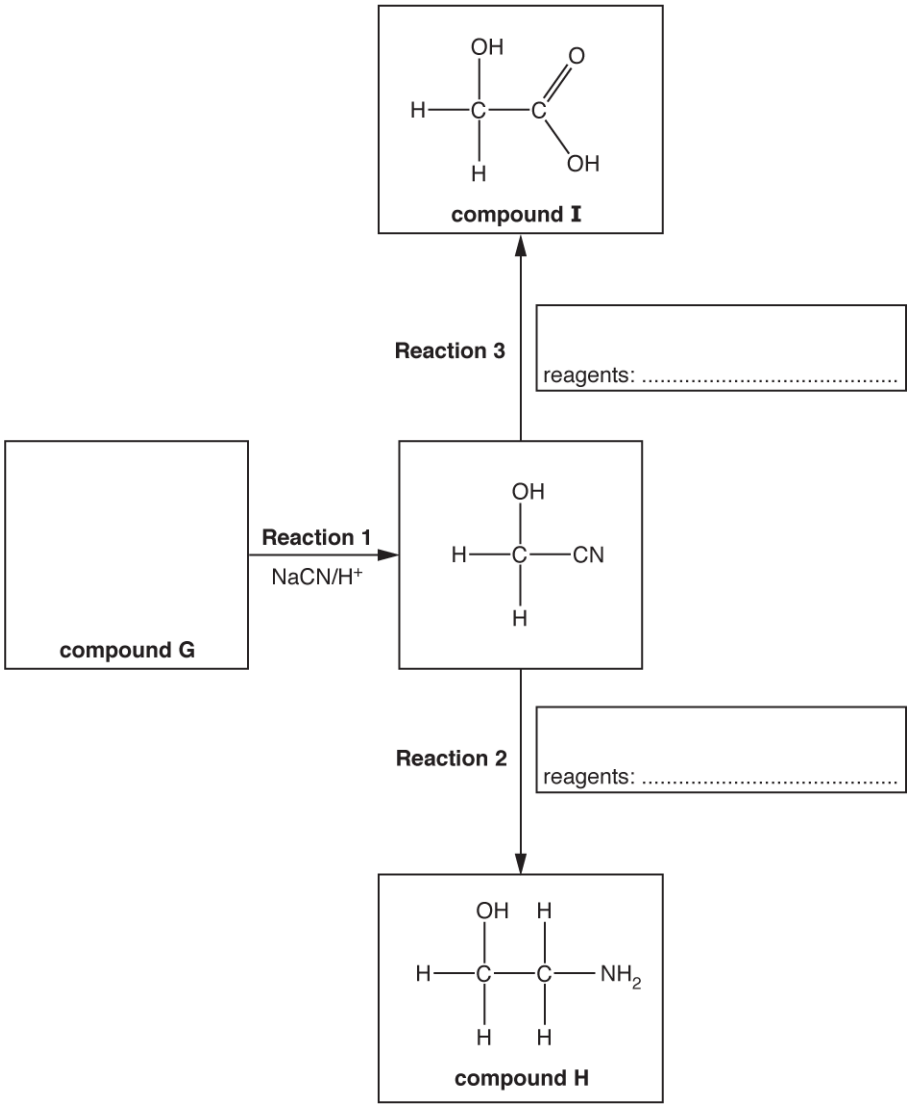
Outline the mechanism for this reaction.

Include curly arrows, relevant dipoles and the structure of the organic product.

[3]

ii. Compound **G** is used to synthesise compounds **H** and **I** as shown in the flowchart below.

Complete the flowchart showing the structure of compound **G** and the **formulae** of the reagents for **Reaction 2** and **Reaction 3**.



[3]

iii. Compound **H** reacts with dilute hydrochloric acid to form a salt.

Explain why compound **H** can react with dilute hydrochloric acid and suggest a structure for the salt formed.

Explanation

Structure

[2]

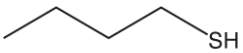
iv. Compound **I** is the monomer for the biodegradable polymer **J**.
Draw **two** repeat units of polymer **J** and suggest a reason why it is biodegradable.

[3]

13. This question is about organic molecules that have a strong smell.

Thiols are foul-smelling, organic sulfur compounds with the functional group –SH.

Butane-1-thiol, shown below, contributes to the strong smell of skunks.



butane-1-thiol

i. Thiols are weak acids.

Write the expression for the acid dissociation constant, K_a, for butane-1- thiol.

[1]

ii. Thiols react with carboxylic acids to form thioesters.

Write an equation for the reaction of butane-1-thiol with ethanoic acid.

Use structures for all organic compounds with the functional groups clearly displayed.

[2]

iii. When beer is exposed to light, 3-methylbut-2-ene-1-thiol is formed, which gives an unpleasant smell and flavour to the beer.

Draw the **skeletal** formula for 3-methylbut-2-ene-1-thiol.

[1]

iv. Propane-1,3- dithiol reacts with carbonyl compounds in a condensation reaction to form a cyclic organic sulfur product.

Write an equation for the reaction of propane-1,3-dithiol with propanone.

Use structures for organic compounds.

[2]

14. Alcohols are used in organic synthesis.

Pentan-2-ol can be prepared by the alkaline hydrolysis of 2-iodopentane.

$$CH_3CH(I)CH_2CH_2CH_3 + NaOH \rightarrow CH_3CH(OH)CH_2CH_2CH_3 + NaI$$

The reaction mixture is boiled for 20 minutes.

i. State the most appropriate technique that could be used to boil the reaction mixture for 20 minutes.

[1]

ii. Describe the mechanism for the alkaline hydrolysis of 2-iodopentane.

In your answer, include the name of the mechanism, curly arrows and relevant dipoles.

name of mechanism: .....

[4]

15. A solid organic compound can be purified by recrystallisation.

Which statement(s) about recrystallisation is/are true?

1 The organic compound is more soluble in hot solvent.

2 The hot solution is cooled before the purified organic compound is collected.

3 The melting point of the purified organic compound is lower than the impure compound.

A 1, 2 and 3

B Only 1 and 2

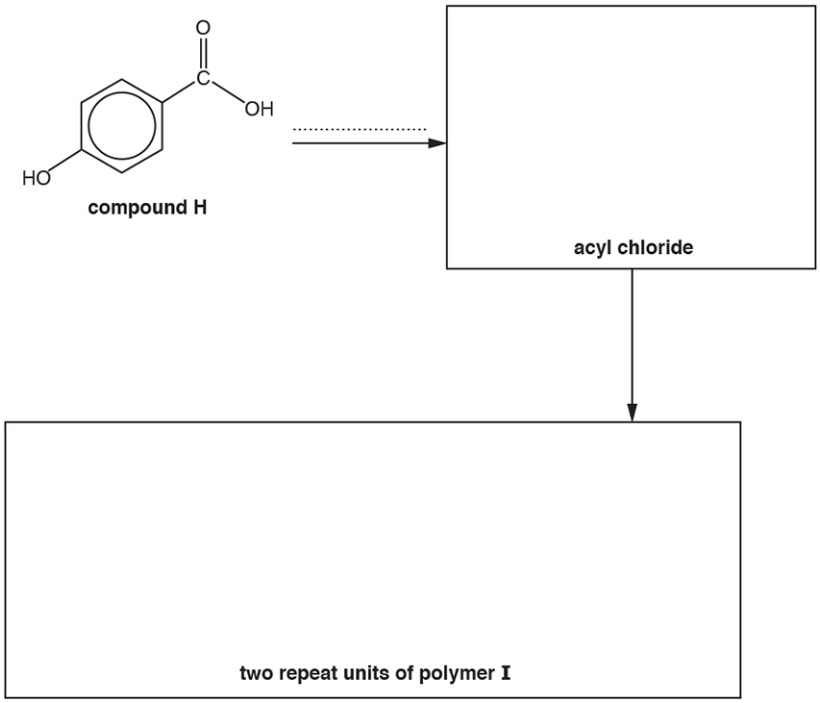
C Only 2 and 3

D Only 1

Your answer ☐ **[1]**

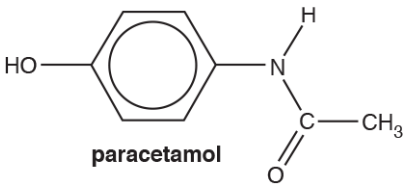
16. Compound **H** is used in the synthesis of polymer **I**, as shown in the flowchart below.

Complete the flowchart by drawing the structure of the acyl chloride and **two** repeat units of polymer **I**, and stating the **formula** of the reagent(s) required for the first stage on the dotted line.



[4]

17. Paracetamol is a solid organic compound used in tablets as a painkiller.



i. Name the functional groups present in paracetamol.

[2]

ii.

iii. * A chemist prepares a pure solid sample of paracetamol from 4-nitrophenol in two stages:

4-nitrophenol paracetamol

Describe a two-stage synthesis of 5.00 g of pure paracetamol from 4-nitrophenol. The overall percentage yield of paracetamol from 4-nitrophenol is 40.0%.

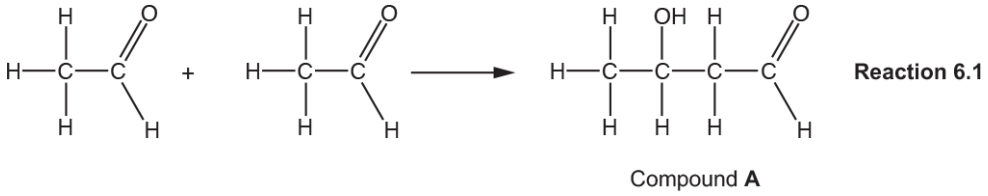
In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol.

[6]

18. This question is about organic reactions.

Compound **A** is formed when ethanal is mixed with OH^-(aq) ions, which act as a catalyst.

The balanced equation is shown in **reaction 6.1** below.



Reaction 6.1

Compound **A**

i. Give the systematic name for compound **A**.

[1]

ii. What type of reaction has taken place?

[1]

iii. **Reaction 6.1** takes place in two steps. OH^- ions act as a catalyst.

In **step 1**, ethanal reacts with OH^- ions to set up an acid–base equilibrium.
In **step 2**, compound **A** is formed.

- Complete the equilibrium for **step 1** and label the conjugate acid–base pairs as: **A1**, **B1** and **A2**, **B2**.

CH^3CHO + OH^- ⇌ +

- Suggest the equation for **step 2**.

[3]

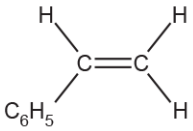
iv. A similar reaction takes place when propanone, $(CH_3)_2CO$, is mixed with $OH^-(aq)$ ions.

Draw the structure of the organic product of this reaction.

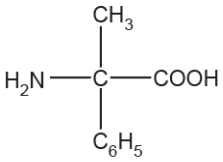
[1]

19. Benzene can be used as the starting material for the synthesis of compounds **D** and **E**, shown below.

In the diagrams C_6H_5 is a phenyl group.



compound D



compound E

Compounds **D** and **E** can be converted into polymers.

i. Draw **two** repeat units of these polymers.

Two repeat units of polymer formed from **D**

Two repeat units of polymer formed from **E**

[3]

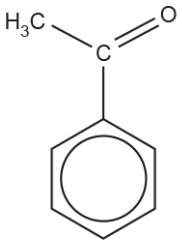
ii. State the **type** of polymer formed from compounds **D** and **E**.

From compound **D**

From compound **E**

[1]

iii. In the synthesis of compounds **D** and **E**, benzene is first reacted with ethanoyl chloride, CH_3COCl, to form phenylethanone, shown below.



phenylethanone

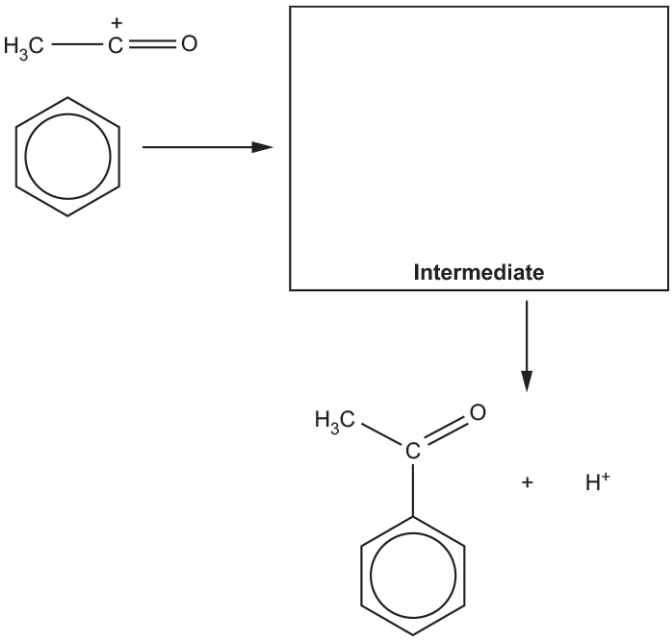
The reaction takes place in the presence of aluminium chloride, $AlCl_3$, which acts as a catalyst. In the mechanism for this reaction,

- ethanoyl chloride first reacts with aluminium chloride to form the $CH_3–C^+=O$ cation
- the $CH_3–C^+=O$ cation then behaves as an electrophile.

Complete the mechanism for the reaction.

Include equations to show the role of the $AlCl_3$ catalyst, relevant curly arrows and the structure of the intermediate.

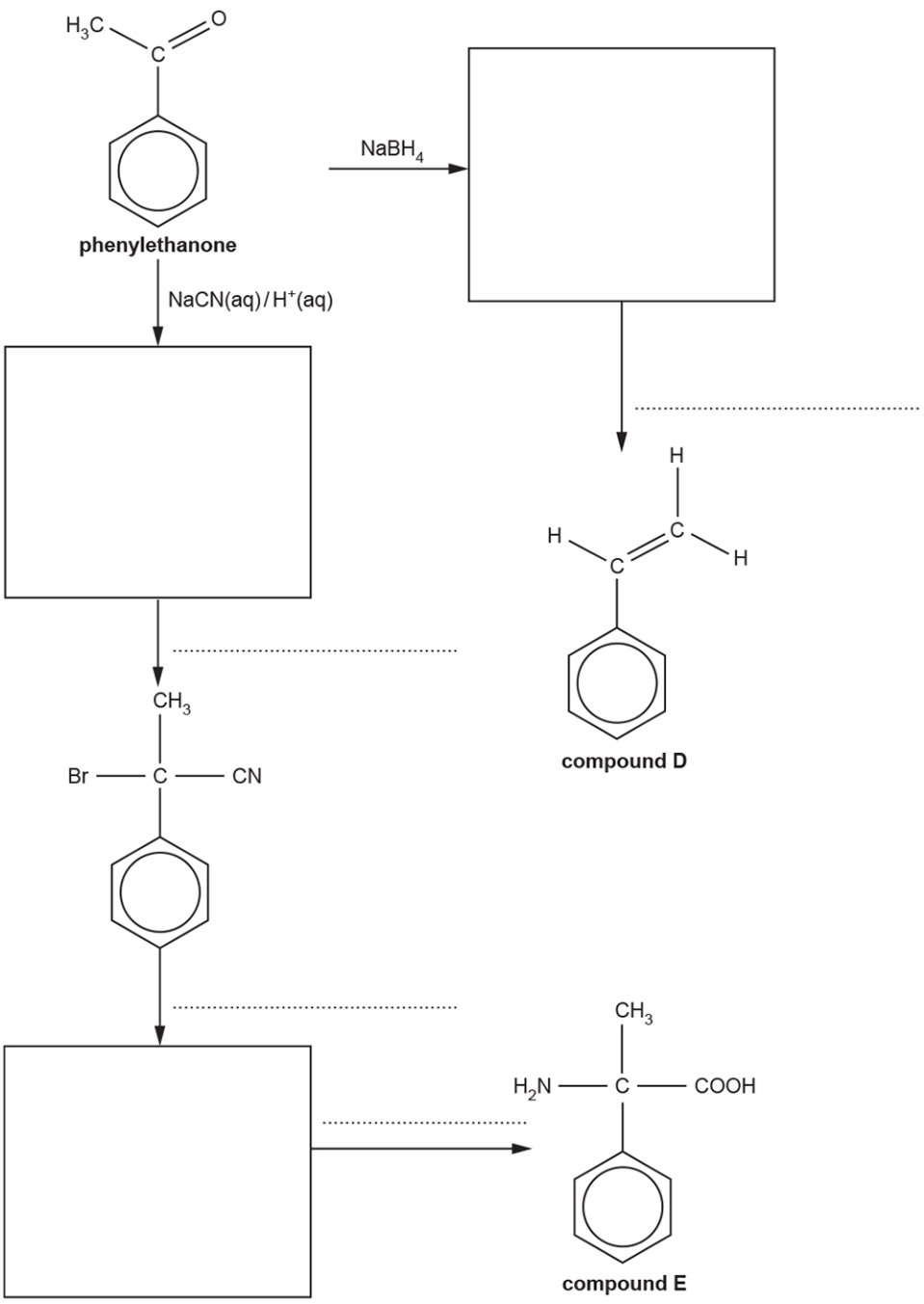
Formation of electrophile



Regeneration of catalyst

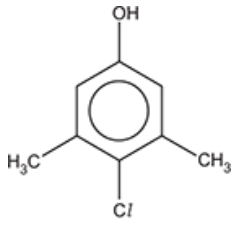
[5]

iv. Complete the flowchart for the synthesis of compounds **D** and **E** from phenylethanone.



[7]

20. Dettol® is a disinfectant containing the antiseptic chloroxylenol, shown below.

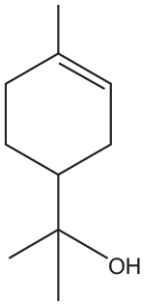


chloroxylenol

Dettol® contains other chemicals including α-terpineol, shown below.

i. α-Terpineol is a chiral compound.

Show with an asterisk, (*), the chiral centre(s) in the structure of α-terpineol.



α-terpineol

[1]

ii. α-Terpineol meets the requirements for *E* / *Z* isomerism.
However, only one *E* / *Z* isomer of α-terpineol exists.

Explain

- why α-terpineol meets the requirements for *E* / *Z* isomerism
- whether α-terpineol is an *E*- or *Z*- isomer
- why only one *E* / *Z* isomer of α-terpineol exists.

[4]

iii. α-Terpineol contains two functional groups.

For each functional group, choose a reagent that reacts with that group **only**.
Draw the structures for the organic products of the reactions.

Show structures for organic compounds.

Reagent(s)

Name of functional group that reacts

Structure of organic product

Reagent(s)

Name of functional group that reacts

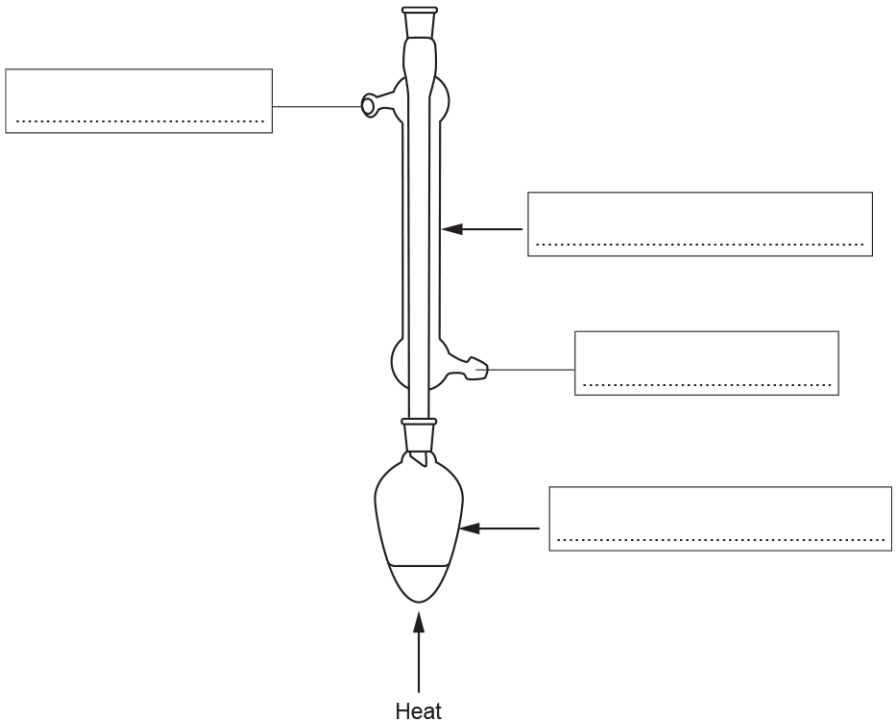
Structure of organic product

[4]

21. This question is about organic chemistry.

This part is about two practical techniques used in organic preparations.

i. Complete the missing labels on the diagram and name the technique.

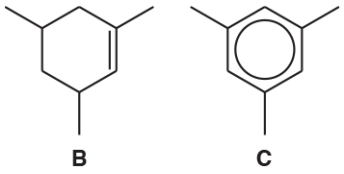


Name of technique: **[2]**

ii. Draw a labelled diagram to show apparatus set up for filtration under reduced pressure (vacuum filtration).

[2]

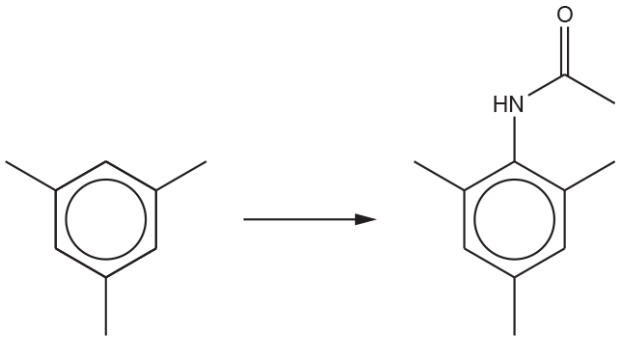
22. Compounds **B** and **C**, shown below, are unsaturated hydrocarbons containing nine carbon atoms.



B **C**

An organic chemist is investigating compound **D** for possible use as a medicine.

The chemist proposes a synthesis of compound D from compound C.



compound C **compound D**

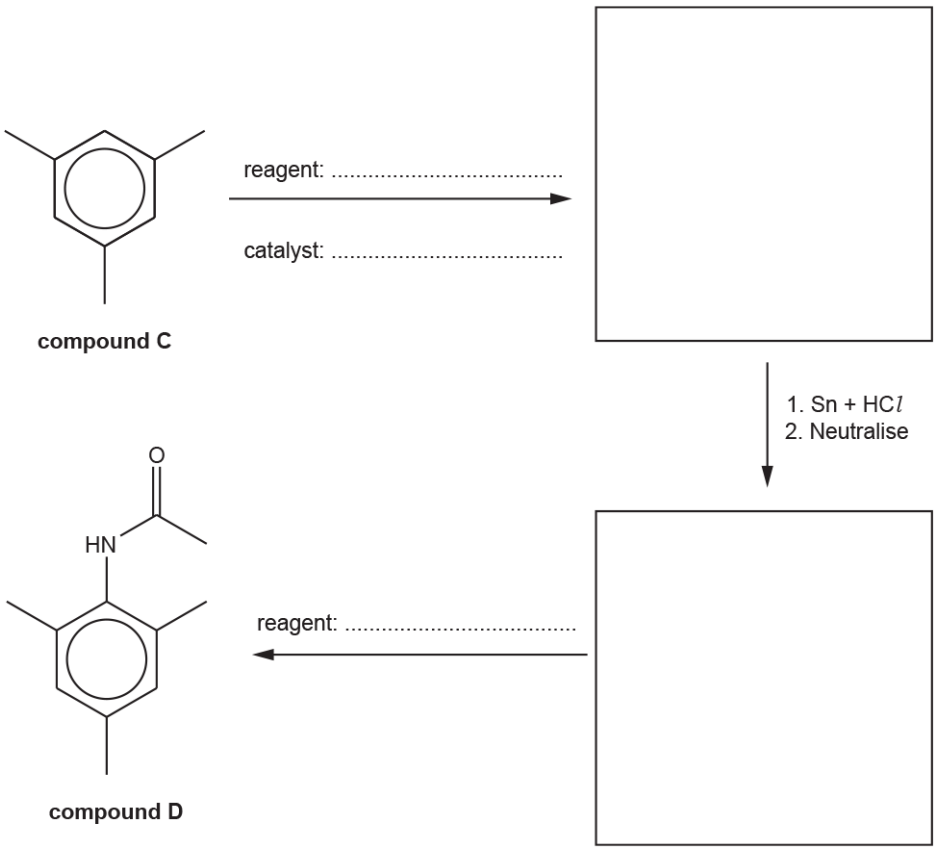
i. Predict the number of peaks in the ^{13}C NMR spectra of compounds **C** and **D**.

	Compound **C**	Compound **D**
Number of peaks	.....	.....

[2]

ii. The chemist develops a three-stage synthesis of compound **D** from compound **C**.

Complete the flowchart.
Show structures for organic compounds.



[5]

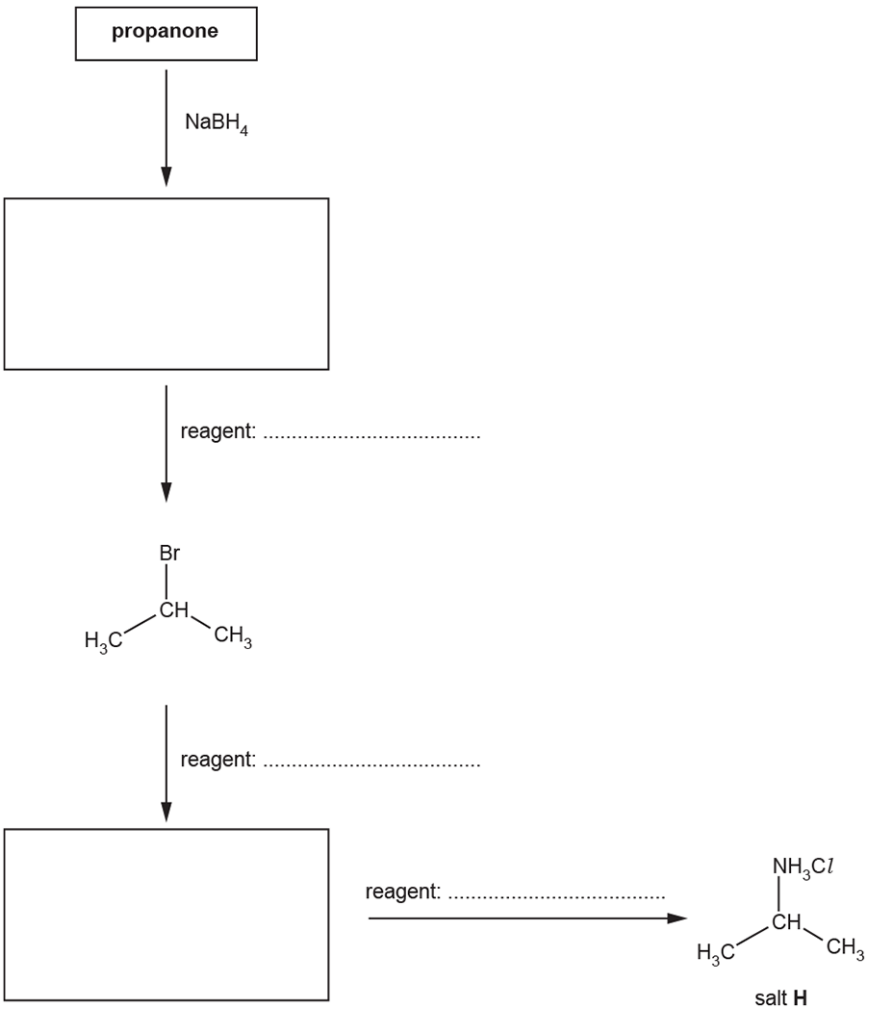
23(a). This question is about organic compounds containing nitrogen.

Salt **H**, $(CH_3)_2CHNH_3Cl$, is used in the manufacture of garden weedkillers.

The flowchart shows the synthesis of the salt **H** from propanone.

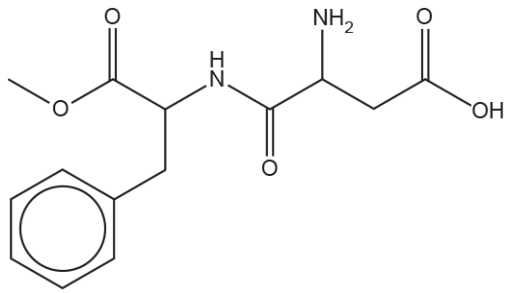
Complete the flowchart.

Show structures for organic compounds.



[5]

(b). Aspartame, shown below, is an artificial sweetener commonly used as a sugar substitute.



aspartame

i. Aspartame contains several functional groups.

Apart from the benzene ring, name the functional groups in aspartame.

[3]

ii. A sample of aspartame is hydrolysed with aqueous acid.

Draw the structures of the **three** organic products of the complete **acid hydrolysis** of aspartame.

[4]

iii. Some people are concerned that aspartame, $C_{14}H_{18}N_2O_5$, may have adverse health effects. Research shows that the safe maximum daily intake of aspartame is 1.7×10^{-4} mol kg^{-1}.

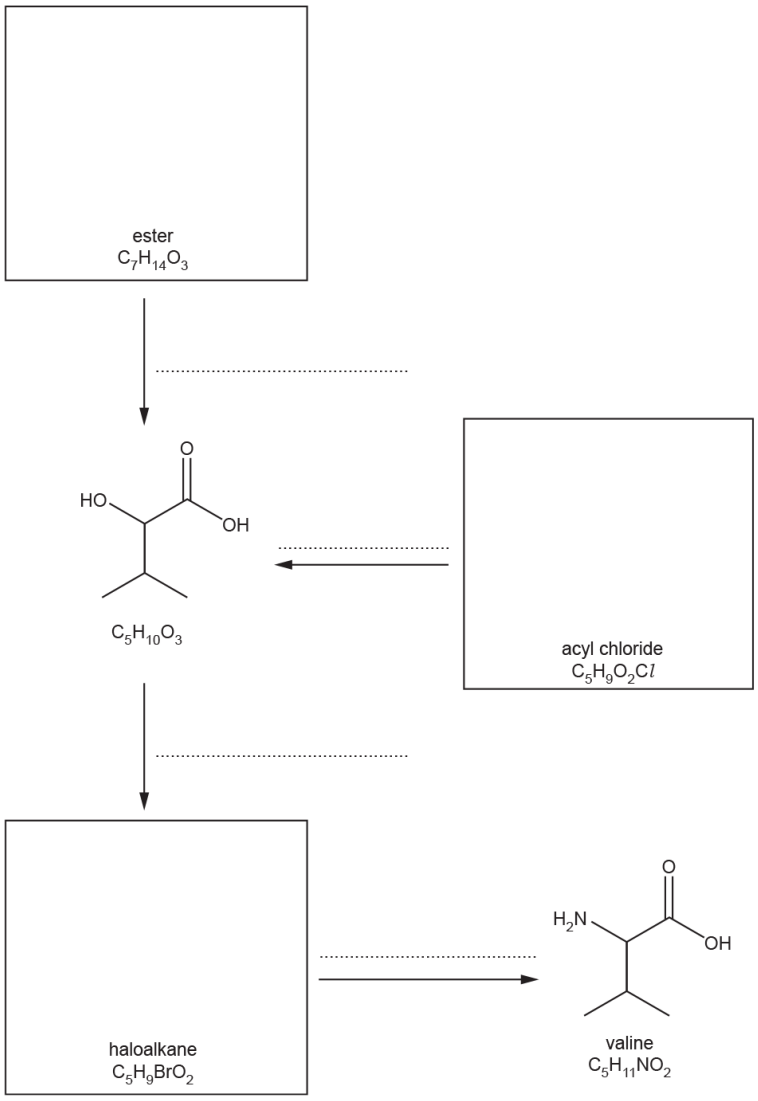
- A typical UK adult has a mass of 75 kg.
- A can of a diet drink contains 167 mg of aspartame.

How many cans of this diet drink is it safe for a typical adult to drink in one day?

Number of cans = ... **[3]**

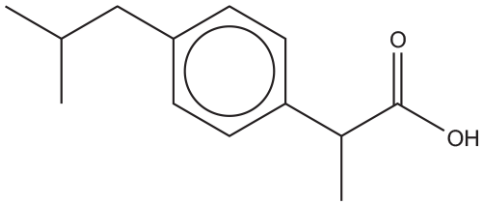
24(a). This question is about organic acids.

Complete the flowchart for two synthetic routes to the amino acid valine.



[7]

(b). Ibuprofen, shown below, is used as a painkiller.



ibuprofen

i. What is the molecular formula of ibuprofen?

[1]

ii. One ibuprofen tablet contains 400 mg of ibuprofen.

Calculate the number of ibuprofen molecules in one ibuprofen tablet.

Give your answer to **3** significant figures.

number of ibuprofen molecules = ... **[3]**

(c). Tablets based on ibuprofen and lysine are now available from pharmacies.

These tablets are claimed to act faster than ibuprofen by being absorbed into the body more quickly than ibuprofen alone.

One type of these tablets contains a salt of ibuprofen and the amino acid lysine (R = $–(CH_2)_4NH_2$) in a 1:1 molar proportion.

i. Suggest the structure of each ion in this lysine salt of ibuprofen, including the position of any charges.

– ion	+ ion

[2]

ii. Suggest why tablets based on a salt of ibuprofen should act faster in the body than ibuprofen.

[1]

25. This question is about organic synthesis.

*A student intends to synthesise compound A using the two-stage route below.

(chloromethyl)benzene Compound A

Plan a two-stage synthesis to prepare 5.44 g of compound **A** starting from (chloromethyl)benzene, $C_6H_5CH_2Cl$. Assume that the overall percentage yield of compound **A** from (chloromethyl)benzene is 25%.

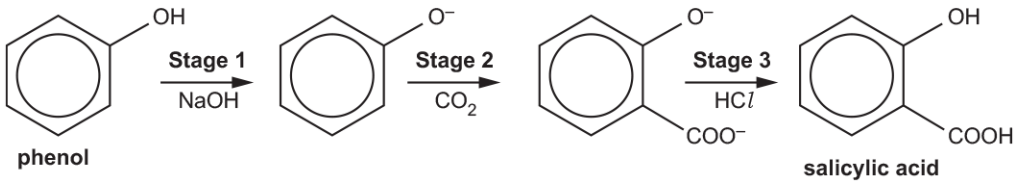
In your answer, include the mass of $C_6H_5CH_2Cl$ required, reagents, and equations where appropriate.

Purification details are **not** required.

[6]

26(a). This question is about reactions of phenol.

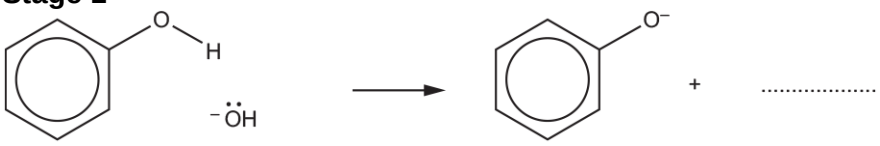
Salicylic acid can be prepared from phenol as shown below.



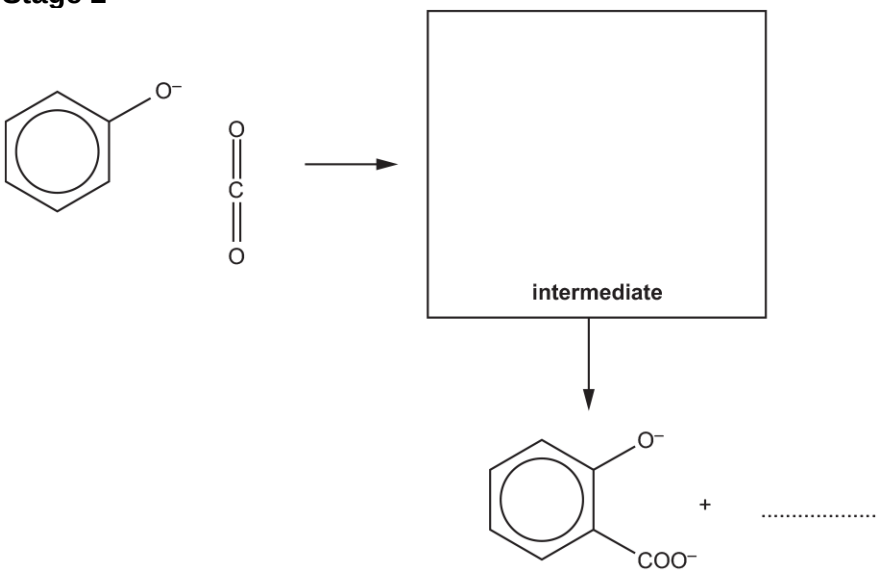
i. Complete the mechanism below for **Stage 1** and **Stage 2**.

Show curly arrows, the structure of the intermediate and the missing formulae on the dotted lines.

Stage 1



Stage 2



[6]

ii. What are the roles of ^{-}OH and CO_2 in the mechanism?

^{-}OH

CO_2 **[2]**

iii. Two molecules of salicylic acid can react together in the presence of an acid catalyst to form compound **B**.

Compound **B** has three rings and a molecular formula of $C_{14}H_8O_4$.

Write the equation for this reaction showing the structures of organic compounds.

[3]

(b). A student reacts phenol with nitric acid and sulfuric acid at 100 °C to form impure crystals of an organic compound, **C**. The student purifies the crystals by recrystallisation.

i. Describe how the student could recrystallise the impure crystals to obtain a pure sample of **C**.

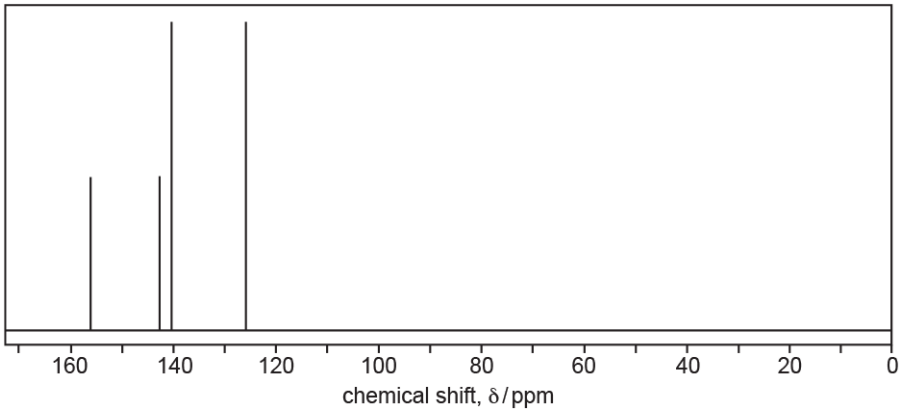
[3]

ii. The pure sample of **C** is analysed to give the following results.

Percentage composition by mass: C, 31.44%; H, 1.31%; N, 18.34%; O, 48.91%.

The mass spectrum of **C** shows a molecular ion peak at $m/z = 229.0$

The ^{13}C NMR spectrum of **C** is shown below.



The table shows directing effects for different groups in the electrophilic substitution of aromatic compounds.

Directing effect	2- and 4- directing	3-directing
Group	–OH	$–NO_2$
	$–NH_2$	

Analyse all the information to suggest the structure for **C**.

Show all your reasoning.

compound C

[6]

27. The ester, methyl ethanoate, can be synthesised by reacting a haloalkane with a carboxylate ion.

The mechanism is nucleophilic substitution.

Outline the mechanism for this reaction.

[3]

28. This question is about nitrogen and its compounds.

Hydrazoic acid, HN_3, is a weak acid ($K_a = 2.51 \times 10^{-5}$ mol dm^{-3}).

i. Calculate the pH of 0.125 mol dm^{-3} hydrazoic acid.
Give your answer to **2** decimal places.

pH = ...**[2]**

ii. When added to water, hydrazoic acid forms an equilibrium mixture containing conjugate acid–base pairs.
Complete the equation for this equilibrium and label the conjugate acid–base pairs as: **A1**, **B1** and **A2**, **B2**.

Equation	HN_3	+	.....	⇌	.....	+	.....
Acid-base pairs	.....		.....		.....		.....

[2]

iii. In the Schmidt reaction, hydrazoic acid, HN_3, reacts with carboxylic acids to form primary amines.

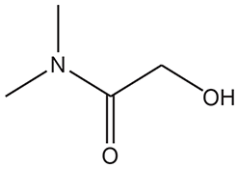
For example, HN_3 reacts with RCOOH to form RNH_2 and two gases that are found in the atmosphere.

Write the equation for the reaction of HN_3 with 2-methylbutanoic acid.

Show structures for organic compounds.

[3]

29. The skeletal formula of an organic compound is shown below.



Which functional groups are present?

A amide and alcohol

B amide and carboxylic acid

C amine and carboxylic acid

D amine, ketone and alcohol

Your answer ☐ **[1]**

30. Which species could react as a nucleophile?

1 NH_3

2 OH^-

3 CH_3NH_2

A 1, 2 and 3

B Only 1 and 2

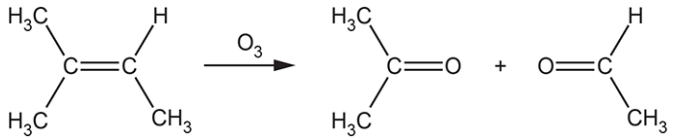
C Only 2 and 3

D Only 1

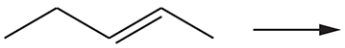
Your answer ☐ **[1]**

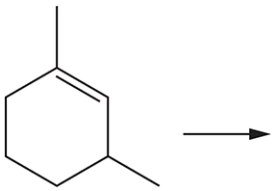
31. 'Ozonolysis' is used in organic synthesis. Ozone breaks C=C bonds to form carbonyl compounds.

For example, the complete ozonolysis of methylbut-2-ene is shown below.



i. Draw the structures of the products you would expect from the ozonolysis of the **two** compounds below.



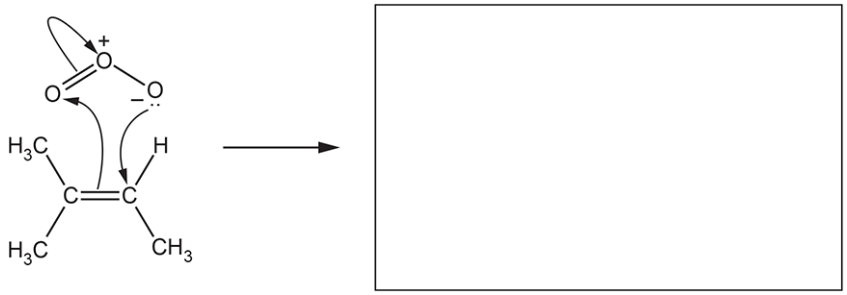


[2]

ii. The mechanism for ozonolysis takes place in several steps.

The curly arrows in the first step in the ozonolysis of methylbut-2-ene are shown below.

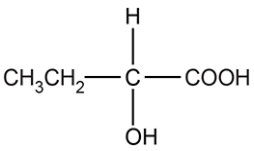
In the box, draw the structure(s) for the product(s) of this step.



[1]

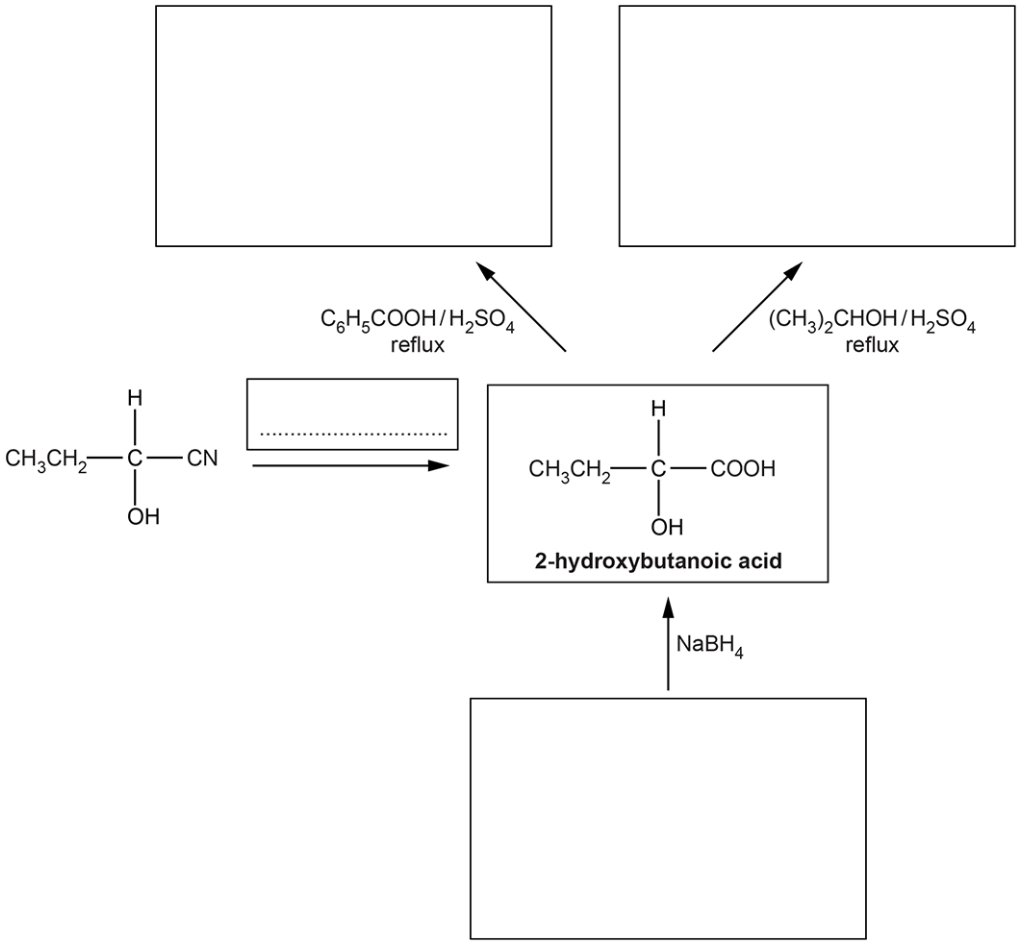
32(a). This question is about compounds that contain the carboxylic acid functional group.

The structure of 2-hydroxybutanoic acid is shown below.



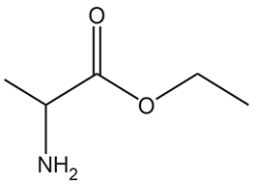
2-hydroxybutanoic acid

Fill in the flowchart for reactions involving 2-hydroxybutanoic acid.



[4]

(b). ***A student intends to synthesise compound **I.



Compound I

Plan a synthesis to prepare 9.36 g of compound **I** starting from 2-chloropropanoic acid, $CH_3CHC/COOH$.

The overall percentage yield of compound **I** from 2-chloropropanoic acid is 64%.

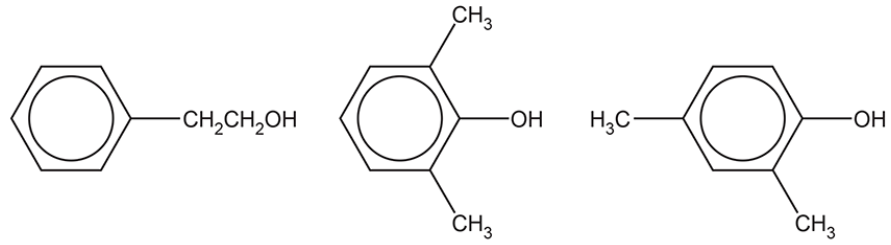
In your answer, include starting mass of 2-chloropropanoic acid, reagents, conditions and equations where appropriate.

Additional answer space if required.

[6]

33. This question is about the chemistry of aromatic compounds.

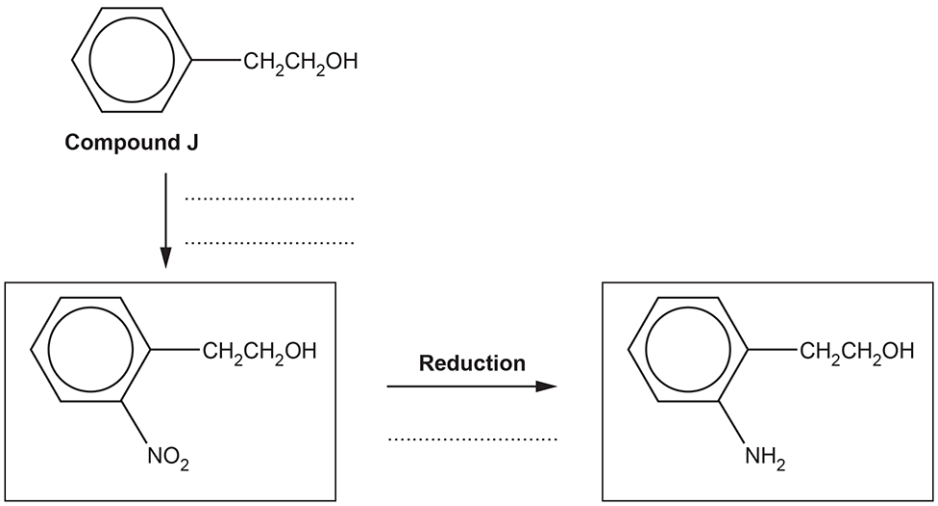
Compounds **J**, **K** and **L**, shown below, are structural isomers.



Compound J **Compound K** **Compound L**

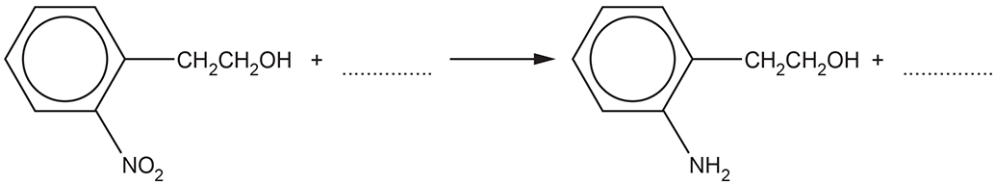
A two-stage synthesis of an amine from compound **J** is shown below.

i. Add the reagents for each stage of this synthesis.



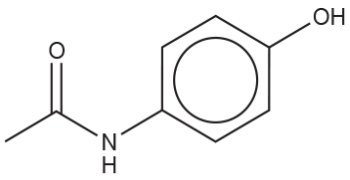
[2]

ii. Fill in the equation for the reduction stage of this synthesis.



[1]

34. The structure of the painkiller paracetamol is shown below.



Paracetamol

Which functional groups are present in paracetamol?

A alcohol, amide

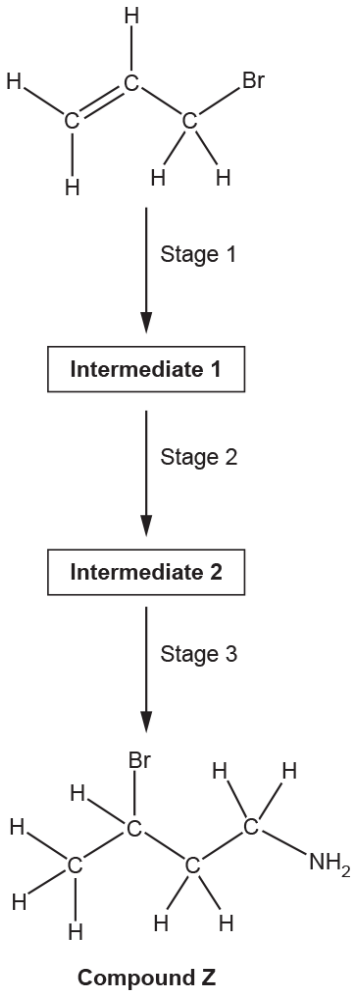
B alcohol, arene, ketone, amine

C phenol, amide

D phenol, ketone, amine

Your answer ☐ **[1]**

35. A student intends to synthesise compound **Z**, as shown in the flowchart below.



Compound Z

Plan this synthesis showing reagents, the structures of **intermediate 1** and **intermediate 2**, and equations.

[6]

36. 1,3-dinitrobenzene is a solid at room temperature.

A chemist prepares 1,3-dinitrobenzene as outlined below.

Step 1	12.5 cm^3 of nitrobenzene (density = 1.20 g cm^{-3}) is refluxed with concentrated nitric acid in the presence of concentrated sulfuric acid as a catalyst.
Step 2	The mixture is cooled. Impure crystals of 1,3-dinitrobenzene appear.
Step 3	The impure crystals are purified to obtain pure 1,3-dinitrobenzene.

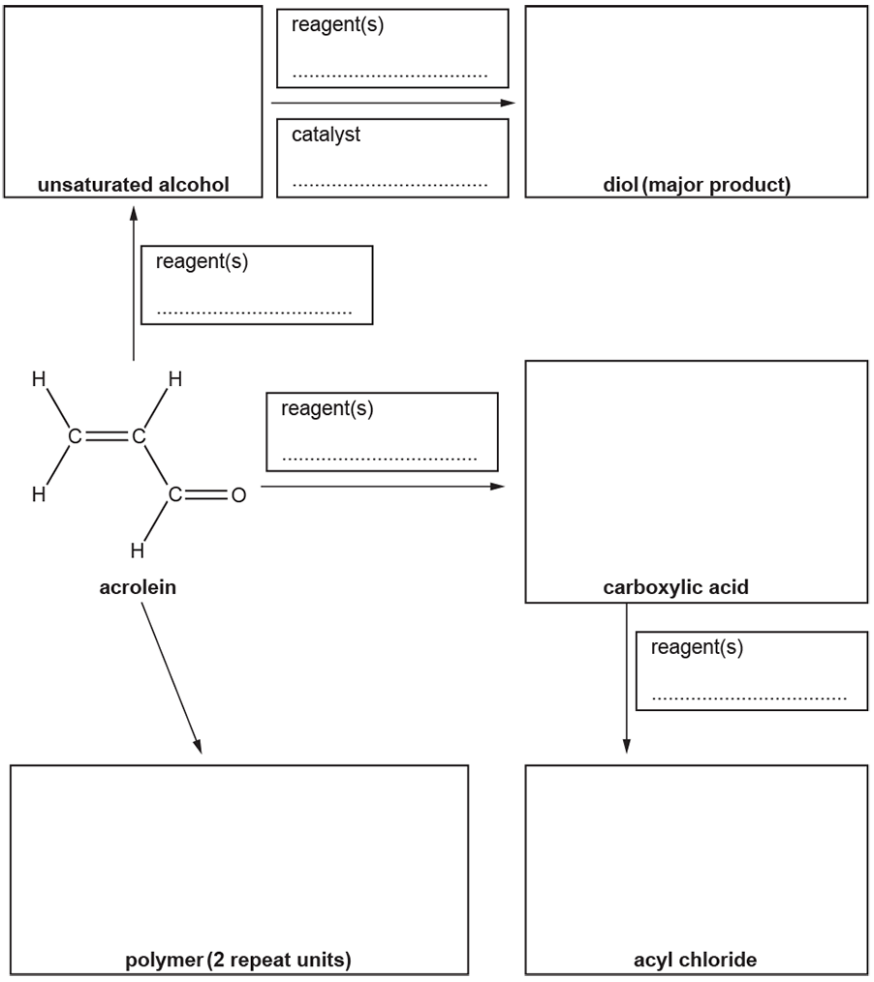
The chemist obtains 15.0 g of pure 1,3-dinitrobenzene.

Describe how to purify the impure crystals in **Step 3**.

[3]

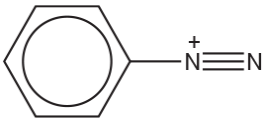
37. This question is about reactions of acrolein, $H_2C=CHCHO$.

Complete the flowchart by filling in each box.



[9]

38. The benzenediazonium ion, shown below, is stable at temperatures below 10 °C.



Benzenediazonium

Above 10 °C, the benzenediazonium ion reacts with water to form phenol.

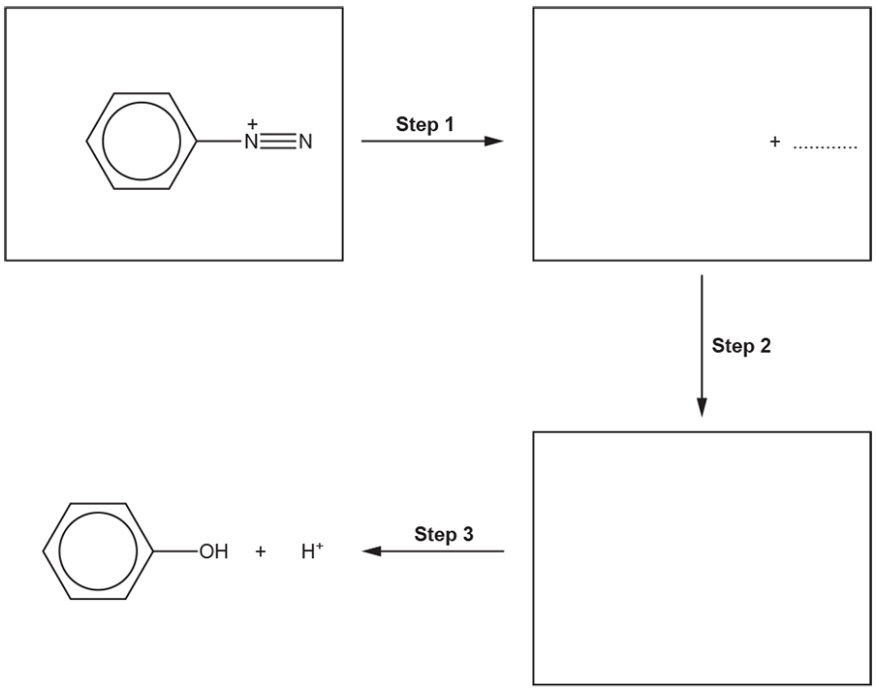
The reaction proceeds in a three-step mechanism.

Step 1 Elimination of nitrogen gas to form a carbocation.

Step 2 Nucleophilic attack by water.

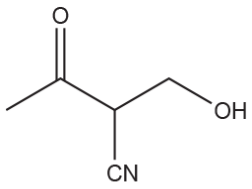
Step 3 Proton loss to form the organic product.

Complete the boxes below with intermediates and curly arrows to show the mechanism for this reaction.



[4]

39. A chemist is investigating compound **A**, shown below, as a potential organic intermediate.



Compound A

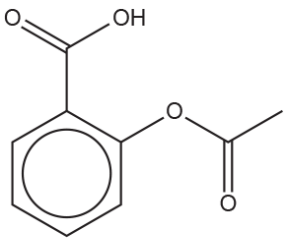
Describe the type of stereoisomerism shown by compound **A** and suggest three reactions of compound **A**, one for each of the **three** functional groups using reagents of your choice.

In your answer, show stereoisomers of compound **A**, your chosen reactants and conditions, and the structures for the organic products produced.

Mechanisms and equations are **not** required.

[6]

40. Aspirin tablets are used for pain relief. The structure of aspirin is shown below.



Aspirin

Aspirin reacts with hot NaOH(aq), under reflux.

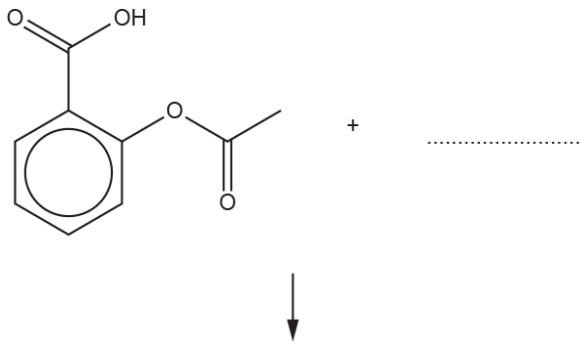
i. Draw a labelled diagram of suitable apparatus for reflux.

[2]

ii. In this reaction, 1 mol of aspirin reacts with 3 mol of hot NaOH(aq).

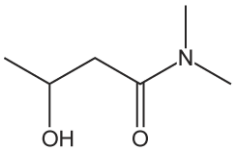
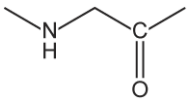
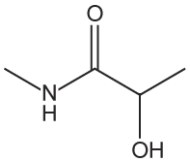
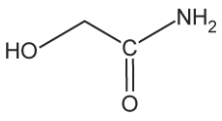
Complete the equation for the reaction of aspirin with an excess of hot NaOH(aq).

Show structures for organic compounds.



[3]

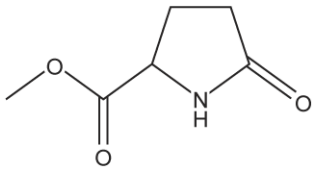
41. Which compound is a secondary amide?

A	
B	
C	
D	

Your answer ☐

[1]

42. The compound below contains an ester and an amide group.



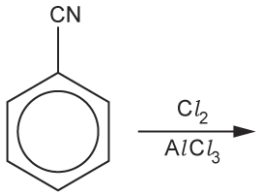
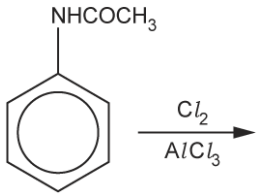
Draw the structures of the organic products formed by the complete **alkaline** hydrolysis of this compound using NaOH(aq).

[4]

43. The table shows directing effects for different groups in the electrophilic substitution of aromatic compounds.

Directing effect	**2- and 4- directing**	**3-directing**
Group	−OH	$-NO_2$
	$-NH_2$	$-COCH_3$
	$-NHCOCH_3$	−CN

i. Draw all organic products formed from monosubstitution reactions of the substituted benzene compounds shown below.

Reaction	Monosubstituted Product(s)
	
	

[3]

ii. The reactions of $C_6H_5NH_2$ are similar to the reactions of phenol.

Write an equation for the tri-substitution of $C_6H_5NH_2$ with chlorine.

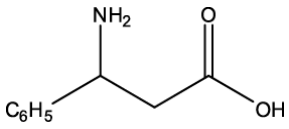
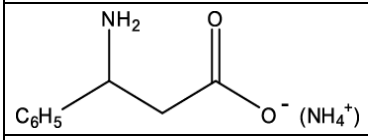
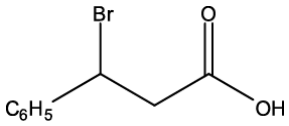
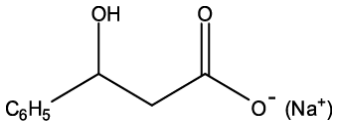
[2]

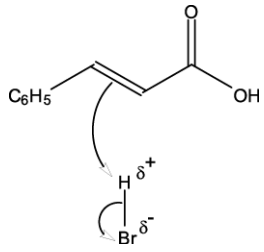
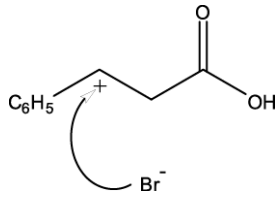
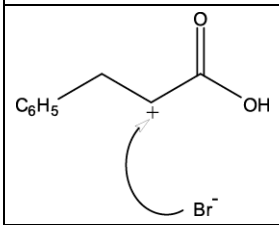
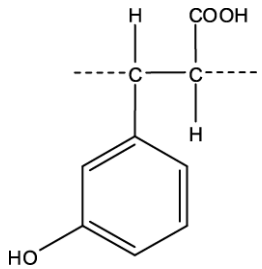
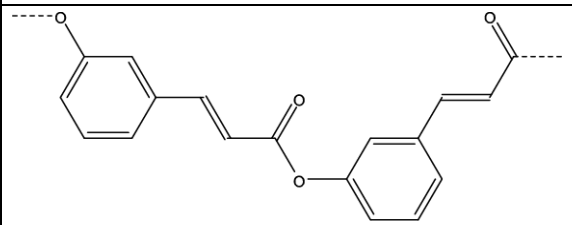
iii. Explain why chlorine reacts much more readily with $C_6H_5NH_2$ than with benzene.

[3]

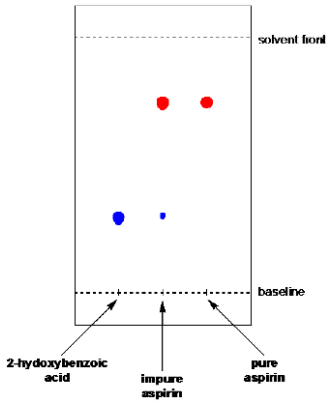
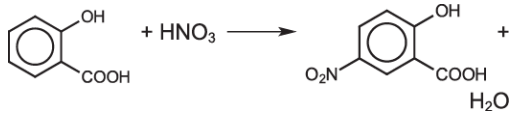
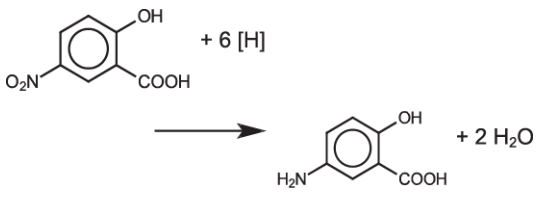
END OF QUESTION PAPER

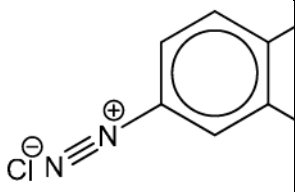
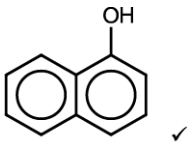
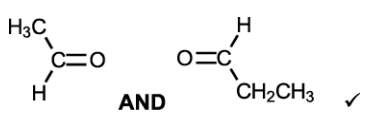
Mark scheme

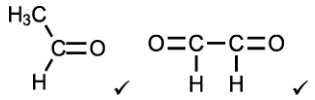
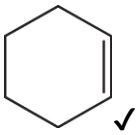
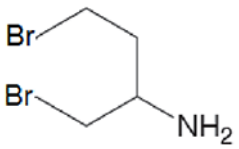
Question			Answer/Indicative content	Marks	Guidance
1			D	1	
			Total	**1**	
2	a		**Product from NH_3/ethanol** 	3	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW**  **ALLOW ECF** from 2-bromo compound as product from Reaction 1 ..... **DO NOT ALLOW** 2-bromo compound *(inconsistent with final product shown)*
			Product from Reaction 1  ..... **Product from NaOH(aq)** 		 ..... **DO NOT ALLOW ECF** from 2-bromo compound as product from Reaction 1 *(inconsistent with final product shown)*
	b		Curly arrow from C=C bond to H of H-Br		**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

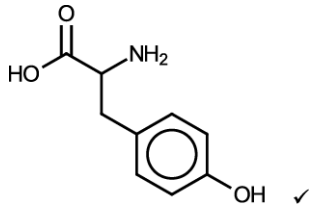
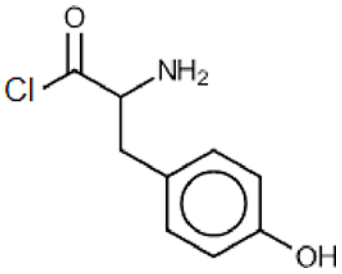
			Correct dipole shown on H–Br **AND** curly arrow showing the breaking of H-Br bond  ..... Correct carbocation **AND** curly arrow from Br^- to C^+ of carbocation  ..... Electrophilic addition		 **DO NOT ALLOW** partial charges shown on C=C double bond **DO NOT ALLOW** δ+ on C of carbocation **ALLOW** formation of the 2-bromo isomer  Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown)
	c	i		1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown (do not have to be dotted) **IGNORE** brackets **IGNORE** *n*
		ii	 Ester link Rest of structure	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown (do not have to be dotted)
			Total	**10**	

3	a		*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Correctly calculates mass of 2-hydroxybenzoic acid. **AND** Outlines full details of the two steps to obtain a pure sample of aspirin from the hot reaction mixture • *Calculation shows all relevant steps.* • *Purification steps are detailed and clear, in the correct order, using appropriate scientific terms, e.g. filter under reduced pressure / using a Buchner flask; dissolve in the minimum volume of solvent.* **Level 2 (3–4 marks)** Attempts a calculation which is mostly correct **AND** Some details of steps to obtain impure aspirin from the hot reaction mixture and recrystallisation • *Calculation can be followed but lacks clarity.* • *Purification steps lack detail, e.g. filter without reduced pressure; dissolve without minimum volume of solvent.* **Level 1 (1–2 marks)** Attempts to calculate the mass of **B** using mole approach but makes little progress with only 1 step correct. **AND** Few or imprecise details about steps to obtain impure aspirin from hot reaction mixture and recrystallisation • *Calculation is difficult to follow and lacks clarity* • *Purification steps are unclear with few scientific terms and little*	6	**Indicative scientific points, with bulleted elements, may include:** **1. Mass of 2-hydroxybenzoic acid** • $n(\text{aspirin}) \text{ needed} = \frac{8.10}{180} = 0.0450 \text{ (mol)}$ • n(2-hydroxybenzoic acid) needed $= 0.0450 \times \frac{100}{90} = 0.0500 \text{ (mol)}$ • Mass = 0.0500 × 138 = 6.9(0) g **2. Purification** **Impure aspirin from hot reaction mixture** • **Cool** reaction mixture • **Filter** product under **reduced pressure** **Recrystallisation of impure aspirin:** • Dissolve impure solid in **minimum volume of hot** water / solvent • **Cool** solution and **filter** solid • **Wash** with cold water / solvent and **dry** **NOTE** *Filtration of hot solution to remove solid particles is **not** required.*

			detail, e.g. just 'filter and crystallise'. **0 marks:** No response or no response worthy of credit.		
	b	i	 Pure aspirin and 2-hydroxybenzoic acid correct Impure aspirin with 2 spots in line with aspirin and 2-hydroxybenzoic acid spots **AND** 2-hydroxybenzoic acid spot fainter than aspirin spot	2	Check measurements on diagram using online measuring tool. Distance from baseline to top of spot for aspirin = 70–80% of baseline → solvent front Distance from baseline to top of spot for aspirin = 25–35% of baseline → solvent front
		ii	Melting point range between 130–140°C **AND** Range ≥ 2°C	1	Range that starts <138 and finishes ≤140
			Total	**9**	
4		i	**Step 1** Add HNO_3 ✓  ✓ **Step 2** Tin **AND concentrated** HCl ✓  ✓	4	**ALLOW** reagent mark if HNO_3 in equation **IGNORE** H_2SO_4 (**NOTE**: H_2SO_4 not required with phenols) **IGNORE** concentrations of acids / temperature **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous Equations **MUST** be completely correct for **one** mark each **DO NOT ALLOW** $3H_2$ **Examiner's Comments**

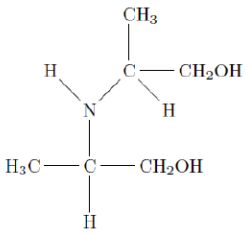
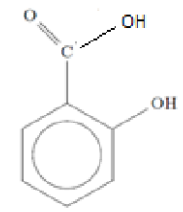
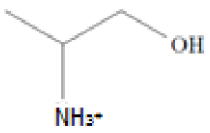
					This question discriminated well. Most candidates knew that nitric acid was involved in the first reaction but some also included sulfuric acid and tried to construct a mechanism involving the nitronium ion, rather than write the expected equation for the reaction. The omission of water as a product was an occasional error. Many correct equations were seen for Step 2, but tin and *concentrated* hydrochloric acid was required to score the reagent mark.
		ii	Nitrogen electron pair **OR** nitrogen lone pair accepts a proton / H^+ ✓	1	**DO NOT ALLOW** nitrogen / N lone pair accepts hydrogen (proton/H^+ required) **ALLOW** nitrogen donates an electron pair / lone pair to H^+ **IGNORE** NH_2 group donates electron pair **Examiner's Comments** Candidates needed to mention the electron pair on the nitrogen atom to score this mark.
		ii i	compound **A** ✓  compound **B**  ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **ALLOW** —N_2Cl **OR** —$N_2^+Cl^-$ **DO NOT ALLOW** —N≡N^+ **OR** —N≡N^+ Cl^- **DO NOT ALLOW** —N_2-Cl (covalent bond) **Examiner's Comments** The vast majority of candidates gave the correct structure for compound B, but common errors were the omission of the chloride ion in the formulae of the diazonium salt, or placing the positive charge on the wrong nitrogen atom.
			Total	**7**	
5		i	• pent-2-ene  ✓	3	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **ALLOW** C_2H_5CHO and CH_3CHO

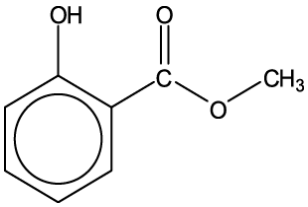
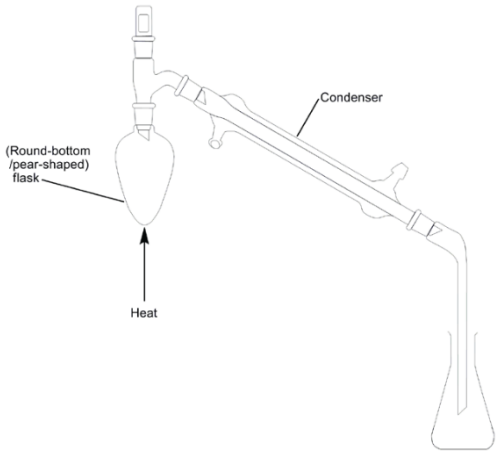
			• hexa-2,4-diene  ✓ ✓		**Examiner's Comments** Many candidates responded well when asked to apply information in a unfamiliar situation. The question discriminated well but a high proportion scored all three marks. Some candidates lost marks in the second part by providing a list of three or more different structures, some of them being incorrect.
		ii	 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **Examiner's Comments** This was a challenging question. Only more able candidates predicted the correct cyclic structure.
			Total	**4**	
6	a		$(CH_3)_2CHBr + FeBr_3 \longrightarrow (CH_3)_2CH^+ + FeBr_4^-$	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** positive charge anywhere on the electrophile **IGNORE** $AlCl_3$ **OR** $AlBr_3$ **Examiner's Comments** Well answered by those candidates who could apply their knowledge and understanding to new situations. It was a step too far for some who stuck to the more familiar equation for the generation of the Br^+ electrophile instead. Others made a good attempt but made errors with the charges.
	b	i	First reactant = HNO_2 ✓ Second reactant =  ✓	3	**ALLOW** $NaNO_2 + HCl$ **OR** $HNO_2 + HCl$ **IGNORE** conditions / concentration **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous

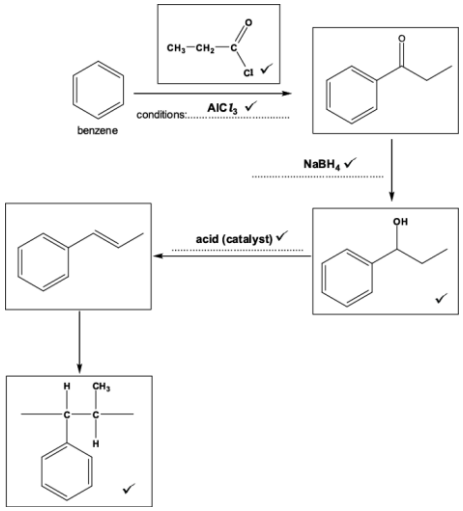
			Third reactant =  ✓		**ALLOW**  **Examiner's Comments** This question required candidates to recognise changes in chemical structure. The first reaction (the formation of a diazonium ion) and the third reaction (the formation of an amide linkage) should be familiar to candidates. The reagents for the first reaction were very well known and although the conditions for the reaction were often quoted they were not required for the mark. The correct structure of the second reactant was rarely seen with the most common incorrect responses being based on cyclic structures. Most candidates were able to deduce the structure of the third reactant.
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 1.35 (g) award 3 marks **IF** answer = 0.54 (g) award 2 marks (no scale-up) **IF** answer = 0.216 (g) award 2 marks (incorrect scale-up) *n*(compound D) = 1.73/346 = 0.00500 mol ✓ *n*(1,3-diaminobenzene) required = 100/40 × 0.005 = 0.0125 mol ✓ Molar mass of 1,3-diaminobenzene = 108 (g mol^{-1}) **AND** Mass of 1,3-diaminobenzene = (108)(0.0125) = 1.35 g ✓	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **If there is an alternative answer, check to see if there is any ECF credit possible** **ALLOW ECF** from incorrect amount, scale-up or molar mass **Alternative 1** n(compound D) = 1.73/346 = 0.00500 mol Molar mass of 1,3-diaminobenzene = 108 (g mol^{-1}) **AND** Mass of 1,3-diaminobenzene = (0.00500)(108) = 0.540 g Mass of 1,3-diaminobenzene required = (0.540)(100/40) = 1.35 g **Alternative 2** 346 g gives 108 g

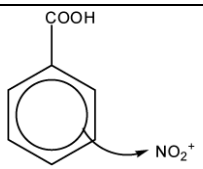
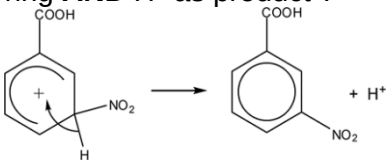
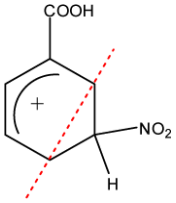
					1.73 g gives 108/364 × 1.73 = 0.54 g 0.54/40 ×100 = 1.35 g **Examiner's Comments** Candidates had been well prepared for this type of percentage yield question and it was very well answered with almost all candidates scoring marks here and a high proportion gaining all three marks for the calculation.
		iii	(compound D has) **two** chiral centres ✓ Four optical isomers exist ✓ (Synthesis could) use enzymes **OR** bacteria **OR** use (chemical) chiral synthesis **OR** chiral catalysts **OR** use natural chiral molecules **OR** single isomers (as starting materials) ✓	3	**ALLOW** (Compound **D**) has two asymmetric carbons **OR** has two stereocentres **ALLOW** four enantiomers **OR** two pairs of enantiomers **INDEPENDENT MARK** **ALLOW** biological catalysts **ALLOW** chiral transition metal complex / catalyst **OR** stereoselective transition metal complex / catalyst **ALLOW** 'chiral pool' / chiral auxiliary **Examiner's Comments** Two chiral centres and four optical isomers was required in the mark scheme and less specific answers did not score the first two marks. Two pairs of enantiomers was an accurate description worthy of the mark and a reference to there being four enantiomers was also given credit. The majority of candidates scored only the third mark with their suggestion of how to improve the synthesis. Some candidates missed the point here and instead described techniques required to separate the optical isomers.
			Total	**10**	

7	a	i	**^{1}H NMR spectrum for 2-aminopropan-1-ol** **Chemical shift, δ/ppm** / **Relative peak area** / **Splitting pattern** 0.8 – 2.0 / 3 / doublet 2.3 – 3.0 / 1 / multiplet 3.3 – 4.2 / 2 / doublet ✓✓✓	3	One mark for each correct row **ALLOW** δ values as a range or a value within the specified range. **ALLOW** δ values +/− 0.2 ppm. **ALLOW** a response that implies a splitting into two for a doublet etc. **ALLOW** sextet/hextet/six (or more than 5) as alternative to multiplet Relative peak area = CH /3H etc. penalise once **Examiner's Comments** Although it could be argued that this question tested the same skill three times, the full range of marks was awarded and errors were seen in the chemical shift, relative peak area and splitting pattern. Fully correct responses included either a chemical shift value within the range specified on the data sheet or a range that matched the one given on the data sheet.
		ii	M^+ peak at 75 (peak 1) $CH_3CH(NH_2)CH_2OH^+/C_3H_9NO^+$ ✓ Fragment peak at 44 (peak 2) $CH_3CH(NH_2)^+/C_2H_6N^+$ ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous Positive charge is essential but **ALLOW** maximum of one mark if both formulae are correct **AND** neither species has a positive charge **Examiner's Comments** Although peak 2 was often correct, the species responsible for the M+ peak was often missing a positive charge. Possibly students have learned that the particles become charged as part of the fragmentation process and don't realise that only charged particles can be detected by a mass spectrometer.
	b	i	Ethanolic ammonia **OR** ammonia/NH_3 **AND** ethanol ✓	1	**ALLOW** ammonia in a sealed tube **ALLOW** dilute ethanolic ammonia/NH_3 **IGNORE** heat **ALLOW** alcohol for ethanol **DO NOT ALLOW** any reference to water or hydroxide ions

					Examiner's Comments A well answered question. Some candidates forgot to use a solvent or suggested the use of aqueous ammonia.
		ii	(compound D)  ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **Examiner's Comments** This question discriminated well. Although there were very few blank pages, many incorrect structures were seen.
	c	i	Alcohol **AND** Amide/peptide ✓	1	**IGNORE** phenol **IGNORE** hydroxyl/hydroxy **IGNORE** attempts to classify alcohol or amide as primary, secondary or tertiary **DO NOT ALLOW** hydroxide **Examiner's Comments** Generally well answered but incorrect functional groups included carbonyl and amine.
		ii	  	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** combination of above as long as unambiguous **ALLOW** + on N or H i.e. $^{+}NH_3$ or NH_3^{+} **ALLOW** $NH_3^{+}Cl^{-}$ **Examiner's Comments** Many candidates were able to score one mark for this question but the amine group was often not protonated and it was

					surprisingly common to see the amine group as NH_2^+.
			Total	**10**	
8			**C**	1	
			Total	**1**	
9		i	 **AND** Acid (catalyst) ✓	1	**Note:** both the structure and condition are required for the mark **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** H^+ / H_2SO_4 / H_3PO_4 / named mineral acid
		ii	**Diagram** Diagram showing correct apparatus for distillation ✓ *i.e.* • Round-bottom/pear-shaped flask • Condenser (correctly orientated) • Stopper/thermometer • Delivery tube and suitable collection vessel  **Labels** (Round-bottom/pear-shaped) flask **AND** condenser **AND** heat (source) ✓	2	**DO NOT ALLOW** conical flask, volumetric flask, beaker in place of round bottomed/pear shaped flask **DO NOT ALLOW** diagram mark if top of distillation head not closed **Note:** suitable collection vessels include: conical flask, boiling tube, test-tube, beaker etc.

			Total	**3**	
10	a		One mark for each correct structure/reagent/condition as shown below  	6	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** names of organic compounds *(question asks for structures)* **ALLOW** aluminium(III) chloride **OR** aluminium trichloride **ALLOW** $FeCl_3$ **OR** Fe as halogen carrier in first step. **ALLOW** sodium borohydride **OR** sodium tetrahydridoborate **IGNORE** [H] for reducing agent in second step **ALLOW** H^+ / H_2SO_4 / H_3PO_4 / named mineral acid for reagent in third step
	b		Use as an organic feedstock ✓ **OR** Combustion for energy production ✓	1	**ALLOW** the production of plastics or monomers or new polymers Combustion alone is **not** sufficient
			Total	**7**	
11	a	i	**Generation of electrophile** $HNO_3 + H_2SO_4 \longrightarrow H_2O + HSO_4^- + NO_2^+$ ✓ **Electrophilic substitution** Curly arrow from p-bond to NO_2^+ ?	**5**	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** $HNO_3 + 2H_2SO_4$? $H_3O^+ + 2HSO_4^- + NO_2^+$ **ALLOW** $HNO_3 + H_2SO_4$?$H_2NO_3^+ + HSO_4^-$

			 --- Correct intermediate ? Curly arrow back from C-H bond to reform p-ring **AND** H^+ as product ?  **Regeneration of catalyst** $H^+ + HSO_4^- \longrightarrow H_2SO_4$ ✓		Then $H_2NO_3^+$? $H_2O + NO_2^+$ **ALLOW** $^+NO_2$ **OR** NO_2^+ First curly arrow must come from the ring to NO_2^+ **DO NOT ALLOW** the following intermediate:  p-ring should cover approximately 4 of the 6 sides of the benzene ring structure **AND** the correct orientation, *i.e.* gap towards C with NO_2 **ALLOW** + sign anywhere inside the 'hexagon' of intermediate **Examiner Comments** The majority of candidates were well prepared for this standard mechanism and frequently scored marks of four or five. Most were able to show equations to generate the electrophile and regenerate the catalyst. Candidates should note the importance of the correct placement of curly arrows and the horseshoe in the intermediate to show the remaining electrons present in the ring structure. These were often poorly represented, leading to marks not being awarded.
		ii	*Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Outlines the main steps of recrystallisation to produce a pure sample of 3-nitrobenzoic acid from the impure solid. **AND** Calculates correct percentage yield of 3-nitrobenzoic acid.	**6**	**Indicative scientific points, with bulleted elements, may include:** **1. Purification** • Recrystallisation • Dissolve impure solid in minimum volume of hot water/solvent • Cool solution and filter solid • Wash with cold water/solvent and dry

AND
Method of checking purity to include comparison to relevant data.
A well-structured response with the steps for recrystallisation and the determination of purity being given in the correct order. Correct use of terminology throughout.

Level 2 (3–4 marks)
Attempts all three scientific points but explanations may be incomplete.
OR

Explains two scientific points thoroughly with very few omissions.

The description of checking for purity or recrystallisation is clear and any calculations structured. Key terminology used appropriately.

Level 1 (1–2 marks)
A simple explanation based on at least two of the main scientific points.
OR
Explains one scientific point thoroughly with few omissions.
There is an attempt at a logical structure. The description of the practical techniques provides some detail but may not be in the correct order.

- *Purification step is unclear with few scientific terms and little detail, e.g. just 'recrystallise'.*
- *Calculation is difficult to follow, may just include a calculation of moles of reactants and/or products.*
- *Purity check specifies a method but this is unclear with little detail, e.g. take melting point.*

0 marks
No response or no response worthy of credit.

2. Percentage yield

- $n(\text{benzoic acid}) \text{ used} = \frac{4.97}{122} = 0.0407 \text{ (mol)}$
- $n(\text{3-nitrobenzoic acid}) \text{ made} = \frac{4.85}{167} = 0.0290 \text{ (mol)}$
- $\text{percentage yield} = \frac{0.0290}{0.0407} \times 100 = 71.3 \text{ (\%)}$

ALLOW 71 to calculator value of 71.29001554 correctly rounded.

CHECK for extent of errors by **ECF**

Alternative correct calculation may calculate theoretical mass of 3-nitrobenzoic acid that can be produced as 0.0407 × 167 = 6.80 (g) followed by:

$$\text{percentage yield} = \frac{4.85}{6.80} \times 100 = 71.3 \text{ (\%)}$$

Calculation **must** attempt to calculate *n*(benzoic acid) in mol.

3. Checking purity

- Obtain melting point
- Compare to known values
- Pure sample will have a (sharp) melting point very close to data book value

ALLOW alternative approach based on spectroscopy or TLC

Spectroscopy

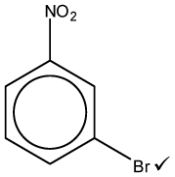
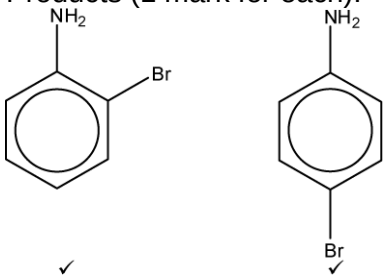
- Run an NMR/IR spectrum
- Compare to (spectral) database
- Spectrum of pure sample will contain same peaks and not others

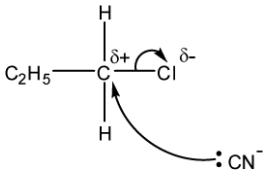
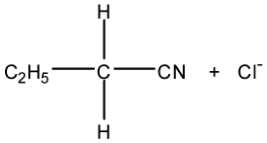
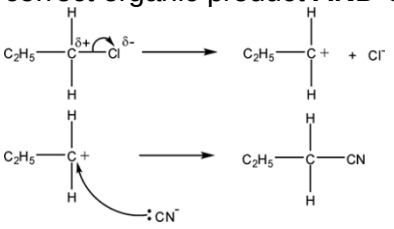
TLC

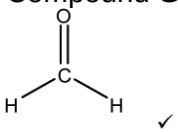
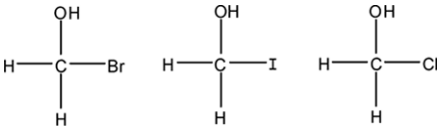
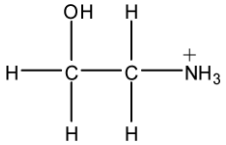
- Run a TLC
- Compare (R_f value) to known data
- Pure sample will have a very similar R_f

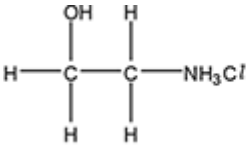
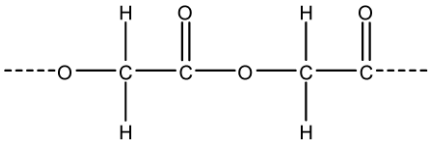
Examiner Comments

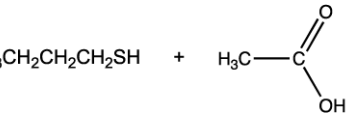
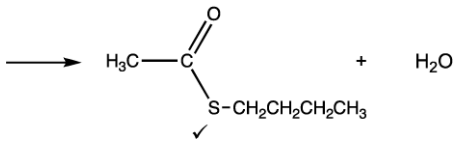
					This question tested some of the practical techniques covered as part of the practical endorsement as well as requiring candidates to calculate a percentage yield for the reaction. This proved to be quite a challenging question with some candidates giving little detail of how to carry out a recrystallisation. Common answers included a statement that the solid should be allowed to dissolve in a solvent and then filtered to obtain crystals. This did not gain credit for the scientific content as there was no indication of the solid dissolving in a hot solvent and then being allowed to cool before carrying out filtration. High quality answers often went above and beyond the requirements of the marking scheme with some candidates discussing the importance of dissolving in the minimum amount of hot solvent to obtain a saturated solution, the need to wash and dry the crystals and provided detail of the apparatus and or method required. Most candidates discussed that purity could be determined by taking the melting point of the product and comparing this to a value obtained from data book. The most comprehensive answers gave an indicated of the apparatus required to carry out the melting point determination and discussed how the melting point becomes higher and sharper as impurities are removed. Common errors included comments about carrying out a boiling point determination. When carrying out a percentage yield calculation, it is important to round answers only at the last stage of the calculation. Early rounding frequently led candidates to obtain answers, which did not gain credit. Weaker Candidates divided the mass of 3-nitrobenzoic acid by the mass of benzoic acid and obtained an answer of 97.6%. Answer = 71.3%
	b	i	**Bromination:** Br_2 **AND** $Al/Br_3/FeBr_3/Fe$ ✓ **Intermediate**	**3**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** any suitable halogen carrier catalyst **ALLOW** Kekulé structure

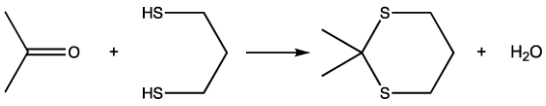
			 **Reduction:** Sn **AND** (concentrated) HCl ✓		**IGNORE** names *(question asks for formulae)* **IGNORE** reaction conditions even if incorrect **IGNORE** 'dilute' for HCl **IGNORE** H_2 **IGNORE** NaOH if seen as a reagent to convert nitro group into amine e.g 'Sn/(concentrated) HCl then NaOH' scores the mark **Examiner Comments** Candidates were able, in the main, to provide the reagents for bromination and reduction. The structure of the intermediate compound in the preparation of 3-bromophenylamine proved to be straightforward, however common errors involved the omission of the halogen carrier catalyst for bromination or stating names rather than formulae as indicated in the question.
		ii	NH_2 is 2,4 directing ✓ Products (1 mark for each): 	**3**	**IGNORE** references to electron donating/withdrawing groups **ALLOW** $-NH_2$ activates the ring causing the new group to join at positions 2 and 4. **ALLOW** ortho and para directing for 2,4 directing **IGNORE** 6-directing **ALLOW** Kekulé structure **IGNORE** names **Examiner Comments** The most able candidates completed this question with a clear statement that the $-NH_2$ group was 2,4 directing and provided two clearly drawn structures of 2-bromophenylamine and 4-bromophenylamine. The most common errors observed included drawing two structures that were identical and explaining the two structures in terms of electron donation from the $-NH_2$ without any indication of positioning. Candidates using the terms ortho and para

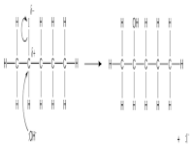
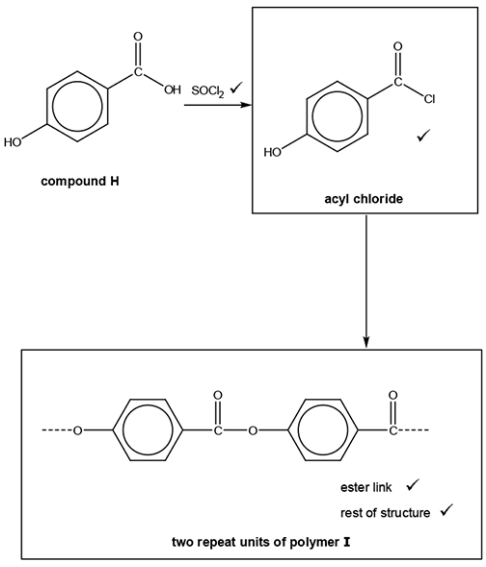
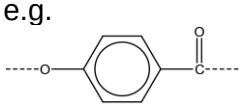
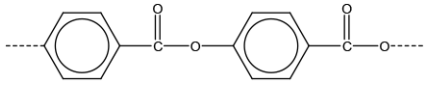
					directing were awarded full marks for their answers.
			Total	**17**	
12		i	curly arrow from $^{-}$CN to carbon atom of C−C*l* bond ✓ Dipole shown on C–C*l* bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C−C*l* bond to C*l* atom ✓  correct organic product **AND** Cl^{-}✓ 	**2**	**ANNOTATE ANSWER WITH TICKS AND CROSSES** Curly arrow must come from lone pair on C of $^{-}$CN OR CN^{-} **OR** from minus sign on C of $^{-}$CN ion (then lone pair on CN^{-} does not need to be shown) **IGNORE** NaCl **ALLOW** S_N1 mechanism: Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C–C*l* bond to C*l* atom ✓ Correct carbocation **AND** curly arrow from $^{-}$CN to carbocation. Curly arrow must come from lone pair on C of $^{-}$CN **OR** CN^{-} **OR** from minus sign on C of $^{-}$CN ion (then lone pair on CN^{-} does not need to be shown) ✓ correct organic product **AND** Cl^{-} ✓  **Examiner Comments** The mechanism for the reaction of 1-chloropropane was well done with the majority of candidates scoring two or three of the marks. Marks were not awarded when candidates used a negative charge or a lone pair sited on the nitrogen as the starting point for a curly arrow in the first stage of the reaction mechanism. The final marking point was awarded for the production of a Cl^{-} ion. The placing of curly arrows, dipoles and lone pairs of electrons are important when communicating by mechanisms.

		ii	Compound **G**  ✓ **Reagents** **Reaction 2:** H_2 **AND** Ni ✓ **Reaction 3:** Correct formula of an aqueous acid e.g. HCl(aq)/H_2SO_4(aq) ✓	**3**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** name(s) **ALLOW**  **ALLOW** any suitable metal catalyst e.g. Pt **ALLOW** $LiAlH_4$ for reagent in reaction 2 **DO NOT ALLOW** $NaBH_4$ for reagent in reaction 2 **IGNORE** names *(question asks for formulae)* **IGNORE** references to temperature and/or pressure **ALLOW** $H^+(aq)$ **IGNORE** dilute **ALLOW** formula of an acid **AND** water e.g. HCl **AND** H_2O H_2SO_4 **AND** H_2O **Examiner Comments** Although many candidates were able to provide the structure of methanal as the starting material for this synthesis, the structures of chloromethanol, bromomethanol and iodomethanol were accepted as suitable alternatives. It should be noted that hydrolysis is carried out using aqueous acid and that dilute acid is not a suitable alternative.
		ii i	**Explanation** Nitrogen electron pair **OR** nitrogen lone pair **AND** accepts a proton / H^+✓ **Structure of salt**  **AND** Cl^- ✓	**2**	**IGNORE** NH_2 group donates electron pair **ALLOW** nitrogen donates an electron pair to H^+ **DO NOT ALLOW** nitrogen donates lone pair to acid **IGNORE** comments about the O in the –OH group Compound **H** is a base is **not sufficient** *(role of lone pair required)* **DO NOT ALLOW** nitrogen/N lone pair

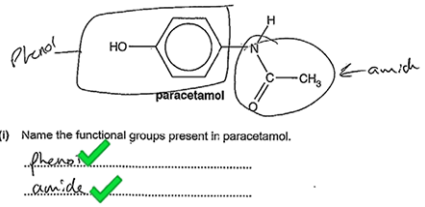
					accepts hydrogen (*proton/H^+ required*) **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW**  *i.e.* charges **not** required **IF** charges are shown **both** need to be present **ALLOW** charge either on **N** atom or NH_3^+ **IF** displayed then + charge must be on the nitrogen **Examiner Comments** Only 20% of candidates were awarded both marks for this question. The commonest error was a failure to state that the N atom has a lone pair of electrons that can gain a proton. Answers stating that amines accept protons or that a salt is produced when an acid reacts with a base were not credited. Where a full displayed structure is given the positive charge must be shown on the nitrogen atom, although $-NH_3^+$ is acceptable. As the question required the formula of the salt, the Cl^- had to be included.
		iv	 Ester link ✓ Rest of structure✓ (polymer **J** is biodegradable because) the ester / ester bond / ester group / polyester can be hydrolysed✓	**3**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** more than two repeat units for second marking point. 'End bonds' **MUST** be shown (do not have to be dotted) **IGNORE** brackets **IGNORE** ***n*** Broken down by water is **not** sufficient **IGNORE** references to photodegradable **Examiner Comments** The most common mark for this question was two out of the three marks available,

					with candidates giving a correct structure of the polymer but failing to express that the polymer was biodegradable due the ability of the ester functional group to undergo hydrolysis.
			Total	**11**	
13		i	$K_a = \frac{[H^+]\,[C_4H_9S^-]}{[C_4H_9SH]}$ ✓ *Square brackets required*	**1**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non- ambiguous **Examiner's Comment:** This part was very well answered. Candidates responded with either near molecular formulae, such as C_4H_9SH, structural formulae or with skeletal formulae. Some candidates made careless errors such as omitting the negative charge or showing $[H^+]^2$ as numerator rather than $[C_4H_9S^-]\,[H^+]$.
		ii	$CH_3CH_2CH_2CH_2SH$ +  →  + H_2O ✓ Structure of thioester ✓ Complete equation ✓	**2**	**ALLOW** correct skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous **ALLOW** C_4H_9SH **ALLOW** CH_3COOH Thioester functional group **must** be fully displayed, **OR** as a skeletal formula but allow SC_4H_9 in thioester **Examiner's Comment:** In this part, candidates were expected to apply their knowledge and understanding of esterification to thiols and thioesters. Over half the candidates obtained a correct structure of the thioester. Most of these candidates constructed a balanced equation although some omitted the water product. Common errors included formation of a conventional ester and H_2S, and retaining the O atom from the OH in the carboxyl group to form –COOS–. As with 4(b)(i), structural and skeletal formulae were used. Candidates are less likely to omit H atoms if the skeletal formula is used.

		ii i	 ✓	**1**	**IF** correct **skeletal** formula is shown, **IGNORE** displayed formula in a second structure **Examiner's Comment:** Just over half the candidates drew the correct structure, displaying a good understanding of interpreting organic nomenclature when drawing a structure. Common errors included omission of the CH_2 adjacent to the terminal –SH group and placing the branch or double bond in wrong positions. Some candidates spoilt an otherwise good response by showing a structural formula or a mixture of skeletal and structural formulae.
		i v	 Reactants ✓ Products **AND** balanced equation ✓	**2**	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non- ambiguous **Examiner's Comment:** In this part, candidates were expected to apply their knowledge and understanding of condensation to an entirely new context. One mark was allocated for the reactants and this was usually scored. The second mark for the novel cyclic compound and water was much more difficult, aimed at stretch and challenge. A significant number of candidates interpreted the information to obtain a correct cyclic structure but this mark was the domain of the most able candidates.
			Total	**6**	
14		i	Reflux	1	
		ii	Nucleophilic substitution (1) *Mechanism* Curly arrow from lone pair on OH^- to δ+ carbon atom (1) Curly arrow and dipole on C–I bond (1)	4	The curly arrow must start from the oxygen atom of the OH^- and must start from either the lone pair or the negative charge

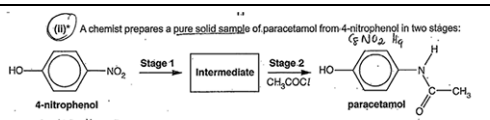
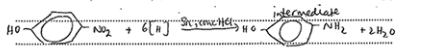
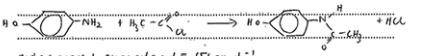
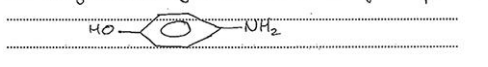
			Correct products (1)		 **do not allow** attack by NaOH
			Total	**5**	
15			**B**	**1**	**Examiner's Comments** Many candidates correctly selected B. Option A proved a good distractor, presumably as candidates linked melting point to recrystallisation without fully interpreting statement 3.
			Total	**1**	
16			One mark for each correct structure/reagent as shown below 	**4**	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** PCl_5 **OR** PCl_3 for reagent mark. **IGNORE** references to temperature for reagent mark **IGNORE** additional reagents shown with $SOCl_2$/PCl_5/PCl_3 e.g. H_2O, $AlCl_3$, HCl etc. **IGNORE** names *(question asks for structures of organic compounds and formula of reagent)* **DO NOT ALLOW** more than two repeat units **ALLOW** 1 mark for one correct repeat unit e.g.  'End bonds' **MUST** be shown (do not have to be dotted) **ALLOW** the 'O' at either end i.e.  **IGNORE** brackets **IGNORE** *n* **Examiner's Comments** Compound **H** was also the focus for this

					question. Most candidates were able to provide the structure of the acyl chloride obtained from **H** but only some identified $SOCl_2$ as the correct reagent. Common incorrect reagents included HCl and $AlCl_3$. Most candidates recognised that polymer **I** was a polyester but only some were able to draw two repeat units correctly. Candidates are advised to practice drawing different polymers, taking care to ensure the correct number of repeat units are present when a specific number is required.
			Total	**4**	
17		i	Phenol ✓ Amide ✓ • **IGNORE** attempt to classify amide, e.g. secondary	2	**IF > 2** functional groups are shown, • Mark 2 groups **ONLY** • Mark incorrect groups **first** Treat carbonyl with aldehyde **OR** with ketone as one functional group, i.e. • carbonyl, aldehyde • carbonyl, ketone • carbonyl **IGNORE** aryl **OR** alkyl group e.g. benzene, phenyl, aryl, arene, methyl **IGNORE** hydroxyl/hydroxy **Examiner's Comments** This part assessed knowledge of functional groups and proved to be a very good discriminator. Able candidates usually identified the phenol and amide functional groups, with 'secondary amide' also seen. In Exemplar 9, the candidate has identified the correct functional groups. The candidate's working by circling the functional groups in the structure shows good examination technique, helping the candidate to arrive at the correct conclusion.

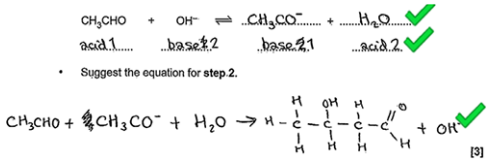
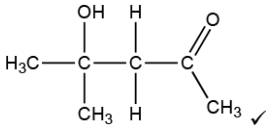
					The phenol group was often incorrectly identified as an alcohol and the amide group as a combination of 'amine', 'ketone', 'keytone' or 'carbonyl'. Neutral responses such as 'hydroxyl' and 'benzene' were ignored. Candidates need to be careful that they do not present an extensive list of many functional groups in the hope that the correct groups are amongst them, as shown in Exemplar 10. Incorrect groups are marked first. **Exemplar 9**  (i) Name the functional groups present in paracetamol. phenol ✓ amide ✓ [2] **Exemplar 10** phenol ✓, ketone ✗, benzene alkyl, amine ✗ [2]
		ii	*Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.* **Level 3 (5-6 marks)** A correct calculation of the mass of 4-nitrophenol. **AND** Identifies the reagents **AND** intermediate. **AND** A **detailed** description of most purification steps. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** Calculates the mass of 4-nitrophenol with some errors **AND** suggests reagents and intermediate with some omissions. **OR** Calculates the mass of 4-nitrophenol with	6	**Indicative scientific points may include:** **<u>Calculation of mass of 4-nitrophenol</u>** **Using moles** • $n(\text{paracetamol}) = \frac{5.00}{151} = 0.0331$ (mol) • $n(\text{4-nitrophenol}) = 0.0331 \times \frac{100}{40} = 0.0828$ (mol) • Mass of 4-nitrophenol = 139 × 0.0828 = 11.5 g **ALLOW** 11.4−11.6 for small slip/rounding **Using mass** • Theoretical mass paracetamol = $5.00 \times \frac{100}{40} = 12.5$ g • Theoretical $n(\text{4-nitrophenol}) = \frac{12.5}{151} = 0.0828$ (mol) • Mass of 4-nitrophenol = 139 × 0.0828 = **11.5** g

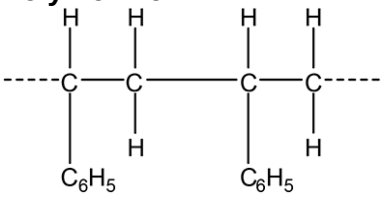
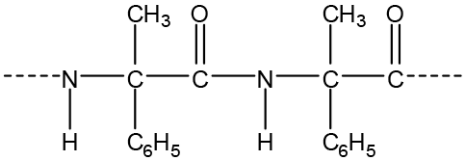
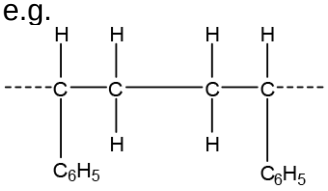
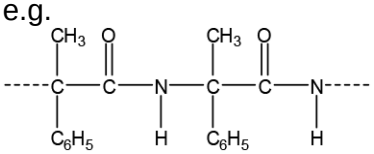
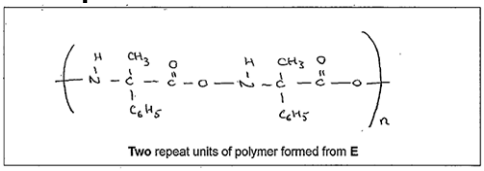
			some errors **AND** describes some purification steps, with some detail. **OR** Suggests reagents and intermediate with some omissions **AND** describes some purification steps, with some detail. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1-2 marks)** Attempts to calculate the mass of 4-nitrophenol **OR** Suggests reagents **OR** intermediate but may be incomplete **OR** Describes few purification steps. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		**NOTE**: Incorrect inverse ratio of $\frac{100}{40}$ gives: • $0.0331 \times \frac{40}{100} = 0.0132$ (mol) • Mass = 139 × 0.0132 = 1.84 g **Reagents and intermediate** • **Reagents**: Sn + (conc) HCl (then NaOH) • **Intermediate**: 4-aminophenol or structure **Purification** • Dissolve impure solid in **minimum volume of** hot solvent • **Cool** solution and filter solid • **Scratch with glass rod** • **Wash** with cold solvent/solvent and **dry** **Examples** of detail in **bold (NOT INCLUSIVE)** **NOTE**: 'Recrystallisation' on its own is **NOT** a detailed description **Examiner's Comments** This part assessed practical aspects of a two-stage organic synthesis. Overall, candidates responded well, and this part was discriminating. Many candidates produced well-structured responses although lower ability candidates do have problems with constructing a cohesive response. Most candidates identified the correct reagents (Sn and concentrated HCl) and the intermediate (4-aminophenol), which was usually shown as its structure. Able candidates usually showed that 11.5 g of 4-nitrophenol is needed for the synthesis. A common error used the 'inverse

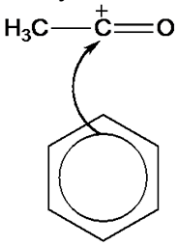
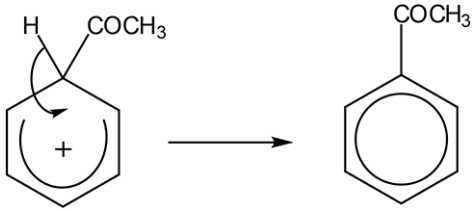
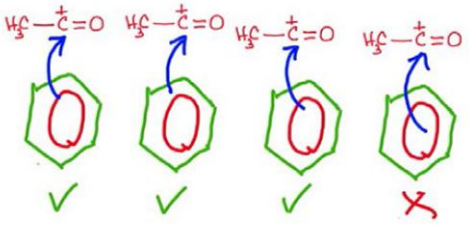
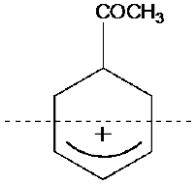
					percentage' ratio of 40/100, resulting in an incorrect mass of 1.84 g. Candidates are recommended to check whether a calculated answer looks sensible. Looking at the structures and with a percentage yield of 40%, 1.84 g does not look to be enough of the starting chemical. Some lower ability candidate responses assumed that 5.00 g was 40% of the required mass and responded with 5.00 × 100/40 = 12.5 g. There were some good descriptions of purification, although finer details such as using a minimum volume of hot solvent, washing with cold solvent, and drying) were often omitted. Candidates needed to respond with more than just 'recrystallisation'. In the purification, common errors were showing the correct steps but in the wrong order and use of a drying agent such as $CaCl_2$ (confusion with part of the purification of an organic liquid). These candidates seemed unaware that adding a solid drying agent to an organic solid would result in impure paracetamol rather than purifying. Exemplar 11 shows an excellent response that addresses all aspects of the problem. In comparison, Exemplar 12 is much less detailed: concentrated HCl has not been shown as a reagent for step 1, the candidate has not shown that they know how to carry out a percentage yield calculation, and the purification is confused, and lacks detail. **Exemplar 11**

					(ii)* A chemist prepares a pure solid sample of paracetamol from 4-nitrophenol in two stages:  $C_6NO_3H_5$ Describe a two-stage synthesis of 5.00 g of pure paracetamol from 4-nitrophenol. The overall percentage yield of paracetamol from 4-nitrophenol is 40.0%. In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol. [6]   molar mass of paracetamol = 151 g mol^{-1} moles in 5g : $\frac{5}{151}$ = 0.0331 mol moles required = 0.0331 ÷ 0.4 = 0.08278 mol moles of 4-nitrophenol required = 0.08278 mol mass of 4-nitrophenol required = 0.08278 × 139 = 11.5g To purify the paracetamol, filter the remaining solution under reduced pressure using Buchner apparatus. Dissolve the remaining solid in the ~~a~~ minimum amount of hot solvent and filter again. Cool the remaining ~~the~~ solution and filter ~~with~~ in an ice bath. Wash the remaining solid with cold solvent. Additional answer space if required. and leave to dry. **Exemplar 12** In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol. [6] 4-nitrophenol is ~~reacted with~~ reduced with (Sn) tin in presence of and acid and forms ~~4-phenyl~~ 4-phenylamide under high temperature  $\frac{40}{100}$ × 5.00 = 12.5g from the beginning is required A pure sample of paracetamol was obtained by crystallisation. The impure solution was heated with a bunsen burner and stirred until crystals start forming. ~~on~~ After formation it was left to cool and and oven was used to evaporate any water left
			Total	**8**	
18		i	3-hydroxybutanal ✓	1	**ALLOW** 3-hydroxybutan-1-al **IGNORE** lack of hyphens or addition of commas **ALLOW** 4-oxobutan-2-ol **OR** 1-oxobutan-3-ol **DO NOT ALLOW** • 3-hydroxybutal • 3-hydroxylbutanal **Examiner's Comments** Most candidates made good attempts at the

					name, the difficulty being that hydroxyl group needed to be shown as a hydroxy- prefix, rather than the suffix -ol. Common errors included 2-hydroxybutanal (counting the carbon chain from the wrong end) and 2- or 3-hydroxybutanoic acid (reading the aldehyde group as a carboxylic acid).
		ii	Addition ✓	1	**IGNORE** nucleophilic **OR** electrophilic **OR** radical **DO NOT ALLOW** addition–elimination, condensation, polymerisation **Examiner's Comments** This part was answered well with most choosing nucleophilic addition. Credit was given just for 'addition'.
		ii i	**ALLOW** any formula provided that number and type of atoms and charge are correct, e.g. For CH_3CHO, **ALLOW** CH_3COH, C_2H_4O, etc. **Step 1**: • Correct equation ✓ One correct acid–base pair ✓ • i.e. A1 and B1 **OR** A2 and B2 $CH_3CHO + OH^- \rightleftharpoons {}^-CH_2CHO + H_2O$ **OR** $CH_3CHO + OH^- \rightleftharpoons CH_3CO^- + H_2O$ ✓ **A1 B2 B1 A2** **OR A2 B1 B2 A1** **Step 2**: $CH_3CHO + {}^-CH_2CHO + H_2O \rightarrow CH_3CHOHCH_2CHO + OH^-$ ✓ For $^-CH_2CHO$: **ALLOW** CH_2CHO^-; CH_3CO^-; $C_2H_3O^-$	3	Throughout, **IGNORE** 'connectivity in any formula or structures shown. Examples in Answer column and in 6a(iv) guidance below **Step 1: ALLOW** H^+ transfer from OH^-, i.e. $CH_3CHO + OH^- \rightleftharpoons CH_3CH_2O^+ + O^{2-}$ ✓ **B2 A1 A2 B1** **OR B1 A2 A1 B2** **Step 2:** $CH_3CHO + CH_3CH_2O^+ + O^{2-} \rightarrow$ $CH_3CHOHCH_2CHO + OH^-$ ✓ For $CH_3CH_2O^+$: **ALLOW** CH_3CHOH^+, $C_2H_5O^+$ **Examiner's Comments** This novel question linked together acid–

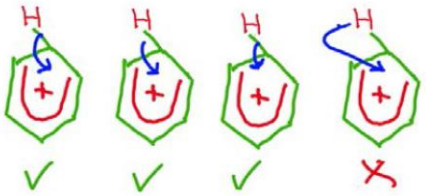
			For $CH_3CHOHCH_2CHO$, **ALLOW** $C_4H_8O_2$		base equilibria with a multi-step process. Many candidates completed an equation to generate acid–base pairs, which were then usually assigned correctly. The final equation was challenging but the highest ability candidates were able to combine together all the information with their earlier responses to arrive at the correct equation. See Exemplar 15. **Exemplar 15** 
		iv	 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous For connectivity, **ALLOW** OH CH3 CH3– C3H– OH— *(Connectivity not being assessed)* **Examiner's Comments** This part was one of the most challenging on the paper. Candidates needed to link the earlier information for combining two ethanal molecules to derive the product for combining two propanone molecules. Despite the challenge, the highest ability candidates were able to come up with the correct structure.
			Total	**6**	

19		i	**Polymer from D**  ✓**Polymer** **from E**  Amide link ✓ 2 repeat units of correct polymer ✓	3 (AO 2.5) (AO 1.2) (AO 2.5)	--- For **BOTH** structures, **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous 'End bonds' **MUST** be shown **BUT ALLOW ECF IF** end bonds omitted in both structures **DO NOT ALLOW** more than 2 repeat units **BUT ALLOW ECF** in subsequent structure **IGNORE** connectivity of C_6H_5 --- **CARE: ALLOW** any consistent repeat unit: C_6H_5 and H groups can alternate or be on opposite sides of chain e.g.  end –NH– may be at either side e.g.  **IGNORE** brackets **IGNORE** *n* **Examiner's Comments** The majority of candidates were able to draw two repeats units of the polymer formed from D and scored at least one mark. While most candidates drew the polymer from E correctly, securing full marks, some candidates were unable to show the amide link correctly. This common error is demonstrated in Exemplar 6. **Exemplar 5**  Two repeat units of polymer formed from E This response demonstrates a common error seen by examiners. The candidate has included an O atom as part of the amide link. So they have also included an

					O atom before the 'end bond'. This is a costly error as the candidate is unable to be given either of the marks available for this polymer.
		ii	**D** Addition / polyalkene **AND** **E**: Condensation / polyamide ✓	1(AO 1.1)	**DO NOT ALLOW** 'additional'
		ii i	**Formation of electrophile** $CH_3COCl + AlCl_3 \rightarrow CH_3–C^+=O + AlCl_4^-$ ✓ **Mechanism** Curly arrow from π-bond to $CH_3C^+=O$ ✓  ---------- Correct intermediate ✓ Curly arrow from C–H bond to reform π-ring ✓ 	5 (AO 2.5) (AO 2.5) (AO 3.1) (AO 2.5) (AO 1.2)	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** '+' charge anywhere on CH_3C^+O i.e. CH_3CO^+ **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **1st curly arrow** must • go to the C of C=O **AND** • start from, **OR** close to **circle of benzene ring**  **IGNORE** curly arrow shown on C=O **DO NOT ALLOW** the following intermediate:  π-ring should cover approximately 4 of the 6 sides of the benzene ring structure **AND** the correct orientation, i.e. gap towards C with $COCH_3$

ALLOW + sign anywhere inside the 'hexagon' of intermediate

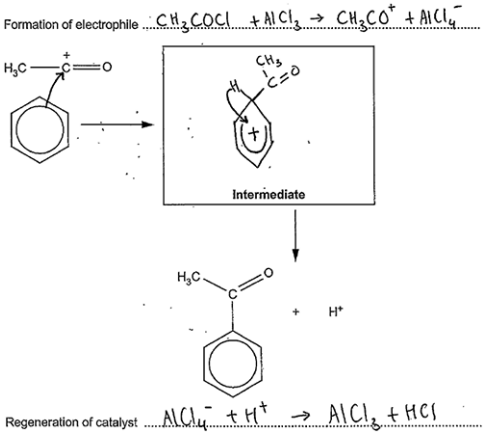
curly arrow must start from, **OR** be traced back to, **any part of** C-H bond and go inside the 'hexagon'



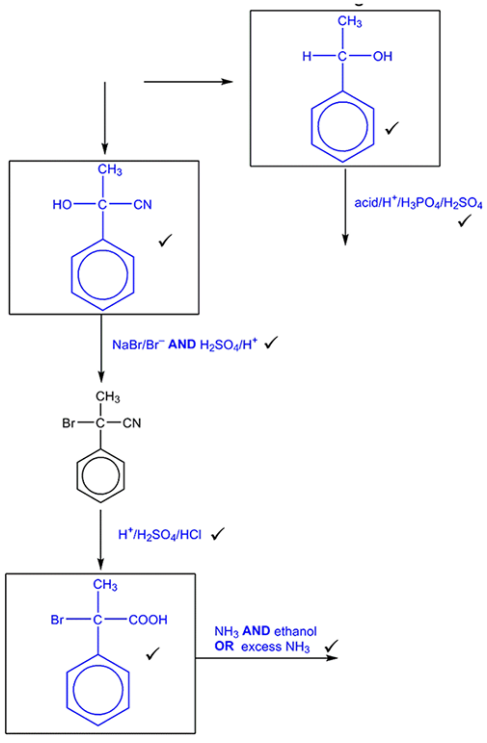
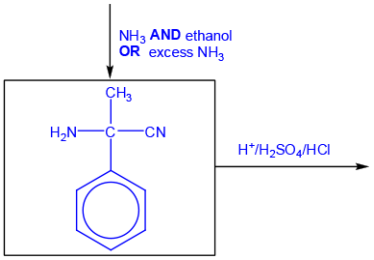
Examiner's Comments

This question required candidates to apply their knowledge of the mechanism of electrophilic substitution to the formation of phenylethanone from benzene. Examiners were encouraged by the number of excellent responses to this question, with the majority of candidates securing four out of five marks. Common errors included accuracy of curly arrows (Exemplar 7 below) and omission of HCl as product from the regeneration of the catalyst. The responses of lower ability candidates also contained errors in the equation for the formation of the electrophile. Such responses used chlorine rather than ethanoyl chloride.

Exemplar 6

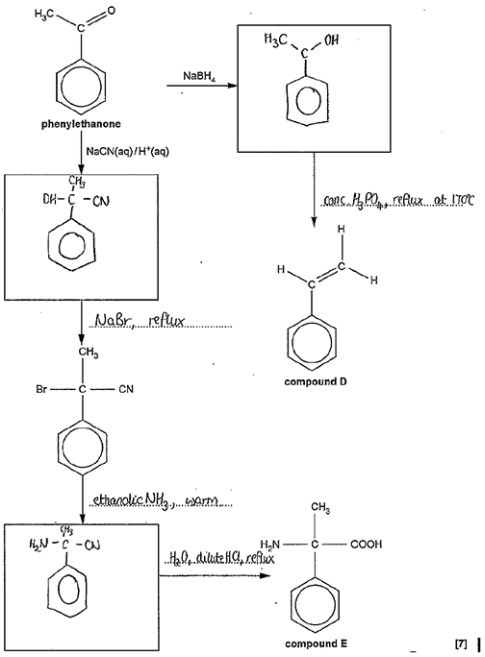


This response demonstrates a near perfect attempt at this question. The equations for the formation of the electrophile and regeneration of the catalyst are correct. The

					first curly arrow is drawn accurately from the circle of the benzene ring to the correct carbon atom of the electrophile. The intermediate is correct, with the π ring over the five carbon atoms and in the correct orientation. Unfortunately the curly arrow drawn to reform the π bond starts at the H atom rather than from the bond. This small error has prevented this candidate from being given full marks.
		i v	**one** mark for each correct structure/reagent 	7(AO 2.5 ×7)	**ALLOW** any vertical bond to the OH **OR** NH2 groups e.g. **ALLOW**  **DO NOT ALLOW** OH–, **OR** NH_2– but **ALLOW ECF** for subsequent use in this part For elimination, **IGNORE** 'concentrated', 'dilute' with acids **BUT DO NOT ALLOW** H_2O/steam/(aq) **ALLOW** HBr for $NaBr/H_2SO_4$ For hydrolysis. **IGNORE** missing (aq) **ALLOW** HNO_3 for hydrolysis but **DO NOT ALLOW** 'HNO_3 and H_2SO_4' **ALLOW** final 2 stages in opposite order i.e. NH_3 before acid hydrolysis  **Examiner's Comments** This question required candidates to apply knowledge of organic reactions from across the specification and discriminated well. Candidates with a good knowledge of reagents and conditions frequently scored over five marks. More detailed feedback is

discussed with Exemplar 7, below.

Exemplar 7



[7]

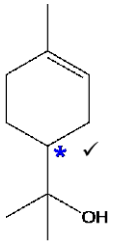
Phenylethanone is the starting point of this flowchart which shows the synthesis of compounds **D** and **E**.

Synthesis of **D**

The first step in the synthesis of D is the reduction of the ketone group. This response demonstrates a common error seen by examiners. The candidate has correctly deduced that than alcohol is formed but has omitted a hydrogen atom. Candidates are advised to take care when drawing structures. If a carbon atom is displayed it should be shown to be making four bonds. The final step of the synthesis is the dehydration of the alcohol with an acid. This candidate has used H_3PO_4. H_2SO_4 was also frequently seen. Lower ability responses included reference to water or steam and this was not credited.

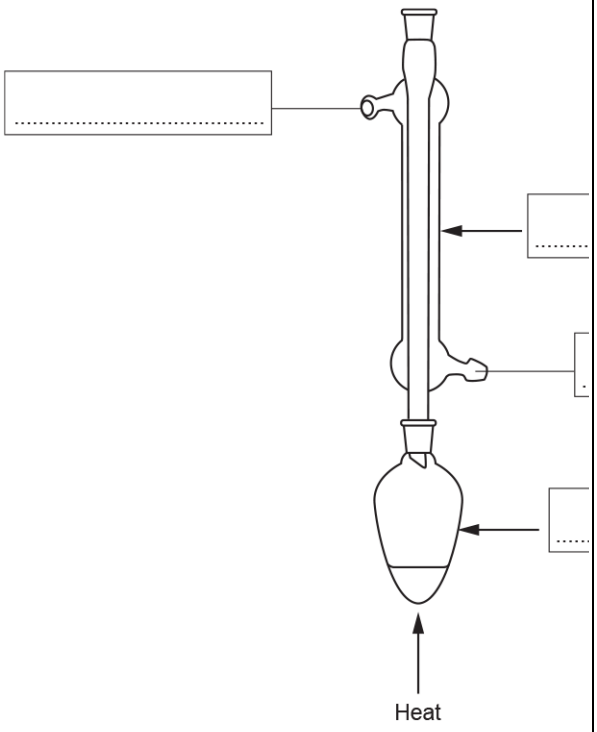
Synthesis of **E**

The first step of the synthesis of **E** from phenylethanone is the reaction with NaCN(aq)/H^+(aq). This candidate identifies that the product of the reaction is a hydroxynitrile but unfortunately this cannot

					be credited due to the incorrect linking of the OH group via the H atom. Candidates should be aware that, when drawing structures, groups must be bonded via the correct atoms. The next step of the synthesis is the substitution of the OH group. The candidate correctly recognises that NaBr is a suitable reagent but omits an acid, e.g. H_2SO_4, which is also required for this reaction. This error was seen frequently by examiners. The final two steps involve the substitution of the Br atom and acid hydrolysis of the nitrile group. In this case the candidate chooses the reaction with excess NH_3. The structure of the correct product of this reaction is shown and the synthesis is completed by identifying a suitable reagent for the final step. Other candidates opted to perform these steps in the reverse order and the mark scheme allowed full credit for either approach. Common errors in the final steps were omissions. Some candidates simply stated NH_3 without mentioning ethanol. Others identified water as important for the hydrolysis but did not include reference to an acid.
			Total	**16**	
20		i		1 AO 2.5	**DO NOT ALLOW** more than one * **ALLOW** a circle for * **Examiner's Comments** Most candidates showed one asterisk at the base of the cyclic part of the structure. The most common error was to show two asterisks, the second being on *$C(CH_3)_2OH$, despite this carbon not being connected to four different groups.

		ii	**MAXIMUM OF 4 MARKS FROM 5 MARKING POINTS** **Requirement for *E*/*Z* isomerism** **2 *marks*** C=C/double bond ✓ Each C (in C=C) is attached to (two) different groups/atoms ✓ **Identification as *E*- or *Z*- isomer** **2 *marks*** *E*/*Z* isomerism linked to (high) priority groups ✓ *Z*- **isomer AND** groups are on **same side** **OR** the ring carbons ✓ **Reason why other *E*/*Z* isomer does not exist 1 *mark*** ring would be strained **OR** ring would break/deform **OR** Cannot form ring if high priority groups are on opposite sides **OR** ring locks groups on one side of C=C bond ✓	4 AO1. 2 x2 AO2. 5x2	**IGNORE** no H attached to C=C **IGNORE** functional', i.e. **ALLOW** different functional groups **ALLOW** in context of groups with largest atomic number ***ORA*** ***Award BOTH identification marks for:*** *Z*- isomer **AND** (high) priority groups on same side Mark independently of previous part Response **MUST** be linked to the ring/cyclic structure **IGNORE** just '*E* isomer is impossible' **IGNORE** C=C bond cannot rotate **IGNORE** Groups can't swap sides **Examiner's Comments** Candidates displayed a good knowledge of the requirements for *E*/*Z* isomerism in terms of a C=C double bond and different groups on the carbon atoms of the C=C bond. Many assigned terpineol as the Z isomer explained in terms of the priority groups being on the same side of the C=C bond. Candidates found it difficult to explain why terpineol has only one *E*/*Z* isomer. Many candidates thought that the C=C bond could not rotate because it was part of the ring. however, a C=C bond cannot rotate whether it is in a ring or not. Few candidates considered the strain put on the ring if the priority groups (being part of the ring) were to be placed in an *E* conformation.
		iii	**First group:** **Reagent** **AND** **Functional group**: Alkene **OR** cycloalkene ✓	4 AO3. 2×4	**CONTACT TEAM LEADER FOR OTHER REACTIONS** --- **ALLOW GROUPS EITHER WAY ROUND**

			Examples of reagents Br_2 or other halogen, HBr, H_2 **AND** Ni (catalyst), H_2O(**g**)/steam **AND** H^+ (catalyst) **Organic product** for reagent with **C=C** in α-terpineol ✓ ***ALLOW*** *product from H_2 or H_2O if H^+ catalyst has been omitted from reagent.* --- **Second group** **Reagent** **AND** **Functional group**: (Tertiary) alcohol ✓ ***Examples of reagents*** NaBr/KBr/Br^- **AND** acid/H^+ (substitution), **OR** HBr Acid/H^+ (catalyst) (elimination), CH_3COOH **AND** acid/H^+ (catalyst) (esterification) $CH_3COOCOCH_3$ (esterification) CH_3COCl (esterification) **Organic product** for reagent with **OH** in α-terpineol ✓ **ALLOW product if catalyst omitted from reagent**		**IN BOXES** Functional group **MUST** be **named** **DO NOT ALLOW** UV with halogens **ALLOW** H_2SO_4/H_3PO_4/acid for H^+ **ALLOW** addition of HBr/ H_2O either way across C=C **ALLOW ANY HALIDE**, i.e. Cl^-, Br^-, I^- **ALLOW** H_2SO_4/H_3PO_4/acid for H^+ **ALLOW** HBr for H^+ and Br^- **ALLOW** name or formula of any carboxylic acid or acyl chloride for esterification **ALLOW** Na → product with –ONa **OR** $–O^-$ **DO NOT ALLOW** $Cr_2O_7^{2-}/H^+$ (tertiary alcohol) **<u>Examiner's Comments</u>** In this question, candidates were given the opportunity to demonstrate some knowledge of organic reaction in a new context. The choice of reaction was up to the candidate. Most candidates were able to identify the alkene group in terpineol and to suggest a reagent that would react with this functional group. A correct structure for the organic product then usually followed. Although most candidates identified the alcohol group, many struggled with a reagent and resulting product. Although the alcohol –OH group has many reactions, (e.g. elimination, substitution, esterification) many candidates were fixated on oxidation with acidified dichromate despite a tertiary alcohol not being capable of oxidation with this reagent. Some candidates quoted acidified dichromate but then copied the structure of terpineol, stating that there was no reaction, despite the question directing

					them to select a reagent that would react with their chosen group.
			Total	**9**	
21		i	 **Water flow AND condenser** Water in at bottom and out at top **AND** condenser ✓ **Flask and technique** Pear-shaped/round-bottom flask **AND** reflux ✓	2 (AO 1.2x2)	**DO NOT ALLOW** conical flask, volumetric flask, beaker in place of round bottom/pear shaped flask **Examiner's Comments** Most candidates labelled some of the apparatus correctly and identified the reflux technique. A significant number showed water flowing in the wrong direction and 'distillation' was given as the name of the technique. The 'condenser' was sometimes labelled incorrectly, e.g. 'condensation tube, 'distillation tube' and 'water jacket'. Only just over half the candidates were given both marks. **OCR support** Candidates are advised to learn the names of chemical apparatus and the practical techniques involved. Diagrams of distillation and reflux apparatus are provided in our Practical Activities Support Guide:

					https:/www.ocr.org.uk/Images/598371-practical-activities-support-guide.pdf
		ii	**Diagram showing knowledge of filtration under reduced pressure** Diagram showing Buchner flask *must have **ONE** side arm* **AND** Buchner/Hirsh funnel on top of flask ✓ *Labels not required* --- **Further details:** • Funnel sealed or stoppered to flask **AND** • Apparatus capable of filtering under reduced pressure **AND** • Label for setup from side arm to indicate reduced pressure **AND** • Label for Buchner flask **OR** Buchner/Hirsh funnel ✓ *ALLOW slips in spelling of 'Buchner'*	2 (AO 2.3) (AO 2.7)	Labels **NOT** required for diagram **ALLOW** diagram of a conical flask with a filtering setup above **AND** Side arm either in conical flask **OR** between flask and filter paper of funnel **IGNORE** absence of seals --- **MUST** imply some type of seal between filter setup and flask. **ALLOW <u>small</u>** gaps Examples of suitable labels (may have arrow from side arm or tube attached) • to pump • to vacuum • air out • suction • reduced pressure • etc. For Buchner flask and Buchner funnel **DO NOT ALLOW** just 'flask **OR** 'funnel' *Flask and funnel used in normal filtration* **<u>Examiner's Comments</u>** Many diagrams were incomplete and it was comparatively rare for both of the two available marks to be given. Important labels were often missing. Some candidates drew diagrams of other techniques, such as distillation. Many responses were not credited with marks and this question was often omitted. Candidates need practice in recognising practical techniques and in drawing acceptable diagrams.
			Total	**4**	

<table>
<tr>
<td>2
2</td>
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<tr><td></td><td>Compound C</td><td>Compound D</td></tr>
<tr><td>Number of peaks</td><td>3 ✓</td><td>8 ✓</td></tr>
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<td>2
(AO3.
2)</td>
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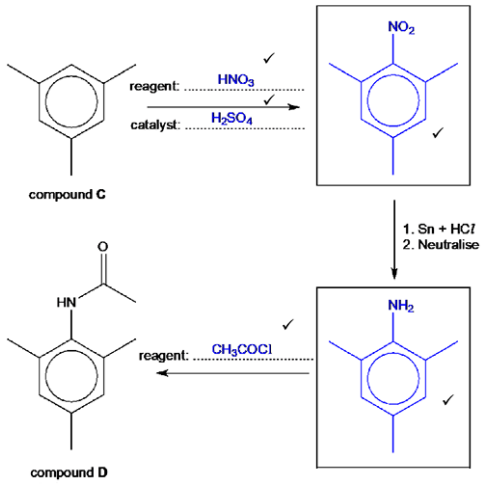
<td>ii</td>
<td> 
</td>
<td>5
(AO3.
2×5)</td>
<td>ALLOW any combination of skeletal OR structural OR displayed formula as long as unambiguous

IGNORE names for organic intermediates (question asks for structures

ALLOW names of reagents and catalyst

Around top arrow, ALLOW 1 of 2 marks if HNO_3 and H_2SO_4 swapped.
i.e.
reagent: H_2SO_4
→
catalyst: HNO_3

IGNORE references to concentration

ALLOW $(CH_3CO)_2O$ for left arrow

IGNORE CH_3COOH
IGNORE acyl chloride

DO NOT ALLOW $AlCl_3/FeCl_3$/Fe4</td>
</tr>
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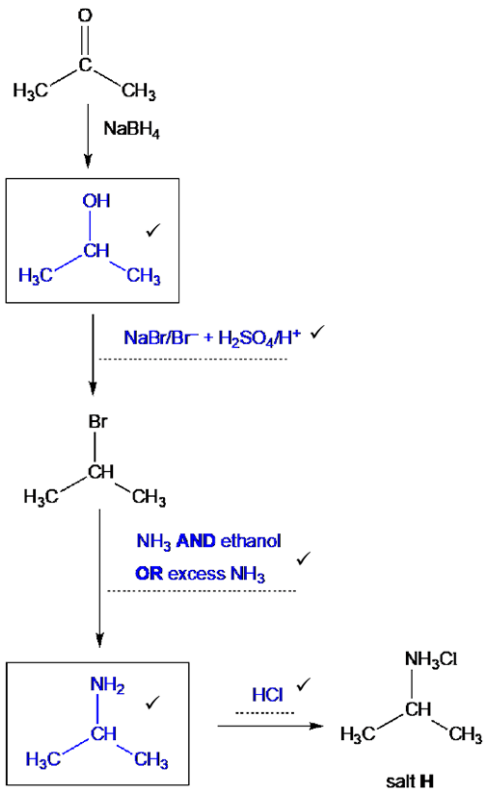
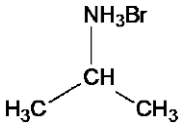
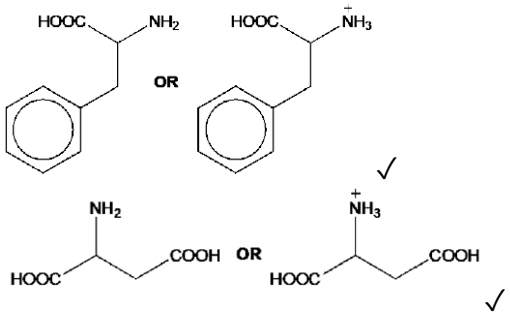
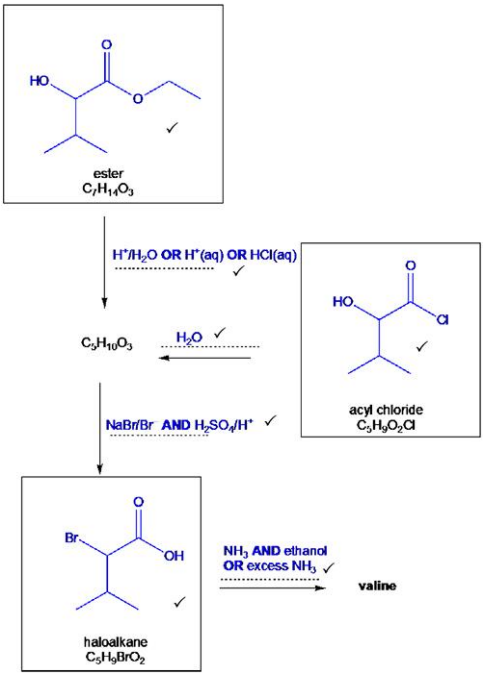
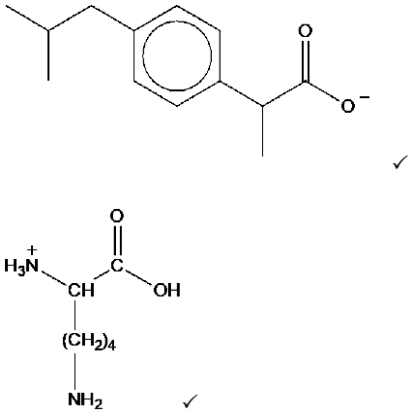
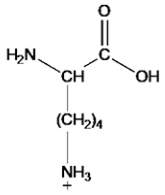
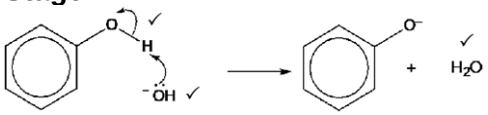
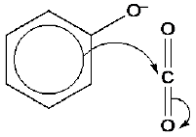
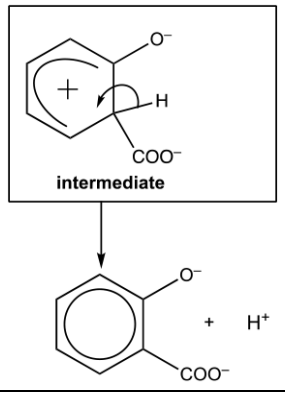
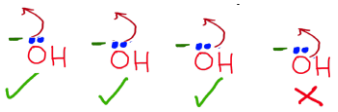
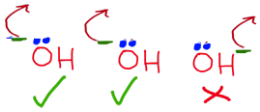
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>7</td>
<td></td>
</tr>
</table>

23	a			5 (AO2. 5×5)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** HBr **ALLOW** for the bottom left structure 
	b	i	Ester Amide Amine Carboxylic acid 4 groups correct ✓ ✓ ✓ 3 groups correct ✓ ✓ 2 groups correct ✓	3 (AO1. 2×3)	**IGNORE** amino acid **ALLOW** carboxyl **IGNORE** attempt to classify amide, e.g. secondary **IGNORE** formulae (question asks for names) **IF > 4** functional groups are shown, • Count 4 groups max but incorrect groups **first** **IGNORE** aryl **OR** alkyl group e.g. benzene, phenyl, aryl, arene, methyl
		ii	**Methanol** **1 mark** H_3C — OH ✓ 	4 (AO2. 5×4)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** + charge on H of NH_3 group, i.e. NH_3^+ If **BOTH** amino acids are shown with NH_3 groups (without the + charge) **OR** as NH_2^+ groups, award 2 of the 3 marks for the amino acids

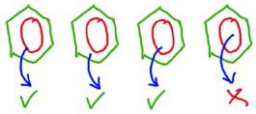
			Both amino acids shown with NH_3^+ ✓		If **BOTH** amino acids are shown as correctly balanced salts, e.g NH_3Cl, all marks can be awarded.
		ii i	**FIRST CHECK ANSWER ON THE ANSWER LINE** **If answer = 22.4 OR 22 OR 23 award 3 marks** n(aspartame) in 1 can = 0.167 / 294 = 5.68 x 10^{-4} (mol) ✓ n(aspartame) limit per day = 1.7x10^{-4} x 75 = 0.01275 (mol) ✓ number of cans = 0.01275 / 5.68 x 10^{-4} = 22.4 ✓	3 (AO2. 2×3)	**If there is an alternative answer, apply ECF and look for alternative methods** **Alternative methods** n(aspartame) in 1 can = 0.167 / 294 = 5.68 x 10^{-4} (mol) ✓ n(aspartame) per kg = 5.68 x 10^{-4} / 75 = 7.57 x 10^{-6} (mol) ✓ number of cans = 1.7 x 10^{-4} / 7.57 x 10^{-6} = 22.4✓ **OR** n(aspartame) limit per day = 1.7x10^{-4} x 75 =0.01275 (mol) ✓ mass(aspartame) limit per day =0.01275 x 294 = 3.7485 (g) ✓ number of cans = 3.7485 / 0.167 = 22.4 ✓
			Total	**15**	
24	a			7 (AO1. 2× 4) (AO2. 5× 3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** names of reagents **DO NOT ALLOW** OH– for HO– but **ALLOW ECF** for subsequent use in **(b)** For hydrolysis, **ALLOW** dilute acid **ALLOW** alkaline conditions followed by protonation of carboxylate i.e. NaOH(aq)/OH^-(aq) **AND** H^+(aq)/HCl(aq) **ALLOW** HBr for NaBr/H_2SO_4
	b	i	$C_{13}H_{18}O_2$ ✓	1 (AO2. 1)	**ALLOW** C, H and O in any order

		ii	**FIRST CHECK ANSWER ON THE ANSWER LINE** **If answer = 1.17 × 10_{21} award 3 marks** *M*(ibuprofen) = 206 ✓ *n*(ibuprofen) = $\frac{400 \div 1000}{206}$ = 1.94 × 10^{-3} (mol) ✓ Number of molecules = 1.94 × 10^{-3} × 6.02 × 10^{23} = 1.17 × 10^{21} to **3 SF** ✓	3 (AO2. 2× 3)	**ALLOW ECF** from **(c)(i)** Calculator: 1.941747573 × 10^{-3} **ALLOW ECF** from *n*(ibuprofen) **3 SF** essential
	c	i	 ✓	2 (AO3. 2× 2)	**IGNORE** small slip in carbon chains **ALLOW** 
		ii	More soluble in water ✓	1 (AO3. 1)	**Answer must be a comparison** **ALLOW** dissolve faster/quicker **IGNORE** absorbed more quickly (given in question)
			Total	**14**	
25			*Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.* **Level 3 (5-6 marks)** Correct calculation of the mass of $C_6H_5CH_2Cl$ **AND** Planned synthesis to form the intermediate $C_6H_5CH_2CN$ followed by hydrolysis to form A with most of the reagents identified and equations are mostly correct. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** Correct calculation of the mass of	6 (AO2. 4×2) (AO2. 7×2) (AO3. 3×2)	**Indicative scientific points may include:** **<u>Calculation of mass of $C_6H_5CH_2Cl$</u>** **Using moles** • *n*(**A**) = $\frac{5.44}{136}$ = 0.04(00) (mol) • *n*($C_6H_5CH_2Cl$) = 0.0400 × $\frac{100}{25}$ = 0.16(0) (mol) • Mass of $C_6H_5CH_2Cl$ = 126.5 × 0.16 = 20.2(4) g **Using mass**

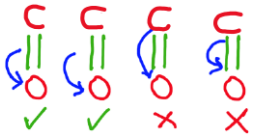
			$C_6H_5CH_2Cl$ **AND** Planned synthesis to form the intermediate $C_6H_5CH_2CN$ with most of the reagents identified and equation is mostly correct **OR** Calculation of the mass of $C_6H_5CH_2Cl$ is partly correct **AND** Planned synthesis includes formation of the intermediate $C_6H_5CH_2CN$ followed by hydrolysis to form **A** with some of the reagents identified **OR** Attempts to calculate mass of $C_6H_5CH_2Cl$ but makes little progress **AND** Planned synthesis includes formation of the intermediate $C_6H_5CH_2CN$ followed by hydrolysis to form **A** with most of the reagents identified and equations are mostly correct *There is a line of reasoning presented with some structure.* *The information presented is relevant and supported by some evidence.* **Level 1 (1-2 marks)** Calculation of the mass of $C_6H_5CH_2Cl$ is partly correct **OR** Attempts to calculate mass of $C_6H_5CH_2Cl$ but makes little progress **AND** Planned synthesis includes formation of the intermediate $C_6H_5CH_2CN$ with the reagent identified **OR** Planned synthesis includes both steps with some of the reagents identified **OR** Attempts equations for both steps but these may contain errors **OR** Describes one step of the synthesis with reagent(s) and equation mostly correct *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.*		• Theoretical mass of ester $= 5.44 \times \frac{100}{25}$ = 21.76 (g) • Theoretical $n(C_6H_5CH_2Cl) = \frac{21.76}{136}$ = 0.16(0) (mol) • Mass of $C_6H_5CH_2Cl = 126.5 \times 0.160$ = 20.2(4) g **ALLOW** small slip/rounding errors such as errors in M_r e.g. use of 137 instead of 136 for $C_6H_5CH_2COOH$ --- *Examples of partly correct calculations* Mass = 1.265 g from $0.0400 \times \frac{25}{100} \times 126.5$ (% yield inverted) Mass = 5.06 g from 0.0400 × 126.5 (% yield omitted) **<u>Synthesis: reagents and conditions</u>** **Stage 1**: Formation of intermediate, $C_6H_5CH_2CN$ • Reagents: CN^-(/ethanol) • Equation: $C_6H_5CH_2Cl + CN^- \rightarrow C_6H_5CH_2CN + Cl^-$ **OR** $C_6H_5CH_2Cl + NaCN \rightarrow C_6H_5CH_2CN + NaCl$ (**OR** use of KCN) **Stage 2**: Formation of **A**, $C_6H_5CH_2COOH$ • Reagents: H^+/H2O (**ALLOW** 'acid hydrolysis' • Equation: $C_6H_5CH_2CN + 2H_2O + H^+ \rightarrow C_6H_5CH_2COOH + NH_4^+$ **OR** $C_6H_5CH_2CN + 2H_2O + HCl \rightarrow C_6H_5CH_2COOH + NH_4Cl$

			0 marks No response or no response worthy of credit.		**Examiner's Comments** This question differentiated well. Those that did not achieve a mark often made little progress in the percentage yield calculation. Many candidates incorrectly detailed a two-step mechanism involving substitution to produce an alcohol followed by oxidation to a carboxylic acid, missing the key detail of an extra carbon in the chain. Candidates that answered this question well calculated the mass of (chloromethyl)benzene required and described the steps required to produce compound A, providing balanced equations for each step. Candidates achieving Level 1 or 2, did not provide balanced equations for both steps or had made little progress with the percentage yield calculation.
			Total	**6**	
26	a	i	**Stage 1**  1 mark for each curly arrow as shown. **Stage 2** Curly arrow from π-ring to C in CO_2 **AND** curly arrow from the C=O bond to O atom ✓  Correct intermediate ✓ Curly arrow from C–H bond to reform π-ring **AND** H^+ formed ✓ 	6 (AO1.1) (AO1.2) (AO2.5) (AO2.5) (AO2.5) (AO1.2)	**ANNOTATE WITH TICKS AND CROSSES** **NOTE**: curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **Curly arrow** from OH^- must • go to the H of O–H **AND** • start from, **OR** be traced back to **any point across width** of lone pair on O of OH^-  • **OR** start from – charge–OH ion  **Curly arrow** from O–H bond must start from, **OR** be traced back to, **any part of** O–H bond and go to O **IGNORE** dipoles on O-H bond **IGNORE** Na^+ **1st curly arrow** must

- go to the C of CO_2
  AND
- start from, **OR** close to **circle of benzene ring**

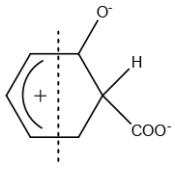


2nd curly arrow must start from, **OR** be traced back to, **any part of** C=O bond and go to O



ALLOW 2nd curly arrow from C=O to any O in CO_2

DO NOT ALLOW the following intermediate:

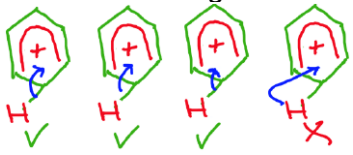


π-ring must cover more than half of the benzene ring structure
AND
the correct orientation, *i.e.* gap towards C with CO_2^-

ALLOW + sign anywhere inside the 'hexagon' of the intermediate.

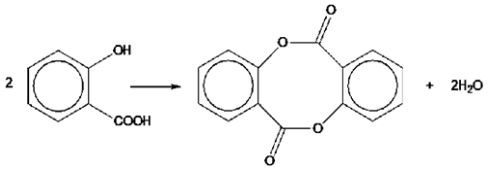
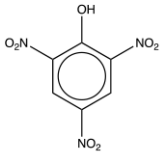
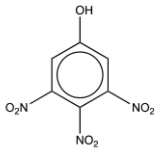
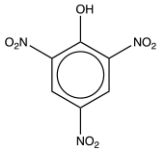
DO NOT ALLOW mark for intermediate if phenolic O– is missing

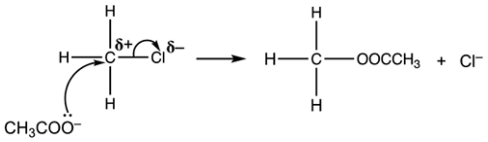
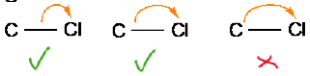
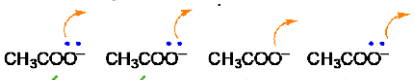
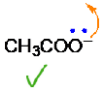
curly arrow must start from, **OR** be traced back to, **any part of** C-H bond and go inside the 'hexagon'



Examiner's Comments

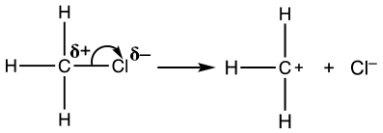
Candidates who answered this question

					well had clear mechanisms. Too often positioning of curly arrows was ambiguous.
		ii	OH^- : base ✓ CO_2: electrophile **OR** electron pair acceptor ✓	2 (AO2. 1×2)	**ALLOW** alkali **IGNORE** 'nucleophile', 'donates electron pair' **IGNORE** lone pair acceptor (*No lone pair involved*)
		iii	 One ester link in organic product ✓ Correct structure of organic product ✓ Correct equation **AND** balanced ✓	3 (AO3. 1) (AO3. 2) (AO2. 6)	**Examiner's Comments** Candidates who found this question difficult often did not recognise the functional groups present in the reacting molecule. Those that identified an esterification reaction often then did not balance the equation.
	b	i	Dissolve in **hot** water/solvent ✓ **Minimum** amount of solvent ✓ Cool **AND** Filter **AND** (leave to) dry ✓ *All three needed*	3 (AO3. 3×3)	**ALLOW** any solvent **IGNORE** • Initial filtering • hot filtration to remove insoluble impurities **DO NOT ALLOW** adding of a drying agent (e.g. $MgSO_4$)
		ii	C : H : N : O 31.44/12 : 1.31/1 : 18.34/14 : 48.91/16 **OR** 2.62 : 1.31 : 1.31 : 3.06 ✓ 6:3:3:7 **OR** $C_6H_3N_3O_7$ ✓ Molecular formula = $C_6H_3N_3O_7$ **AND** use of *M* = 229.0 (directly linked to molecular formula) ✓	6 (AO1. 2× 2) (AO3. 1) (AO3. 2) (AO3. 1×2)	**ALLOW** alternative approach for empirical formula and evidence that 229 is equal to $C_6H_3N_3O_7$ **DO NOT ALLOW** ECF from the empirical formula with the wrong molar ratio  2,4,6  3,4,5  2,4,6

			Any trisubstituted $–NO_2$ substituted phenol that is consistent with M = 229.0 ✓ **Evidence for substitution** 2,4,6 **OR** 3,4,5 substituted phenol **AND** 4 peaks/ C environments from ^{13}C NMR ✓ 2,4,6 substituted phenol **AND** directing effects of –OH ✓		
			Total	**20**	
27			**Mechanism:**  **NOTE:** Can be any C–X bond, e.g. C–Cl, C–Br, C–I but must be consistent. **Curly arrow on C–X** Dipole shown on C–X bond of CH_3X, $C^{\delta+}$ and $X^{\delta-}$ **AND** curly arrow from C−X bond to X atom ✓ **Curly arrow from CH3COO⁻** Curly arrow from CH_3COO^- to C atom of C–X bond ✓ --- **Products** Correct organic product **AND** X^- ✓	3 (AO2.5) (AO1.2) (AO2.5)	ANNOTATE ANSWER TICKS AND CROSSES --- **NOTE:** Curly arrows can be straight, snake-like, etc. but **NOT** double headed or half headed arrows **1st curly arrow** must start from, **OR** be traced back to, **any part** of C–Cl bond and go to Cl  **2nd curly arrow** must • go to the C of C–Cl **AND** • start from, **OR** be traced back to **any point across width** of lone pair on O of CH_3COO^-  • **OR** start from '–' **on O** of CH_3COO^- ion  (*Lone pair **NOT** needed if curly arrow from O–*) --- If CH_3COOH used instead of CH_3COO^-, **ALLOW** X^- **OR** HX as 2nd product **ALLOW** S_N1 mechanism

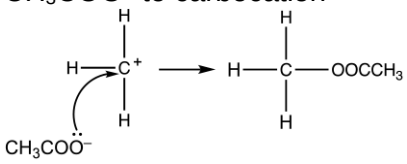
First mark

Dipole shown on C–Cl bond, $C^{\delta+}$ and $Cl^{\delta-}$, **AND** curly arrow from C−Cl bond to Cl atom ✓



Second mark

Correct carbocation **AND** curly arrow from CH_3COO^- to carbocation



Curly arrow must be from lone pair on O of CH_3COO^-

OR from minus on O of CH_3COO^- ion (no need to show lone pair if curly came from – charge) ✓

Third mark

Correct organic product **AND** Cl^- ✓

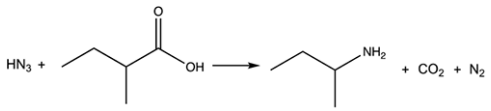
Examiner's Comments

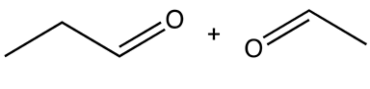
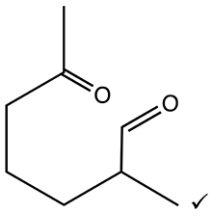
Candidates were required to apply their knowledge of nucleophilic substitution of haloalkanes to outline a similar mechanism for an unfamiliar nucleophile.

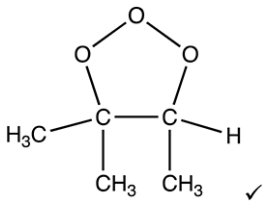
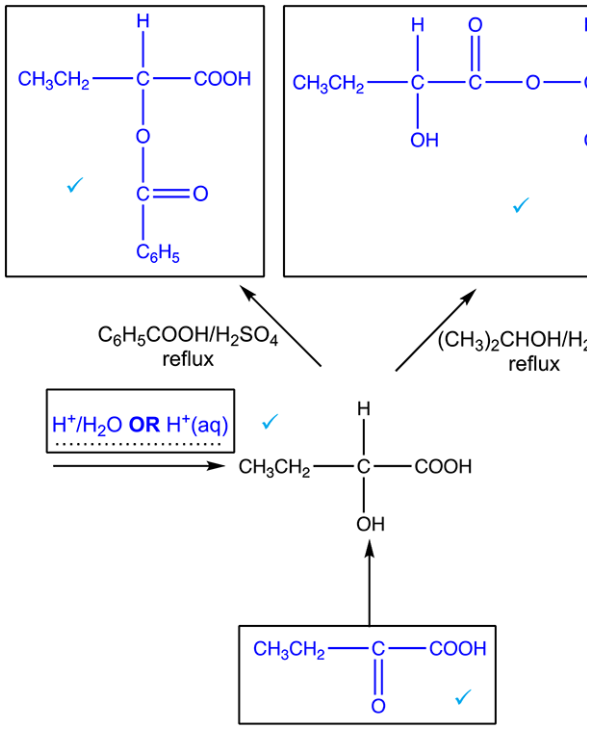
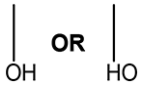
Most candidates were able to show a correct curly arrow for breaking the C–X bond, with a dipole shown. The role of the unfamiliar ethanoate ion proved to be much more difficult, with curly arrows not starting from either a lone pair or the – charge. A mark was given for the correct products but the halide ion was often omitted.

This question discriminated extremely well. Higher-attaining candidates provided clear mechanisms and were commonly given all 3 marks. Many candidates could not work out where to start, beyond breaking the C–X bond. It was common to see reactants and products with the wrong number of carbon atoms, and the structure of ethyl methanoate instead of methyl ethanoate

					being shown as the product. When confronted with a question set in a novel context, candidates are advised to apply knowledge and understanding from reactions that they have studied – here the reaction of a haloalkane with a OH– ion.
			Total	**3**	
28		i	FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 2.75 award 2 marks --- $[H^+]^2 = K_a \times [HN_3]) = 2.51 \times 10^{-5} \times 0.125$ $[H^+] = \sqrt{(K_a \times [HN_3])}$ $[H^+]^2 = 2.51 \times 10^{-5} \times 0.125$ **OR** $[H^+] = \sqrt{(2.51 \times 10^{-5} \times 0.125)}$ **OR** $[H^+] = 1.77\ldots. \times 10^{-3}$ (mol dm^{-3}) ✓ pH = –log $1.77\ldots. \times 10^{-3}$ = 2.75 (Must be to **2DP**) ✓	2 (AO2. 2×2)	**ALLOW ECF** throughout **IGNORE** error with HN_3 shown as NH3 **ALLOW** pH mark by **ECF** **ONLY** if $2.51 \times 10^{-5} \times 0.125$ used **AND** pH < 7 --- **Common errors (Must be to 2 DP)** pH = 5.50 → 1 mark (*No square root*) $[H^+] = 6.26 \times 10^{-4}$ from $\sqrt{(2.51 \times 10^{-5})} \times 0.125$ pH = 3.20 → 1 mark $[H^+] = 8.87 \times 10^{-6}$ from $\sqrt{(0.125)} \times 2.51 \times 10^{-5}$ pH = 5.05 → 1 mark **Examiner's Comments** Most candidates found this pH calculation easy and most obtained a pH of 2.75 for both marks.
		ii	• Correct equation ✓ • Correct acid–base pair labels for correct equation ✓ HN_3 + H_2O ⇌ N_3^- + H_3O^+ ✓ **A1** **B2** **B1** **A2** ✓ **OR** **A2** **B1** **B2** **A1**	2 (AO1. 2×2)	**ALLOW** 1 mark for one correct acid–base pair **WITH** correct labels e.g. H_2O H_3O^+ **WITH** B1 A1 **OR** B2 A2 **Examiner's Comments** This unfamiliar acid–base pair question was answered comparatively well. Most candidates identified one correctly labelled

					acid–base pair, usually H_3O^+ and H_2O. The higher-attaining candidates were able to write the correct equation and to identify both acid–base pairs.
		iii	Structure of 2-methylbutanoic acid ✓ Structure of organic product (primary amine) ✓ CO_2 **AND** N_2 as products ✓ 	3 (AO3. 2×2) (AO2. 6)	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous **Common error** With NH_3, → CO_2 + H_2 **ALLOW ECF** for equation using a different amine isomer of the organic product *e.g.* $(CH_3)_2CHCH_2NH_2$ **DO NOT ALLOW ECF** from unbranched species, e.g. $CH_3CH_2CH_2NH_2$ **IGNORE** HN_3 in equation, even if missing **IGNORE** poor connectivity to all groups **Examiner's Comments** Candidates were expected to interpret information for an unfamiliar organic reaction and to write a balanced question. The information included important clues which were sometimes ignored, showing the importance of using any information provided. The structure of 2-methylbutanoic acid was usually correct although many candidates did show 3-methylbutanoic acid instead, numbering from the wrong end of the chain. The amine structure proved to be more difficult with many showing an amide instead. Even when an amine was shown, it often included four C atoms instead of three. Finally, candidates were told that the two gases (N_2 and CO_2) are present in the atmosphere. Many candidates clearly did not use this clue, included substances that are not atmospheric gases such as H_2, H_2O and NH_3. As always, the advice is to use the information provided – it often includes hints to help candidates. **Misconception** Branched and substituted carboxylic acids

					are named counting from the start of the main stem, e.g. In Q5(b)(iii), 2-methylbutanoic acid is $CH_3CH(CH_3)CH_2COOH$. The correct name is obtained by starting from the carbon atom with the functional group. i.e. The COOH carbon in number 1: 2-methylbutanoic acid is $CH_3CH_2CH(CH_3)COOH$. The same rule is used for all organic compounds, e.g. 2-methylbutanal is $CH_3CH_2CH(CH_3)CHO$ and **not** $CH_3CH(CH_3)CH_2CHO$
			Total	**7**	
29			A	1 (AO1.1)	**Examiner's Comments** Most candidates correctly selected A. The most common incorrect response was option D as candidates had misinterpreted the amide group as a ketone and an amine.
			Total	**1**	
30			A	1 (AO1.1)	**Examiner's Comments** Many candidates did not identify CH_3NH_2 as a nucleophile and selected option B.
			Total	**1**	
31		i	 **BOTH** structures required for ✓ 	2 (AO3.1×1) (AO3.2×1)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous

		ii		1 (AO3.2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **Examiner's Comments** Most candidates were able to score 1 mark for correctly drawing the structures of the two aldehyde products of the first reaction. The second reaction proved more challenging, with most candidates incorrectly drawing two products. Few candidates were given this mark. A common error was to produce multiple products (rather than a ring structure) or to put positive/negative charges on the oxygen atoms within the ring structure.
			Total	**3**	
32	a			4 (AO2.5×4)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** any vertical bond to the OH group e.g. **ALLOW**  **IGNORE** connectivity of CH_3CH_2 group **IGNORE** inorganic by-products **ALLOW** HCl/H_2O, H_2SO_4/H_2O **IGNORE** dilute **Examiner's Comments**

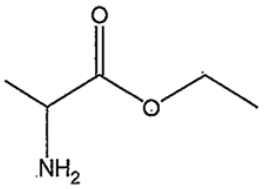
					The majority of candidates were able to identify at least one of the structures. A significant number of candidates did not check the number of bonds of each atom in their structures and frequently had too many or too few hydrogen atoms attached. Most candidates identified that acidic conditions were required but some missed the aqueous condition that was also required for the mark.
	b		**Level 3 (5-6 marks)** Correct calculation of mass of $CH_3CHClCOOH$. **AND** Planned synthesis includes substitution of –Cl and formation of compound **I** (or its corresponding ammonium salt) with the correct reagents and some conditions identified and equations are mostly correct. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** Calculation of mass of $CH_3CHClCOOH$ is correct **AND** Planned synthesis includes one step of the synthesis with the correct reagent and some conditions identified and equation is mostly correct **OR** Calculation of mass of $CH_3CHClCOOH$ is partly correct **AND** Planned synthesis includes substitution of –Cl and formation of compound **I** (or its corresponding ammonium salt) with the correct reagents **OR** Attempts to calculate mass of $CH_3CHClCOOC_2H_5$ but makes little progress **AND** Planned synthesis includes substitution of –Cl and formation of compound **I** (or its	6 (AO3. 3×6)	**Indicative scientific points may include:** **<u>Calculation of mass of $CH_3CHClCOOCH_3$</u>** **Using moles** • $n(\mathbf{I}) = \frac{9.36}{117.0}$ = 0.08(00) (mol) • $n(CH_3CHClCOOC_2H_5) = 0.0800 \times \frac{100}{64}$ = 0.125 (mol) • Mass of $CH_3CHClCOOH = 108.5 \times 0.125$ = 13.5625 g **Using mass** • Theoretical mass of $\mathbf{I} = 9.36 \times \frac{100}{64}$ = 14.625 (g) • Theoretical $n(CH_3CHClCOOH) = \frac{14.625}{117.0}$

			corresponding ammonium salt) with the correct reagents and some conditions identified and equations are mostly correct *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1-2 marks)** Calculation of mass of $CH_3CHClCOOH$ is partly correct **OR** Planned synthesis includes both steps with some of the reagents and conditions identified **OR** Attempts equations for both steps but these may contain errors **OR** Describes one step of the synthesis with reagents, conditions and equation mostly correct *There is an attempt at a logical structure with a line of reasoning.* *The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		= 0.125 (mol) • Mass of $CH_3CHClCOOH$ = 108.5 × 0.125 = 13.5625 g **ALLOW** slip/rounding errors such as errors in M_r, e.g. use of 107.5 instead of 108.5 for $CH_3CHClCOOH$ → 13.4375 **----------** ***Examples of partly correct calculations*** Mass = 5.5552 g from $0.0800 \times \frac{64}{100} \times 108.5$ (% *yield inverted*) Mass = 8.68 g from 0.0800 × 108.5 (% *yield omitted*) **<u>Synthesis:</u> *Either order for 2 stages*** **Substitution of –Cl → amine:** • Reagents: (excess) NH_3 • Condition: ethanol • Equation: $CH_3CHClCOOH + 2NH_3 \rightarrow CH_3CHNH_2COOH + NH_4Cl$ **OR** $CH_3CHClCOOH + NH_3 \rightarrow CH_3CHNH_2COOH + HCl$ **Esterification of amine → compound I** • Reagents: CH_3CH_2OH

					• Conditions: acid (catalyst), e.g. H_2SO_4 (reflux/heat) • Equation: $CH_3CHNH_2COOH + CH_3CH_2OH \rightarrow CH_3CHNH_2COOCH_2CH_3 + H_2O$ **OR ----------** **Esterification of carboxylic acid → ester** • Reagents: CH_3CH_2OH • Conditions: acid (catalyst), e.g. H_2SO_4 (reflux/heat) • Equation: $CH_3CHClCOOH + CH_3CH_2OH \rightarrow CH_3CHClCOOCH_2CH_3 + H_2O$ **Substitution of –Cl → amine:** • Reagents: (excess) NH_3 • Condition: ethanol • Equation: e.g $CH_3CHClCOOCH_2CH_3 + 2NH_3 \rightarrow CH_3CHNH_2COOCH_2CH_3 + NH_4Cl$ **OR** $CH_3CHClCOOCH_2CH_3 + NH_3 \rightarrow CH_3CHNH_2COOCH_2CH_3 + HCl$ **OR** $CH_3CHClCOOCH_2CH_3 + NH_3 \rightarrow CH_3CHNH_3ClCOOCH_2CH_3$ *(ammonium salt)* **Examiner's Comments** This question was marked using a level of response mark scheme. Most candidates gave an answer worth of at least Level 2 (3-4 marks) by providing the synthetic steps

with reagents and equations for the synthesis of compound I. Exemplar 2, below, shows a frequent Level 2 response. The best performing candidates correctly determined the mass attempting to calculate the mass and showed the synthesis efficiently, using equations to communicate the preparation of compound I, with these responses being given Level 3 (5-6 marks). A number of responses omitted the mass calculation, such responses received Level 2 (1-2 marks).

Exemplar 2

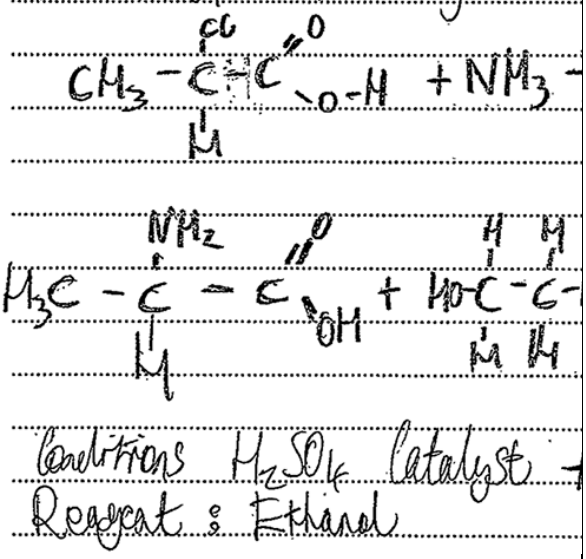


Compound I

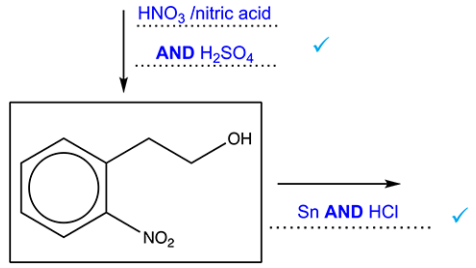
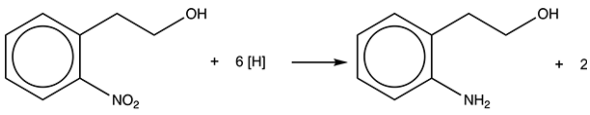
Plan a synthesis to prepare 9.36 g of compound **I** starting $CH_3CHClCOOH$. The overall percentage yield of compou is 64%.

In your answer, include starting mass of 2-chloropropano equations where appropriate.

$9.36 \times \frac{100}{64} = 14.625$ g to St



In this response the candidate has attempted to calculate the starting mass but has made little progress. Two stages of the synthesis have been covered with the reagents and most of the conditions identified. Both equations are complete. This is a Level 2 response and 4 marks

					have been given as the repones is logical and well communicated
			Total	**10**	
33		i		2 (AO1. 2×2)	**IGNORE** references to concentration **IGNORE** 'dilute' for HCl **IGNORE** H_2 **IGNORE** NaOH if seen as a reagent to convert nitro group into amine e.g 'Sn/(concentrated) HCl then NaOH' scores the mark
		ii		1 (AO2. 6)	**Examiner's Comments** Candidates were familiar with the reagents required in these two reactions. The most able candidates were able to identify the use of 6[H] as the reducing agent and the production of 2 water molecules. Incorrect responses commonly included the use of HCl and $NaBH_4$ as a reactant.
			Total	**3**	
34			**C**	1 (AO1. 2)	**Examiner's Comments** D was the most common incorrect response, separating the amide into a ketone and amine. This was followed by A, not recognising that a phenol OH is distinct from alcohol OH. A common strategy was to circle or label the functional groups on the structure of paracetamol.
			Total	**1**	
35			**Level 3 (5–6 marks)** A **three** stage synthesis in the **correct** order **AND** Equations for each stage are mostly correct **AND** Most reagents correct *There is a well-developed line of reasoning which is clear and logically*	6 (AO3. 3 ×6)	**Mark second page as SEEN** **Indicative scientific points may include:** **IGNORE conditions** ***Stage 1: Reaction with CN^-*** • Reagents: CN^- (in ethanol)

structured. The information presented is relevant and substantiated.

Level 2 (3–4 marks)
Synthesis includes at least **two** stages in **any** order **OR** uses NH_3 and HBr in the **correct** order (without chain extension)
AND
some of the reagents and some equations correct

There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.

Level 1 (1–2 marks)
Planned synthesis includes reagents for **any** two stages
OR
Describes one stage with reagents and equation mostly correct

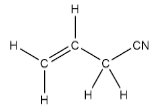
There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.

0 mark
No response or no response worthy of credit.

- Equation:

$H_2C=CHCH_2Br + CN^- \rightarrow H_2C=CHCH_2CN + Br^-$

Intermediate 1

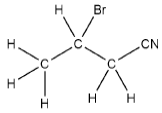


Stage 2: Addition of HBr to C=C

- Reagents**:** HBr
- Equation:

$H_2C=CHCH_2CN + HBr \rightarrow CH_3CHBrCH_2CN$

Intermediate 2



Stage 3: Reduction of CN

- Reagents: H_2 (with Ni)
- Equation:

$H_3CCHBrCH_2CN + 2H_2 \rightarrow CH_3CHBrCH_2CH_2NH_2$

Needs CN^- before HBr
– CN^- would react with both Br atoms

Needs HBr before H_2
– H_2 would react with C=C
Alternative three stage syntheses:

Alternative using $LiAlH_4$
Caution - Can be done as stage 2 or 3

- Reagents: LiAlH4
- Equation:

$H_2C=CHCH_2CN + 4[H] \rightarrow H_2C=CHCH_2CH_2NH_2$
OR
$H_3CCHBrCH_2CN + 4[H] \rightarrow CH_3CHBrCH_2CH_2NH_2$

Needs CN^- before HBr and $LiAlH_4$

Can have HBr and $LiAlH_4$ in any order

Alternative using radical substitution:
Stage 1: Reaction with CN^-

- Reagents: CN^- (in ethanol)
- Equation:

$H_2C=CHCH_2Br + CN^- \rightarrow H_2C=CHCH_2CN + Br–$

Stage 2: Reduction of CN and C=C

- Reagents: H_2 (with Ni)
- Equation:

$H_2C=CHCH_2CN + 3H_2 \rightarrow CH_3CH_2CH_2CH_2NH_2$

Stage 3: Reaction with Br_2

- Reagents: Br_2 (with UV)
- Equation:

$CH_3CH_2CH_2CH_2NH_2 + Br_2 \rightarrow CH_3CHBrCH_2CH_2NH_2 + HBr$

Needs CN^- before H_2
Needs H_2 before Br_2

Two stage synthesis using NH_3 and HBr forming product with no lengthening of carbon chain

Stage 1: Reaction of NH_3

- Reagents: NH_3 (in ethanol)
- Equation:

$H_2C=CHCH_2Br + NH_3 \rightarrow H_2C=CHCH_2NH_2 + HBr$

OR $2\ NH_3 \rightarrow NH_4Br$

Stage 2: Addition of HBr to C=C

- Reagents: HBr
- Equation:

$H_2C=CHCH_2NH_2 + HBr \rightarrow CH_3CHBrCH_2NH_2$

Needs NH_3 before HBr

– HBr would react with C=C

Examiner's Comments

This challenging level of response question was generally well attempted. Many candidates recognised the reagents required in this synthesis but fewer candidates were able to deduce three correct reagents in the right order with equations to achieve Level 3. Most candidates achieved Level 2 4 marks. Many correctly identified suitable reagents but carried out the stages in the wrong order. A common error was to carry out electrophilic addition with HBr first then react with cyanide ion, not realising both Br groups would react and the reaction would not be selective. Alternatively, having introduced the nitrile group then carried out the reduction first, not realising that the C=C would also be reduced.

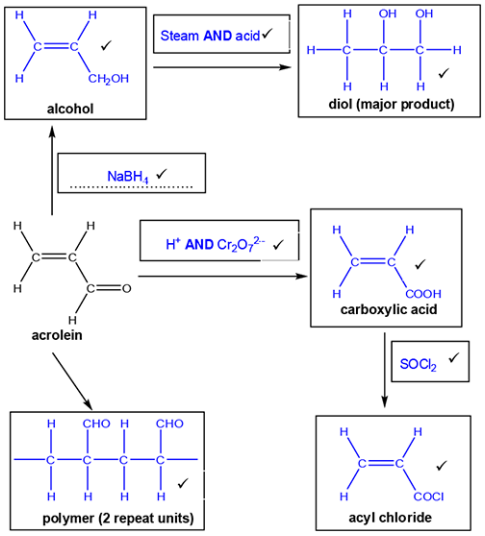
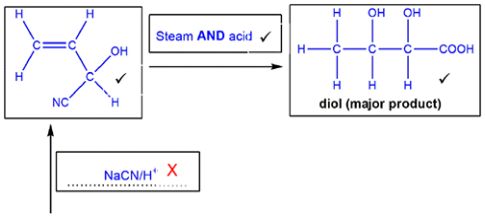
The lowest scoring responses were often incomplete and despite identifying some reagents did not give equations. Candidates are encouraged to read the questions carefully so they can make sure their response covers all the detail required. Many candidates used molecular formula in their equations. It is usually preferrable in organic chemistry to give structures. Some gave surplus information such as the mechanisms and reaction conditions for each reaction.

The key to answering this question well was knowing reagents for different functional group interconversions as well as planning each step to make sure of a logical synthesis. Some candidates were seemingly confused by the term 'intermediate' and gave an intermediate as in a mechanism, e.g. carbocation.

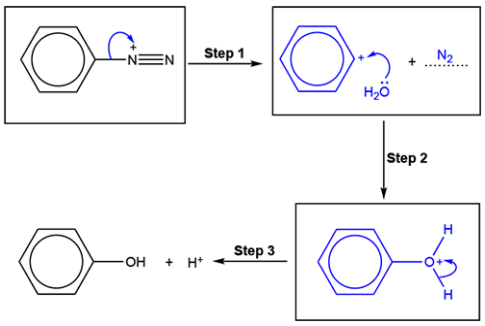
OCR support

A useful resource for teaching how to

					identify functional groups and practice at devising synthetic routes is the Topic exploration pack on Organic synthesis. This should be used in conjunction with the reaction pathways summaries.
			Total	**6**	
3 6			Dissolve in the minimum quantity of hot water/solvent ✓ Cool (to allow crystals form) **AND** Then filter (under reduced pressure) ✓ (Leave to) dry ✓	3 (AO3. 3 ×3)	**ALLOW** any solvent **IGNORE** • Initial filtering • Filtration between dissolving and cooling (implies hot filtration) • Washing with cold solvent **DO NOT ALLOW** use of drying agent (e.g. $MgSO_4$) **Examiner's Comments** About a quarter of candidates gained all 3 marks. They were able to give clear, well-structured answers with all the steps as carried out in PAG 6 practical activities. The best answers were often in the form of bullet pointed steps and often included extra details such as a hot filtration step or promoting crystallisation by scratching the surface. Many candidates lost the first mark as their responses didn't give sufficient detail, e.g. hot solvent, not just warm and minimum volume required. Some missed the cooling step essential for formation of crystals before filtration. Some missed that the crystals need to be dried following filtration but often if only given 1 mark this was the mark given. Lots of confusion with purification with organic liquid was seen, such as references to use of a separating funnel, drying agents and distillation. Some also went on to explained how to check purity using melting point determination. **OCR support**

					A useful resource for revising the steps for purification of an organic solid is the Topic exploration pack: Experiments on organic synthesis in Learner Activity 2.
			Total	**3**	
37			 **Only possible alternative that can gain credit:** Reaction with NaCN/H+ 	9 (AO1.2 ×4) (AO2.5 ×5)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** Correct names instead of formula for all reagents throughout e.g. For H^+ and $Cr_2O_7^{2-}$, **ALLOW** acidified dichromate For Steam and acid • For steam, **ALLOW** $H_2O(g)$ **OR** H_2O with T ≥ 100°C • For acid, **ALLOW** H^+ **OR** H_2SO_4 **OR** H_3PO_4 • Note both needed for 1 mark. **ALLOW** either way round. For $NaBH_4$ • **IGNORE** water / aqueous /acid • **ALLOW** $LiAlH_4$ For $SOCl_2$, **ALLOW** PCl_5 **OR** $COCl_2$ • **IGNORE** H^+ OR HCl For H^+ and $Cr_2O_7^{2-}$, **ALLOW** H_2SO_4 **AND** $K_2Cr_2O_7$ **OR** $Na_2Cr_2O_7$ **ALLOW** Tollens' reagent **IGNORE** connectivity except **DO NOT ALLOW** -COH for aldehyde For polymer **ALLOW** alternating side chains. **IGNORE** brackets and use of 'n' 'End bonds' **MUST** be shown (solid or dotted) **IF** NaCN/H^+ reacted with acrolein instead of $NaBH_4$

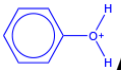
					• No mark for NaCN/H+ **OR** HCN • Unsaturated alcohol award mark for product as shown • Final product must have CN hydrolysed as shown **Examiner's Comments** This question discriminated well. Many candidates were able to demonstrate an excellent knowledge of organic reactions and it was not uncommon to see scores of at least 7 marks. This question identified which candidates had learned their synthetic routes including necessary reagents and conditions. Marks were often lost for small details such as missing Hs (check all Cs have four bonds) or not specifying that steam is required for hydration of alkenes or missing the acid needed for oxidation. Many suggested the use of NaOH or just a mixture of acids to product the diol. The minor 1,3-diol or 1,1-diol product was often seen. The sequence leading to an acyl chloride from acrolein was usually the most well answered. However, quite a few tried to use HCl to make the acyl chloride. Many lost marks for the polymer for incorrect connectivity on the aldehyde, e.g. -COH or attempting to make a polymer via connection of the aldehyde group. **OCR support** This topic guide provides a summary of synthetic routes. Copies of the summary posters without the conditions can be found on Teach Cambridge. This should be used in conjunction with the organic synthesis topic exploration pack.
			Total	**9**	
38			**Mechanism**:	4 (AO	**ANNOTATE ANSWER TICKS AND CROSSES** ----------



M1: Curly arrow from C−N bond to N^+ ✓

M2:  **AND** N_2 ✓

M3: Curly arrow from lone pair of O of H_2O to C^+ ✓

M4  **AND** Curly arrow from O–H bond to O+ ✓

For all marks, treat additional curly arrows as CON

ALLOW M3 shown in bottom box

IGNORE partial charges
ALLOW M3 AND M4 combined
e.g.

For  **DO NOT ALLOW M2** for carbocation

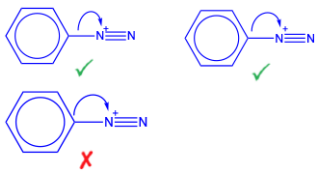
BUT

ALLOW for M3 and/or M4 by ECF,

3.2 ×4)

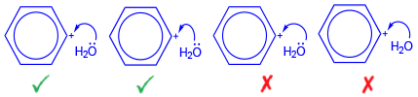
NOTE: Curly arrows can be straight, snake-like, etc. but **NOT** half arrows

1st curly arrow must start from, **OR** be traced back to, **any part of** C–N^+ bond and go to N **OR** + of N^+



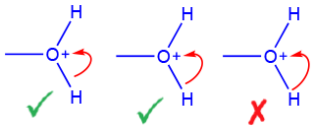
2nd curly arrow must

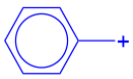
- start from, **OR** be traced back to **any point across width** of lone pair on O of H_2O
- go to the C or + of C^+ of $C_6H_5^+$



3rd curly arrow must

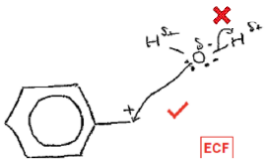
- start from '–' **of O–H** of $–OH_2^+$
- go to O or + of O^+



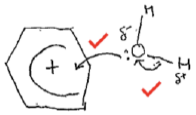
For  **DO NOT ALLOW M2** for carbocation

BUT

ALLOW for M3 and/or M4 by ECF, e.g.



e.g.

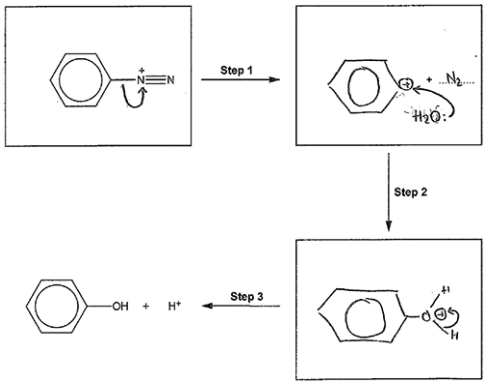


Examiner's Comments

This question required candidates to apply their understanding of organic mechanisms to an unfamiliar reaction. The stem to the question includes important information and clues that should have guided candidates towards this unfamiliar mechanism, with the prompts for the three steps being critical. Many responses fell back to the familiar mechanism for electrophilic substitution, an approach that could not be credited.

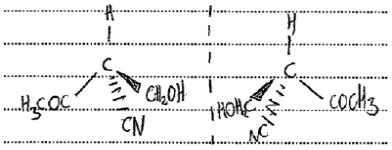
This question discriminated very well but many candidates scored few marks.

Exemplar 1



This response has been included to show a candidate with an excellent understanding of the meaning of curly arrows and the importance of charges and dipoles. The prompts in the question are followed and the candidate has been given all four marks.

Notice how the curly arrows start either from a bond or from a lone pair. The candidate has also realised that the addition of H_2O produces a positively charged oxonium ion. Many candidates omitted the '+' charge or showed the curly arrow for loss of a proton going to a H atom rather than the O atom of water.

					Assessment for learning In organic chemistry mechanisms, a curly arrow shows the movement of an electron pair and demonstrates the direction of electron flow in organic reactions. A curly arrow must start from: • A lone pair or negative charge and go to an atom to show where a bond **forms** • A bond to show where a bond **breaks**. In Question 2 (c), curly arrows: • start from a C–N bond to form the intermediate carbocation by elimination of N_2 • go from a lone pair on the water O atom to the + charge of the carbocation • go from an O–H bond to the + charge on the oxonium ion, losing a proton H^+ in the process.
			Total	**4**	
3 9			**Level 3 (5–6 marks)** Suggests **ALL** of the following • Reagents and conditions for **3** functional groups • Products for **3** functional groups • Optical isomerism with description and 3D optical isomers shown *There is a well-developed line of reasoning which is clear and logically structured.* *The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Suggests **two** of the following	6 (AO 3.1 ×3) (AO 3.2 ×3)	**CHECK TOP OF QUESTION FOR RESPONSES** ---------- *Indicative scientific points may include:* **Stereoisomerism** • Optical isomerism identified with description: e.g. chiral centre /non-superimposable mirror images • 3D Optical isomers drawn, e.g.  *Description is subsumed in 3D diagrams*

- Reagents and conditions for **2** functional groups
- Products for **2** functional groups
- Optical isomerism with description **OR** an attempt to show 3D optical isomers

There is a line of reasoning presented with some structure.
The information presented is relevant and supported by some evidence.

Level 1 (1–2 marks)
Suggests **two** of the following

- Reagents and conditions for **1** functional group
- Products for **1** functional group
- Identifies optical isomerism with description **OR** an attempt to show 3D optical isomers

There is an attempt at a logical structure with a line of reasoning.
The information is in the most part relevant.

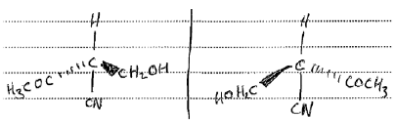
0 mark *No response or no response worthy of credit.*

Key points to check

CHECK TOP OF QUESTION for responses
IGNORE CONNECTIVITY

in 3D isomer structures

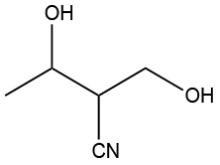
- *IGNORE bond angles*
- *Wedges needed*
- *ALLOW*



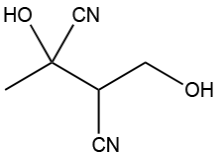
Some responses will not fit into this exact pattern and a best-fit match may be needed

Reactions of ketone/carbonyl e.g.

$NaBH_4$

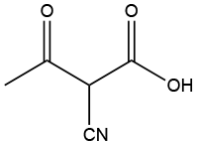


HCN **OR** CN^-/H^+ (e.g. $NaCN/H^+$)

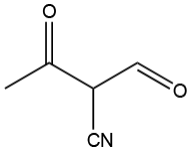


Reactions of –OH, e.g.

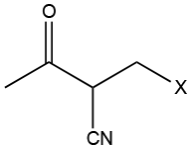
$H^+/Cr_2O_7^{2-}$ **OR** $H_2SO_4/K_2Cr_2O_7$ reflux



$H^+/Cr_2O_7^{2-}$ **OR** $H_2SO_4/K_2Cr_2O_7$ distil



$NaBr/KBr/Br^-$ **AND** $acid/H^+$ **OR** HBr



X = halogen

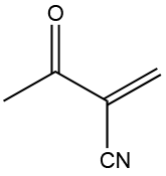
Acid/H^+ (catalyst) (e.g. H_2SO_4)

Clear communication
Focus on

- Clear diagrams of 3D optical isomers
- Diagrams of unambiguour structures
- Reagents and functional group formed are linked
- Communication is more a general feel for the quality of theresponses.

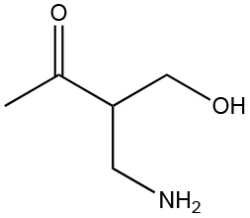
Slips and minor errors in structures

- Do not penalise the odd slip or omission, e.g. An extra C in a chain; a C short in a chain, C shown instead of CH_2 or skeletal
- You need to judge the extent of any slip based on the whole response. Remember that each candidate

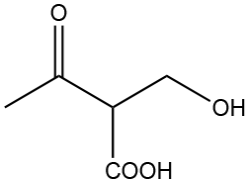


Reactions of C–CN, e.g.

H_2 **AND** metal catalyst e.g. Ni, Pt, Pd



H^+/H_2O e.g. HCl(aq) or H_2SO_4(aq)



OTHER REAGENTS, CONDITIONS AND PRODUCTS
e.g. $LiAlH_4$ as reagent

Check with Team Leader

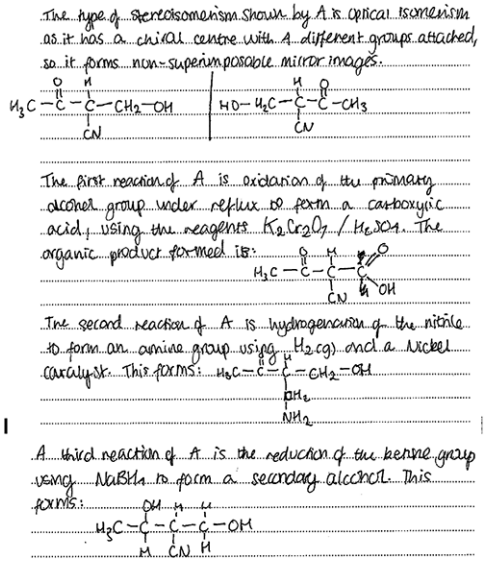
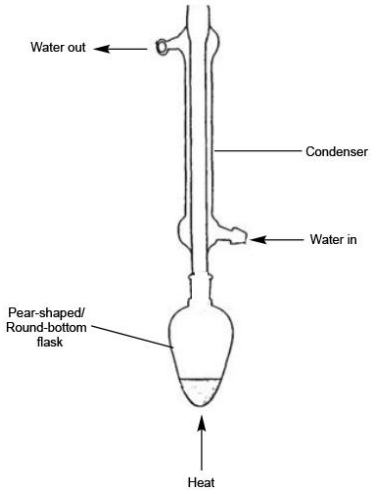
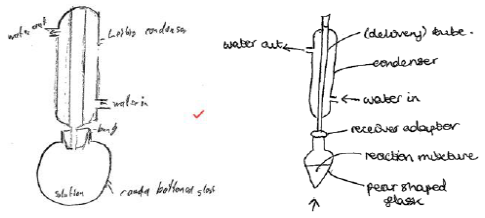
Examiner's Comments

Overall, candidates performed well when answering this question. They were required to identify that compound **A** shows optical isomerism and to choose a reaction for each of the three functional groups. Candidates were also expected to use structures for the organic products.

To achieve the highest level of response, a description of optical isomerism should be accompanied by 3D diagrams of the optical isomers.

Optical isomerism was usually identified,

					with associated diagrams with almost all candidates identifying the chiral centre. Most attempted 3D diagrams but candidates do need to take care that the groups attached to the chiral C atom are those in compound A and that no parts of chains are omitted. Optical isomers do also require use bold and dashed wedges to be used. Most candidates showed good knowledge and understanding of reactions for the three functional groups. • For the primary alcohol, most chose $H^+/Cr_2O_7^{2-}$, with distil (→ aldehyde) or reflux (→ carboxylic acid); a significant number chose a concentrated acid (→ alkene) or Br– -/H+ (→ haloalkane) • For the ketone, most chose $NaBH_4$ (→ secondary alcohol) • For the nitrile, most chose either H_2/Ni (→ amine) or H^+(aq) (→ carboxylic acid). Clear diagrams of the products were usually seen although many omitted a CH_2 from the amine branch for hydrolysis of the nitrile or an extra CH_2 in the aldehyde or carboxylic acid branch from oxidation of the primary alcohol. Some candidates chose 2,4-DNP for a reaction of the ketone and treated the question as one requiring tests, and then proving that the compound was a ketone from no reaction with Tollens' reagent. The question asked for the organic product and the 2,4- DNP product is beyond the demands of this specification (although this was seen very rarely). Candidates adopting this reaction were limiting the extent of their response and candidate should have considered this requirement before selecting 2.4-DNP. Exemplar 2

					 This exemplar shows a good response that lacks 3D diagrams for the optical isomers. The candidate has clearly given reagents and conditions and has shown the organic products. In the response, you can see that the candidate initially showed an extra CH_2 in the –COOH branch, and a mistake in the amine branch. The absence of 3D structures limits the response to Level 2 and 4 marks have been awarded for choosing correct and relevant reagents and conditions, and for the clear communication of the structures.
		Total	**6**	
40	i	 **Reaction apparatus (Labels NOT required)**	2 (AO 3.3 ×2)	For open system, **DO NOT ALLOW**  **For open system, ALLOW** label. e.g. 'open at top'

flask

AND upright condenser

AND open system at top ✓ *(Could be labelled)*

Labels AND direction of water flow

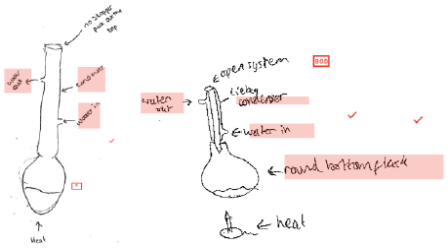
Pear-shaped/round-bottom flask

AND condenser

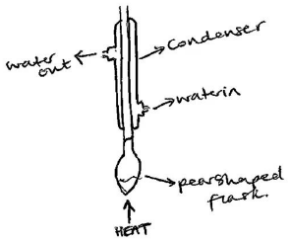
AND water in at bottom and out at top ✓

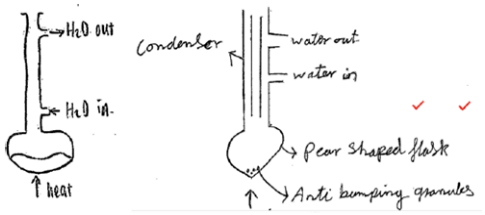
Heat **NOT** required

DO NOT ALLOW flask, conical flask, volumetric flask
DO NOT ALLOW thermometer
DO NOT ALLOW condensing tube as label

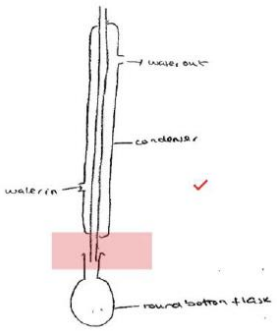


ALLOW line across flask





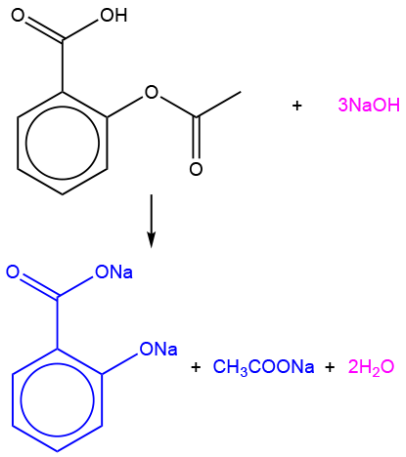
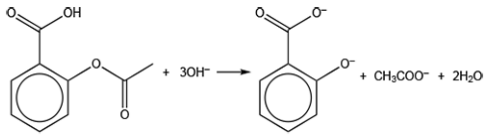
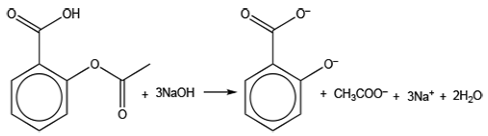
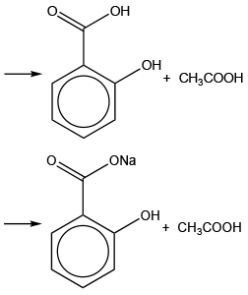
ALLOW small gap between flask and condenser **BOD**, e.g.

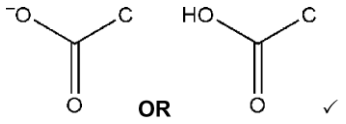


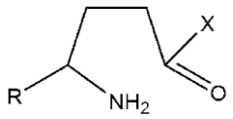
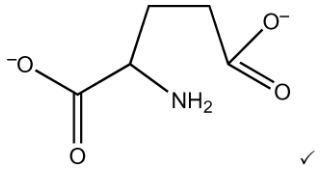
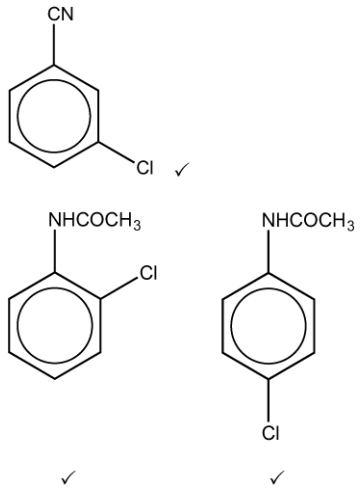
If in doubt, ask Team Leader

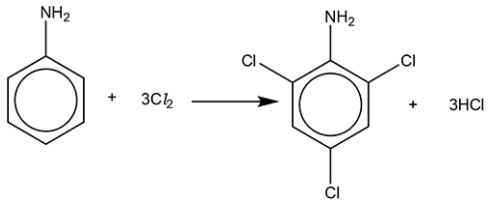
Examiner's Comments

Most candidates drew a diagram that looked like a vertical condenser above a flask. The quality of the diagrams was not very good. Candidates then needed to label

					their diagram. Errors included a bung or thermometer inserted at the top of the condenser and water flowing the wrong way in the condenser. For labelling, candidates were expected to use scientific terminology. Responses such as 'condensation tube' and vague terms such as 'flask' were not credited. These labels were often omitted. A significant number drew a set up for distillation instead of reflux.
		ii	 Organic products ✓ ✓ ***2 marks*** 3NaOH AND $2H_2O$ ✓ ***1 mark*** NOTE: ALLOW O^-Na^+ for ONa throughout **SCROLL DOWN FOR PRODUCTS**	3 (AO 2.6 ×3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** annotations of provided structure of aspirin at top left **ALLOW** equation with 3OH– **OR** 3NaOH giving anions for organic products, i.e.  **OR**  **ALLOW** 1 of the 2 organic products mark for BOTH structures as COOH and OH (or mixture) e.g 

					Examiner's Comments This question was the hardest part of Question 5 and about half the candidates were not given any marks. Some drew the sodium carboxylate salt of aspirin structure, leaving the ester link intact. A large number of candidates realised that the ester would be hydrolysed. Sometimes the sodium salts were often not shown and, even they were shown, the phenol group was often shown intact. The hardest mark was the formation of $2H_2O$ and a large number of candidates showed the more intuitive but incorrect '$3H_2O$' instead.
			Total	**5**	
4 1			**C**	1	**Examiner's Comments** More than three quarters of candidates were able to identify C as being the secondary amide, with many annotating each structure with the correct functional group. Some gave B, i.e. a secondary amine not amide, and a few gave A, i.e. tertiary amide not secondary.
			Total	**1**	
4 2			**Hydrolysis of ester:** Methanol / CH_3-OH ✓ **Formation of carboxylate / carboxylic acid from hydrolysis of ester or amide:**  ✓ *C=O of Carboxylate or carboxylic acid group must be attached to a C But ignore rest of molecule*	4	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** incorrect connectivity on OH **…BUT ALLOW ECF** on subsequent structures **DO NOT ALLOW** CH_3O^- (Na^+) **OR** sodium methoxide **ALLOW** $-COO^-Na^+$ **OR** $-COONa$ **DO NOT ALLOW** esters or amides **ALLOW** NH_3^+**IGNORE** missing Hs on carbon chain

			Hydrolysis of amide: Breaks amide bond in ring to give: ✓  *Where R can be H or any other structure For X, ignore group attached to C=O* **Correct hydrolysis product:**  ✓		Must be completely correct structure **ALLOW** $-COO^-Na^+$ **OR** −COONa **Examiner's Comments** Just over a quarter of candidates were able to gain all 4 marks. The successful candidates clearly identified where theester and amide would be hydrolysed on the structure provided, helping them draw out the correct products. This question differentiated well. Most were able to gain some credit for hydrolysing the ester to give methanol and a carboxylate or carboxylic acid, leaving the amide bond and ring intact. However, some lost the first mark for giving the methoxide ion, assuming that the alkaline conditions are capable of deprotonating the alcohol group. Lower attaining candidates often broke other C-C bonds in the ring forming a range of products. A few displayed the structure as $C=O^-Na^+$ and some also protonated the amine group either with the ring intact or broken.
			Total	**4**	
4 3		i	 ✓ ✓ ✓	3	**IGNORE** additional copies of the same structures **IGNORE** connectivity to CN and $NHCOCH_3$ in products. **IGNORE** HCl / H^+ **IGNORE** multisubstituted products **ALLOW** protonation of $NHCOCH_3$ group i.e. $NH_2^+COCH_3$ **ALLOW ECF** small slips on $NHCOCH_3$ e.g. extra O or missing 3 on CH_3 **Examiner's Comments** Most candidates were able to correctly recognise the correct direction for substitution, with over half gaining all 3 marks. Marks were most often lost for giving

					multiple substitution products despite being asked for the monosubstituted products. Many unnecessarily drew the same structures but with differentorientations i.e. substituting on carbon-3 of a ring is the same as substituting on carbon-5. **Misconception** Ensure students understand the term 'monosubstituted' and practise naming compounds to give the lowest possible numbering. This will also help them to recognise the equivalent structures.
		ii	 Correct organic product ✓ Correct balanced equation ✓	2	**ALLOW** any trichlorophenyl amine structure **ALLOW** $C_6H_2Cl_3NH_2$ **OR** $C_6H_4Cl_3N$ (allow elements in any order) for correct organic product **IGNORE** incorrect structural or molecular formula **IF** correct structure is drawn **ALLOW** ammonium salt of trichloro product $C_6H_2NH_3Cl_4$ **ALLOW** multiples for balanced equation **ALLOW** 1 mark for use of Br_2 with a correctly balanced equation **Examiner's Comments** The majority of candidates were able to give a suitable tri-substituted product, with many showing the structure although not asked for in the question. Many were also able to give a correct balancedequation too. Some were unsure how phenylamine would react showing the reaction with the aminegroup or only giving a monosubstituted product. Some didn't form HCl as another product, reacting phenyl amine with 1.5 Cl_2 instead. Others gave hydrogen as the product.
		iii	(In phenylamine) a (lone) pair of electrons on N is (partially) delocalised / donated into the π-system / ring ✓	3	Must be clear that electrons come from N not just NH_2

			Electron density increases/is higher (than benzene) ✓ **ORA** (phenylamine is) **more** susceptible to electrophilic attack **OR** (phenylamine) attracts/accepts electrophile/Cl_2 **more** **OR** (phenylamine) polarises electrophile/Cl_2 **more** ✓ **ORA**		**ALLOW** the electron pair (in the p-orbitals) on N atom becomes part of the π-system / ring **ALLOW** diagram to show movement of lone pair into ring from N **ALLOW** lone pair of electrons on N is (partially) drawn / attracted / pulled into π-system / ring **ALLOW** lone pair on N (i.e. no reference to electrons) **ALLOW** π-bond instead of π-system / ring **DO NOT ALLOW** (two) lone pair**s** are delocalised/donated into the π-system / ring **Responses must be comparative for 2nd and 3rd marking point.** **IGNORE** activating **IGNORE** charge density **IGNORE** electronegativity **IGNORE** phenylamines react more readily with electrophiles/Cl_2 (*given in question*) **ALLOW** Cl^+ for electrophile **IGNORE** Cl for electrophile **ALLOW** Benzene can't polarise electrophile/Cl_2 but phenylamine can (polarise electrophile/Cl_2) **Examiner's Comments** Similar questions have been seen previously and many candidates were able to give clear and concise responses. The first marking point was the most frequently lost as although many described $-NH_2$ aselectron donating, they were not able to fully explain its role. Some understood that a lone pair wasdonated into the π-ring but did not specify that the lone pair was on the nitrogen. Other marks were lostby not making comparison to benzene, e.g. high electron density, polarises Cl_2. Some repeated theinformation from the question regarding phenylamine being more reactive with electrophiles but notexplaining why. Lower attaining candidates often described the structure of the benzene ring or

					referredto phenylamine being more electronegative.
			Total	**8**	