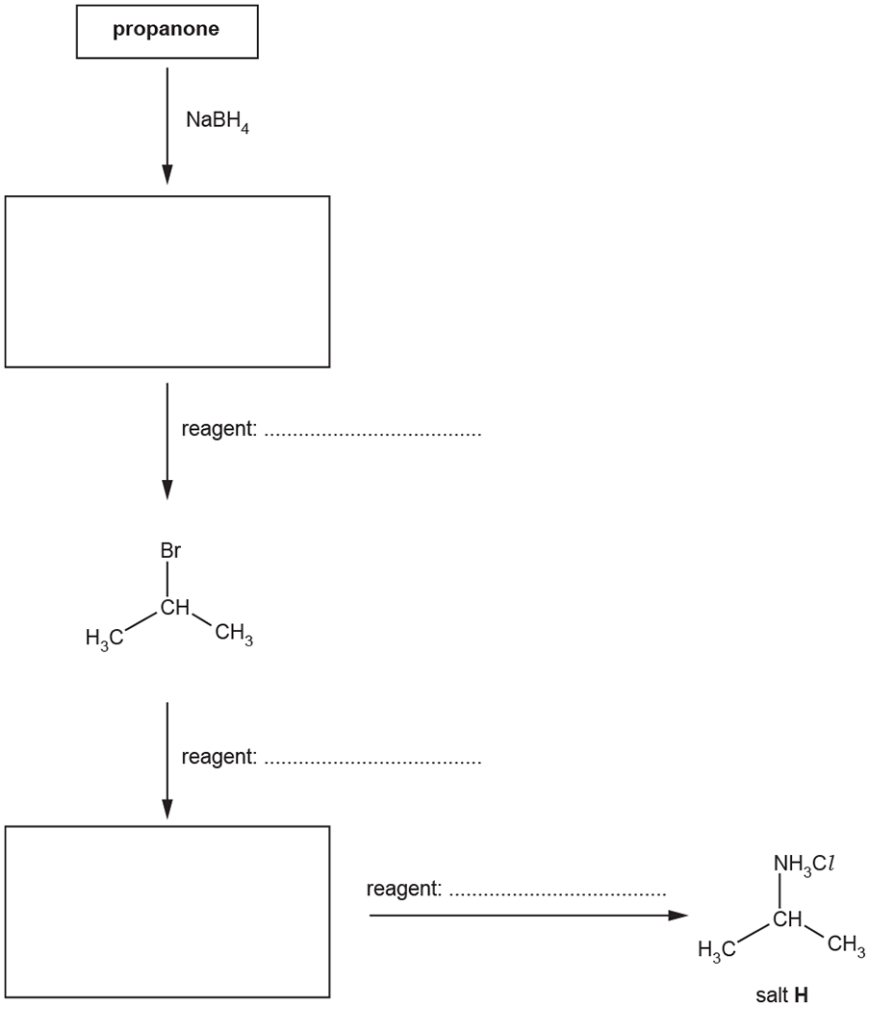
Synthesis

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

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

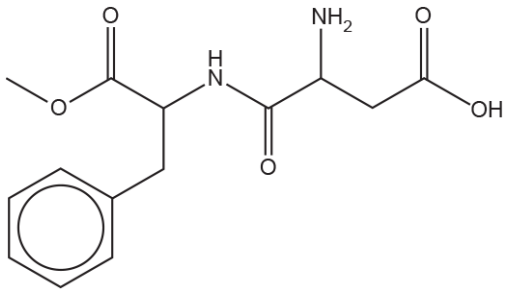
The flowchart shows the synthesis of the salt **H** from propanone.

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.

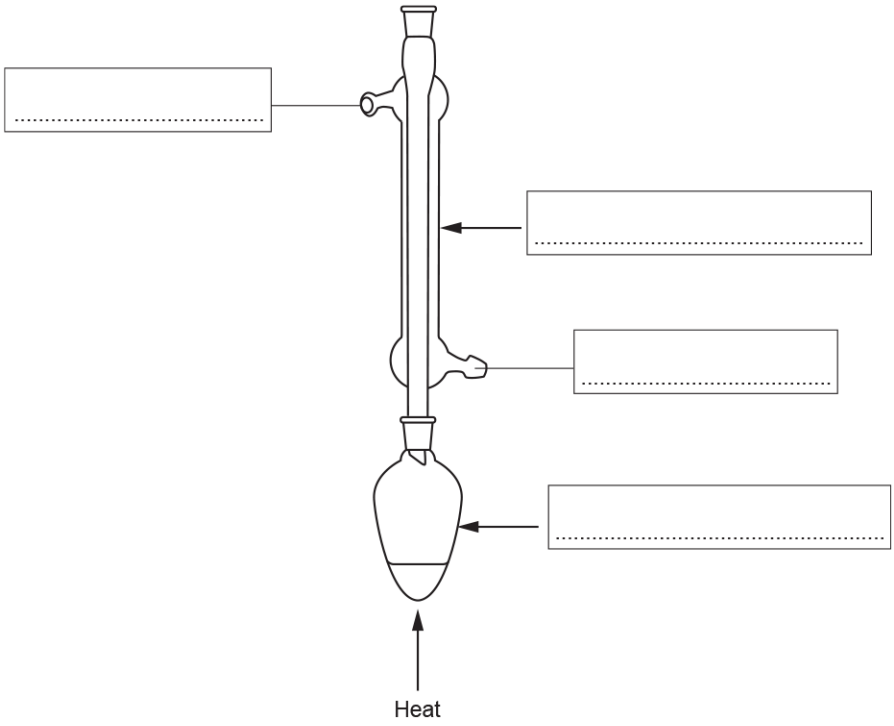
How many cans of this diet drink is it safe for a typical adult to drink in one day?

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

2. 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.

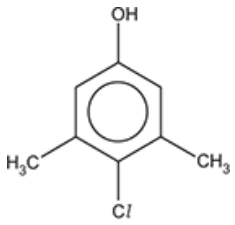


Name of technique: _____ **[2]**

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

[2]

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

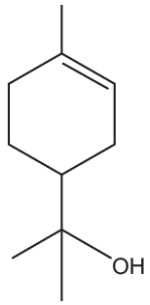


chloroxylenol

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

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) ---

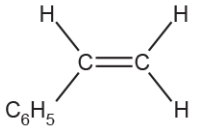
Name of functional group that reacts ---

Structure of organic product

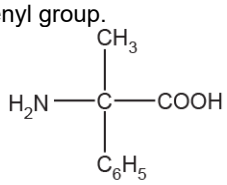
[4]

4. 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**.

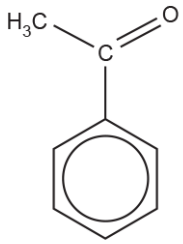
From compound **D**

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

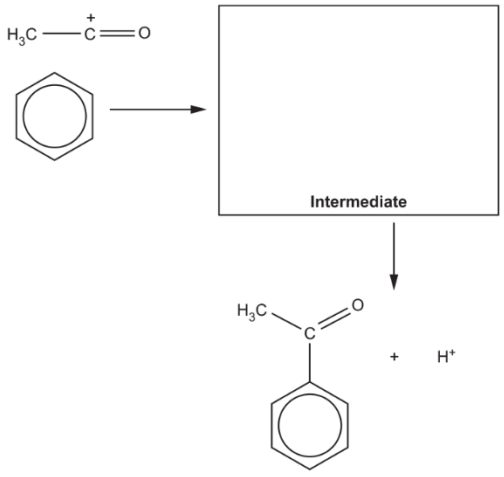
The reaction takes place in the presence of aluminium chloride, $AlCl_3$, which acts as a catalyst.
In the mechanism for this reaction,

- 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

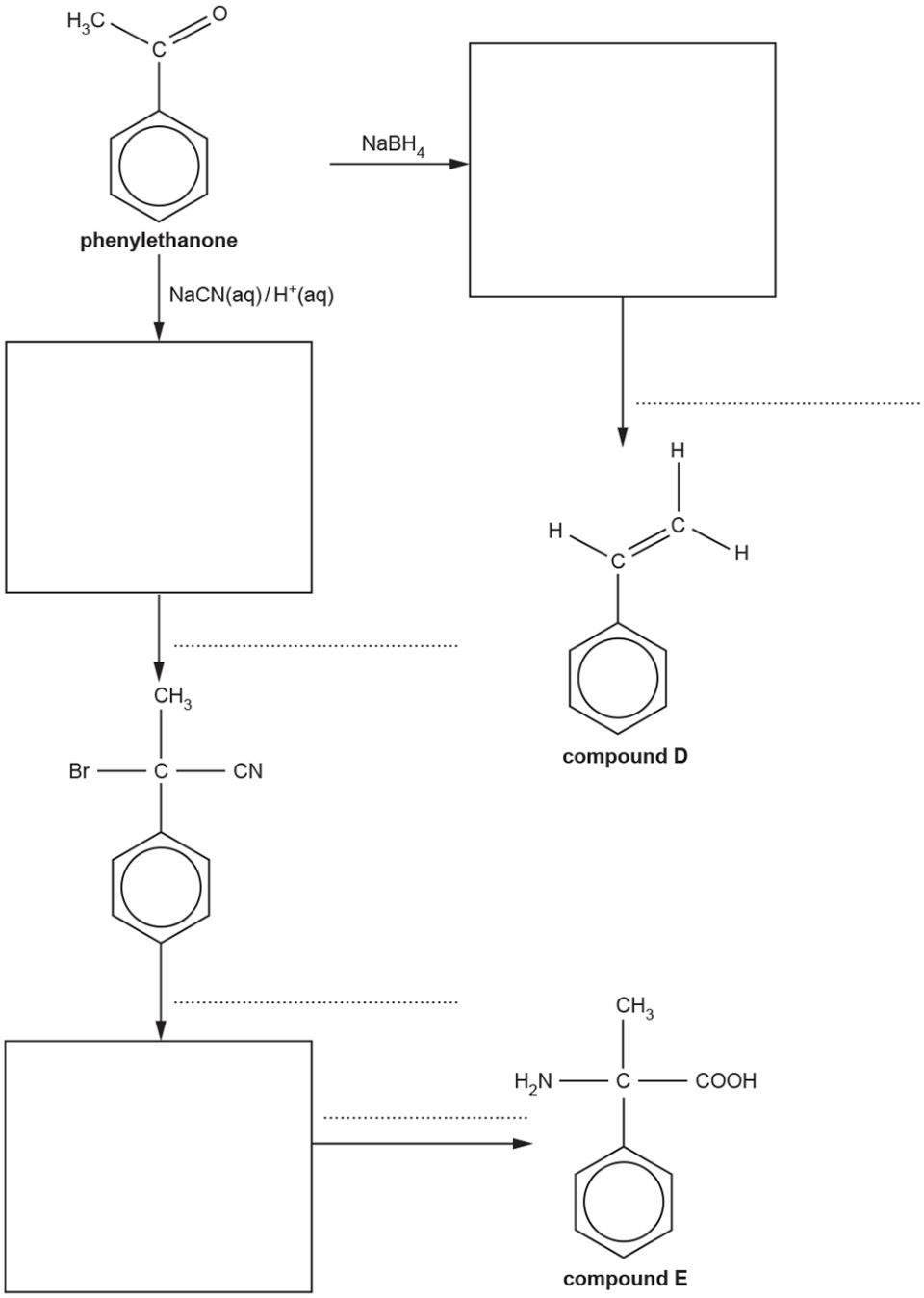


Regeneration of catalyst

---

[5]

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

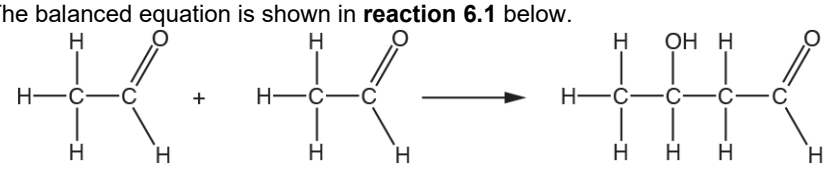


[7]

5. 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**.

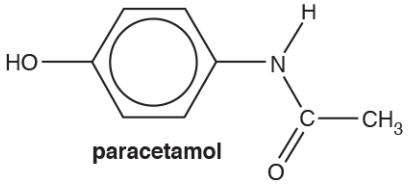
[3]

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]

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



paracetamol

i. Name the functional groups present in paracetamol.

---

[2]

ii. * 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%.

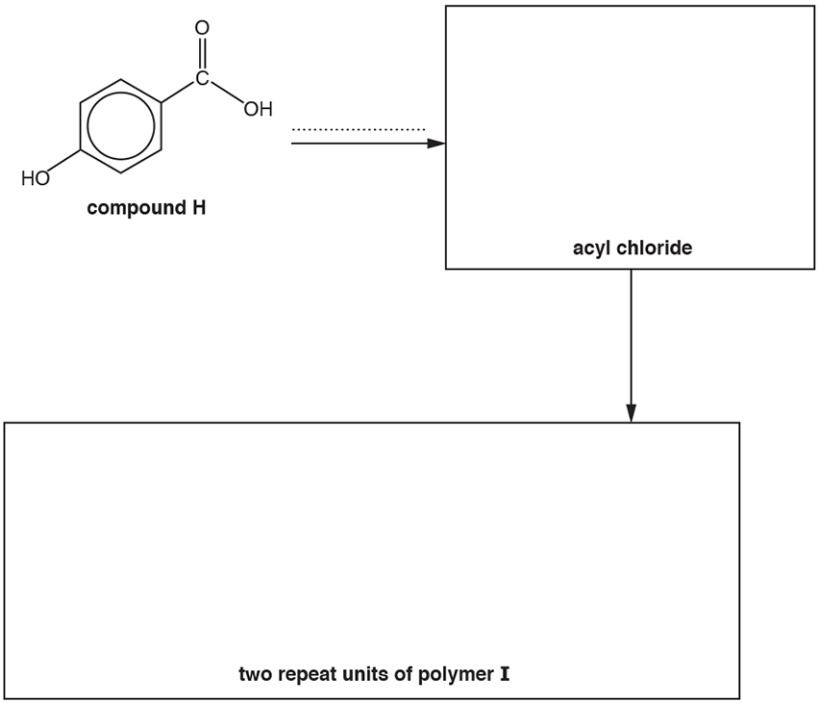
In your answer, include the mass of 4-nitrophenol required, the reagents and intermediate, and details of the purification of paracetamol.

[6]

---

7. 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]

8. 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.

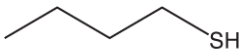
name of mechanism: .....

[4]

9. 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.

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.

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]

10. 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.

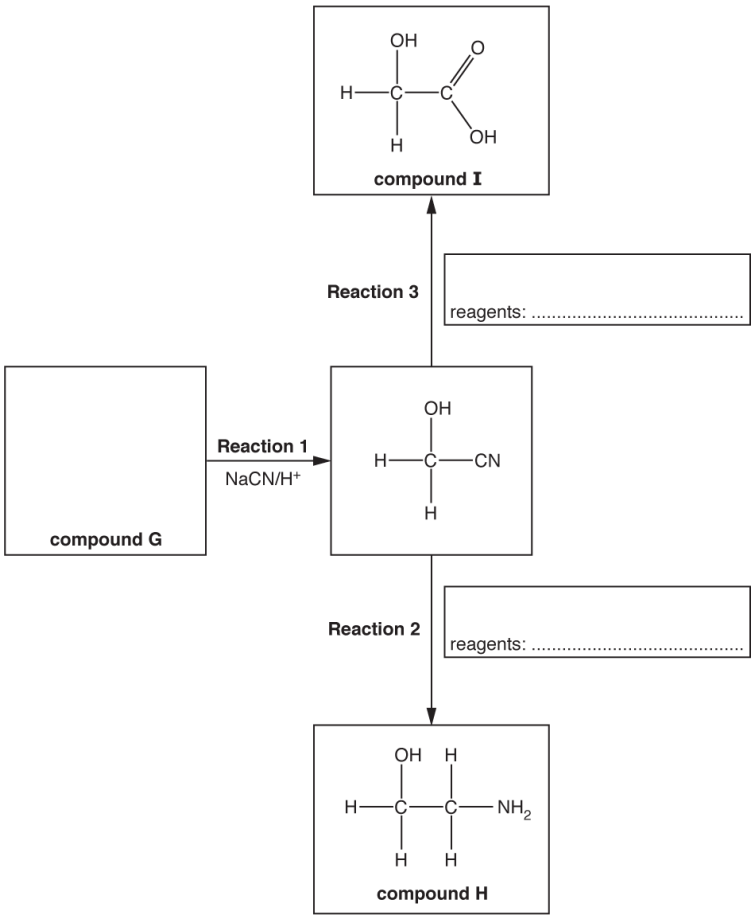
Outline the mechanism for this reaction.

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**.



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]

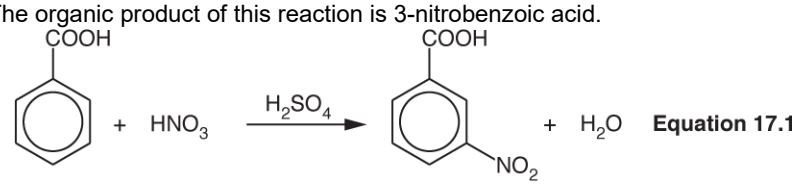
iv. Compound **I** is the monomer for the biodegradable polymer **J**.
Draw **two** repeat units of polymer **J** and suggest a reason why it is biodegradable.

---**[3]**

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.

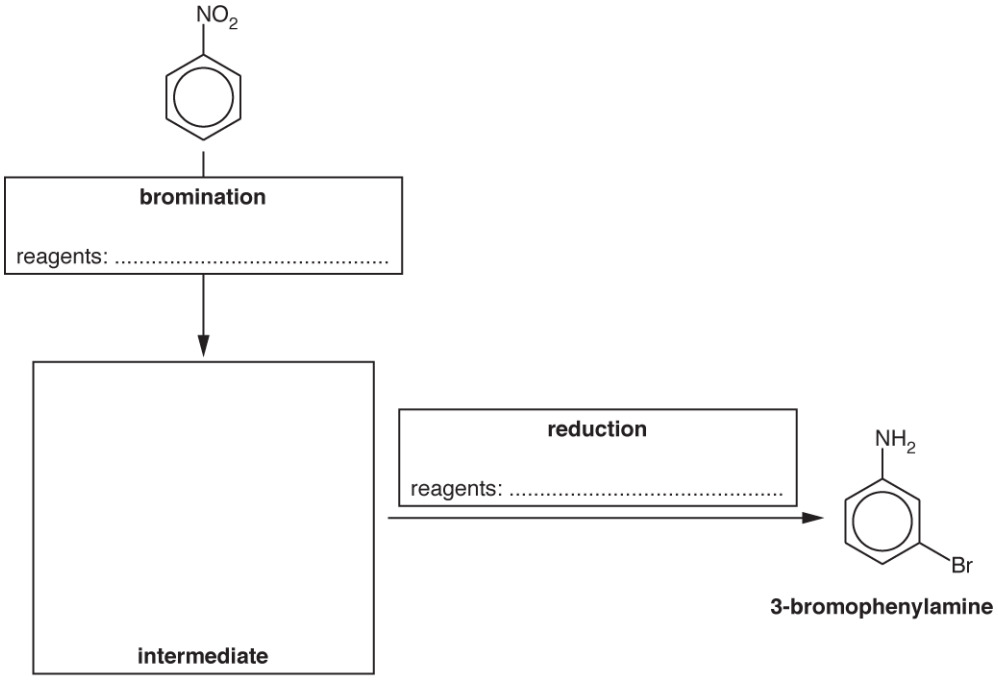
Describe a method to obtain a pure sample of 3-nitrobenzoic acid from the impure solid, determine the percentage yield and check its purity.

---

[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.



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

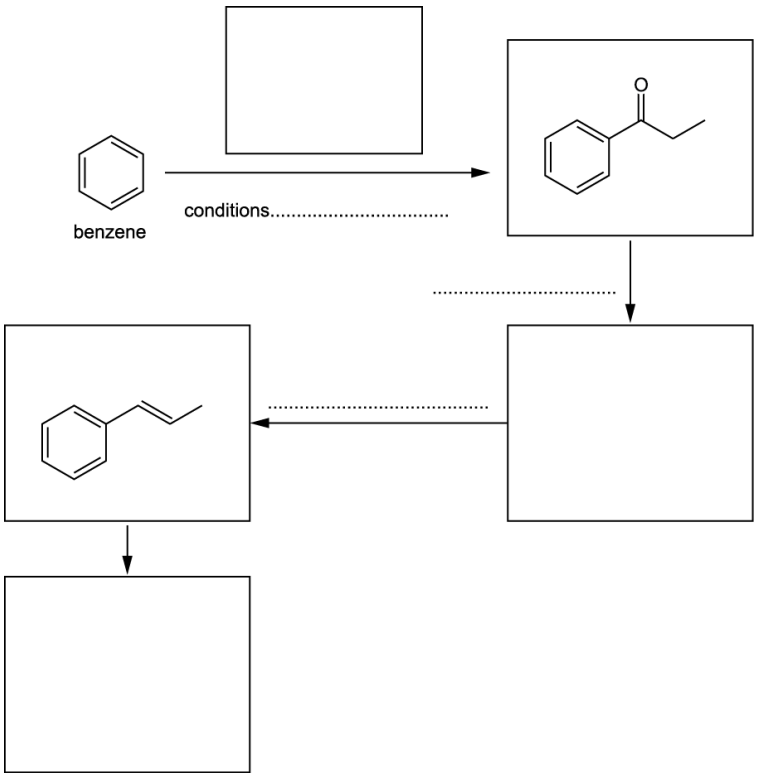
Structures

[3]

12(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]

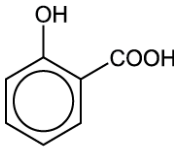
(b). Polymer **I** cannot be disposed of in landfill sites as it is not biodegradable.

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

---

[1]

13. '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. 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]

14(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.

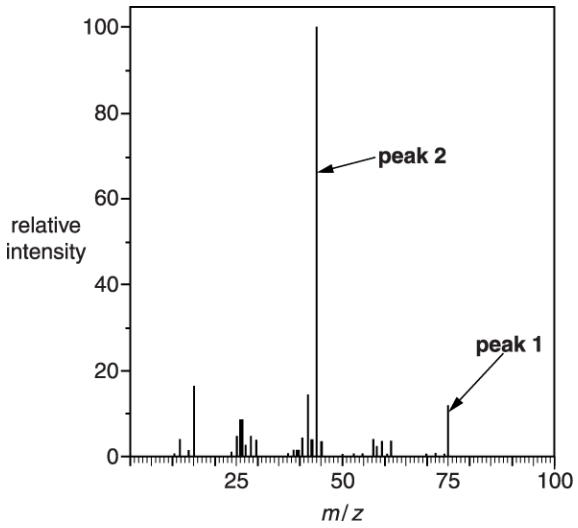
i. For the ^1H NMR analysis, the sample was dissolved in D_2O.

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**.

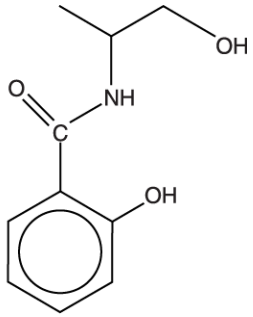
Compound **D** has a molecular formula of $C_6H_{15}NO_2$.

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**.

---

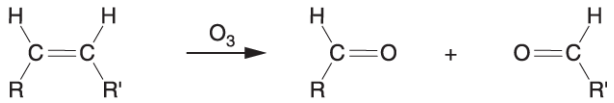
[1]

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

[2]

15. ‘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]

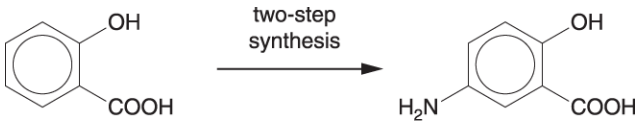
ii. In another ozonolysis reaction, organic compound **G** reacted to form **only** hexane-1,6-dial.

Compound **G** has six carbon atoms.

Draw the structure of compound **G**.

[1]

16. 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.

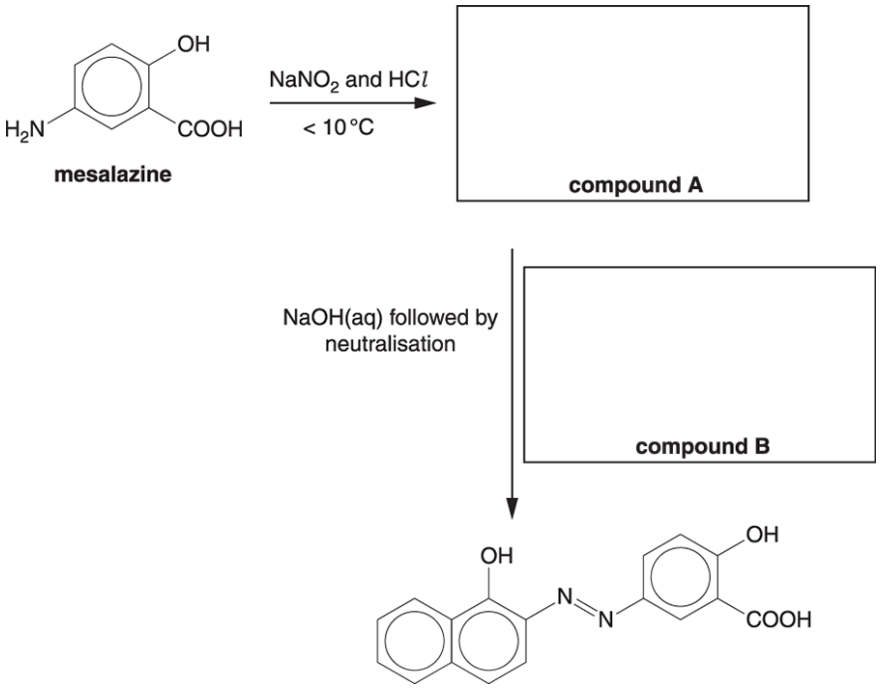
---

[1]

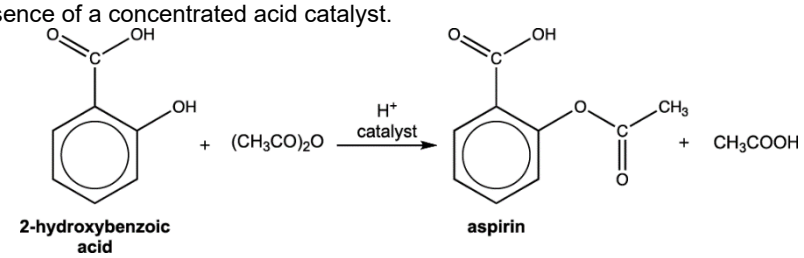
iii. Mesalazine reacts in another two-stage process as shown below.

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

[2]



17. * 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.

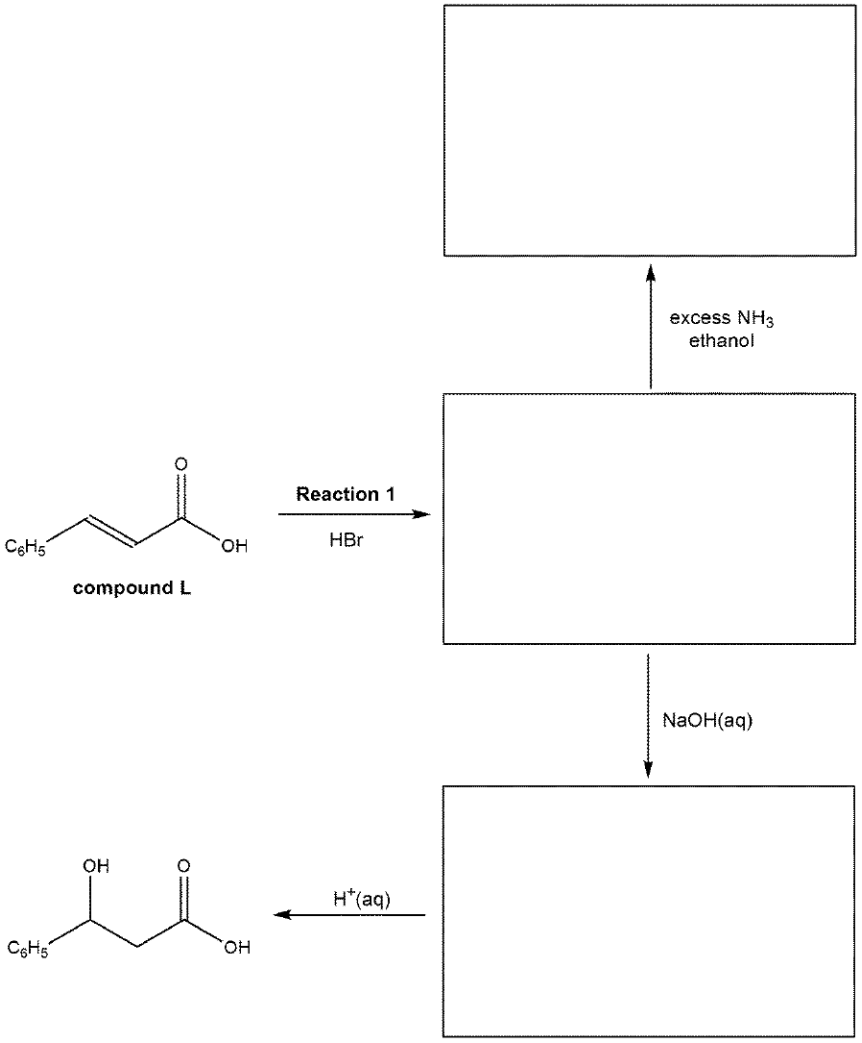
---

[6]

18(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.

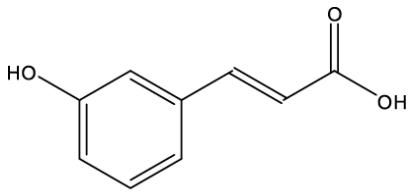


[3]

(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]

END OF QUESTION PAPER