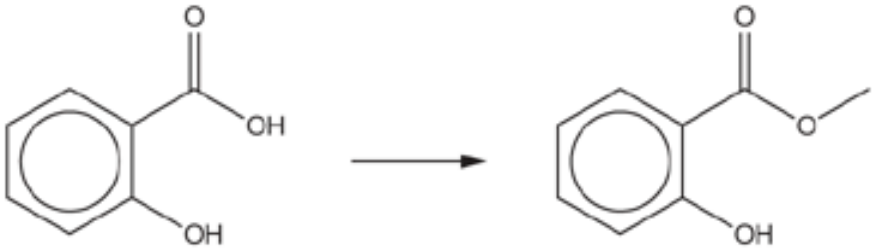
1. Oil of wintergreen is a liquid used in medicine to relieve muscle pain.

Compound **H** is a component in oil of wintergreen and can be synthesised from compound **G**, as shown below. The boiling point and density of compound **H** are stated.



Compound G **Compound H**

boiling point = 222 °C
density = 1.174 g cm^{-3}

A student prepares a sample of compound **H** by the method below.

Step 1	Reflux 8.97 g of compound **G** for 30 minutes with an excess of methanol in the presence of a small amount of sulfuric acid as a catalyst.
Step 2	Add an excess of aqueous sodium carbonate, Na_2CO_3(aq). Two layers are obtained.
Step 3	Purify the impure compound **H** that forms from the resulting mixture.

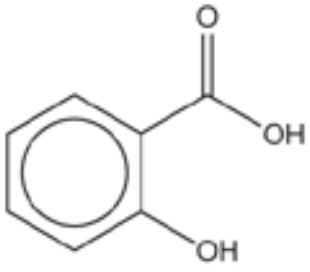
The student follows this method and obtains 5.32 g of pure compound **H**.

i. **In Step 2**, Na_2CO_3(aq) removes the sulfuric acid catalyst **and** any unreacted compound **G** from the mixture.

Write equations for this removal.

Removal of sulfuric acid

Removal of unreacted compound **G**



Compound G

[3]

ii. Another student suggests that adding aqueous sodium hydroxide would be more effective in removing the sulfuric acid catalyst than Na_2CO_3(aq).

Comment on whether the student's suggestion is an improvement for the preparation of compound **H**.

[1]

2. This question is about reactions of alcohols.

There are 4 structural isomers of $C_4H_{10}O$ that are alcohols:
$CH_3CH_2CH_2CH_2OH$
$CH_3CH_2CHOHCH_3$
$(CH_3)_2CHCH_2OH$
$(CH_3)_3COH$

Alcohols take part in many different types of reaction, including

- elimination
- oxidation
- substitution
- esterification.

For each type of reaction, choose appropriate reagent(s) and/or catalyst, and show the organic product formed.

Esterification reaction of $(CH_3)_3COH$

Reagent(s) and/or catalyst

organic product

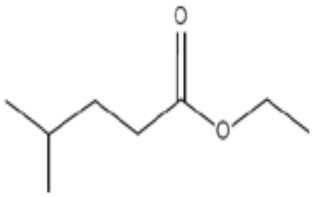
[2]

3(a). Short-chain carboxylic acids, such as methanoic acid, HCOOH, are soluble in water.

Explain, with a labelled diagram, how HCOOH interacts with water when it dissolves.

---**[2]**

(b). Ester **F** has the structure shown below.



Ester F

i. What is the systematic name for this ester?

---**[1]**

ii. Ester **F** can be prepared from a carboxylic acid in two steps.

Step 1 The carboxylic acid is converted into an acyl chloride.
Step 2 The acyl chloride is converted into ester **F**.

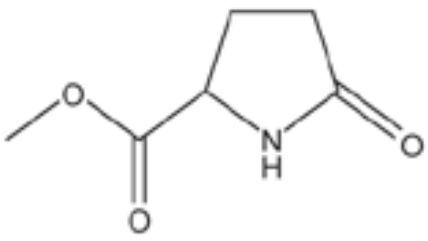
Write equations for **Step 1** and **Step 2**.
Show organic compounds as structures.

Step 1

Step 2

[4]

(c). 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]

4. 1,6-Diaminohexane, $H_2N(CH_2)_6NH_2$, reacts with hexanedioyl dichloride, $ClOC(CH_2)_4COCl$ to form a polyamide and one other product.

What is the other product formed in this reaction?

A HCl
B H_2O
C CO
D NH_3

Your answer ☐ **[1]**

5. Three reactions involving sulfuric acid are shown below.

Reaction 1
Dilute sulfuric acid is reacted with nickel(II) hydroxide to form a green solution.

The solvent is allowed to evaporate leaving hydrated crystals of compound **D**, with the percentage composition by mass: Ni, 22.33%; S, 12.20%; O, 60.87%; H, 4.60%.

Reaction 2
Concentrated sulfuric acid is reacted with hydrogen bromide, HBr, to form three products:

- an element which exists as diatomic molecules
- a gaseous compound **E**
- a liquid.

At RTP, 1.00 dm^3 of compound **E** has a mass of 2.67 g.

Reaction 3
Concentrated sulfuric acid acts as a catalyst when 2-hydroxypropanoic acid reacts to form compound **F** (M_r = 144).

In this reaction, 2 mol of 2-hydroxypropanoic acid forms 1 mol of compound **F** and 2 mol of water.

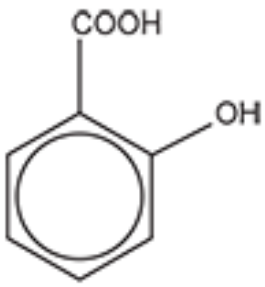
Identify compounds **D**, **E** and **F** and construct equations for the reactions.

Show structures for any organic compounds.

[6]

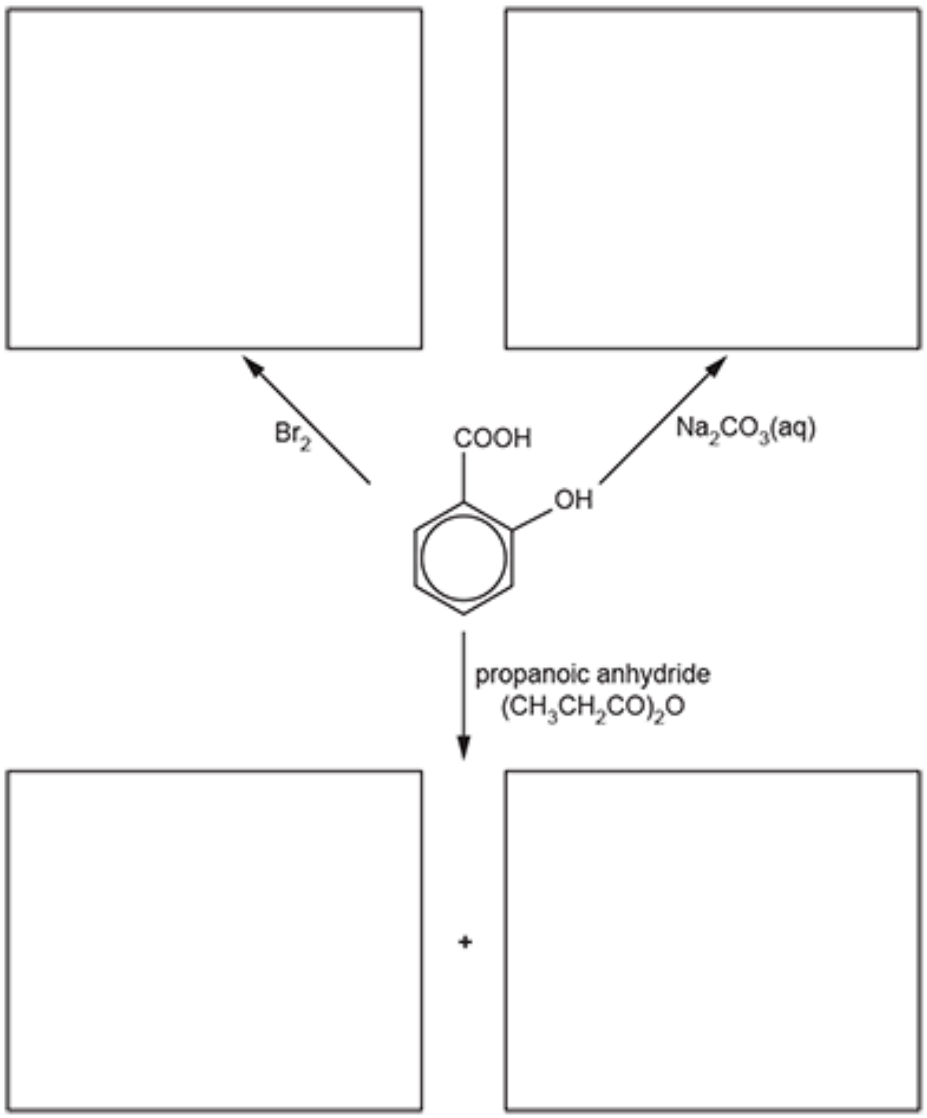
6. This question is about aromatic compounds containing the –COOH and –OH functional groups.

Salicylic acid, shown below, is used in the manufacture of some important medicines.



Salicylic acid

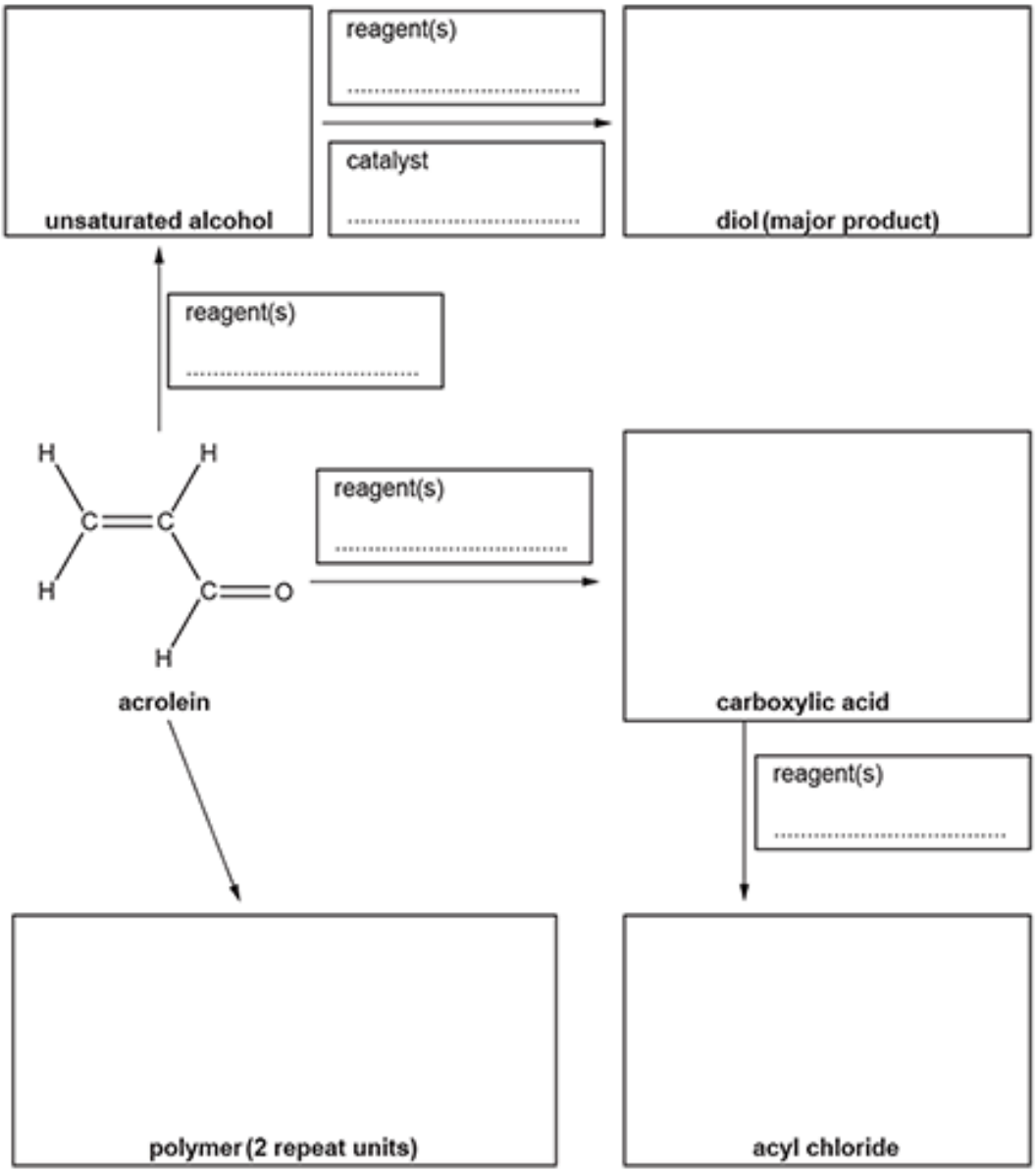
Complete the flowchart for reactions of salicylic acid, by adding the organic products in each box.



[4]

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

Complete the flowchart by filling in each box.



[9]

8. Which compound(s) is/are hydrolysed by HC*l* (aq) to produce butanoic acid?

1 $CH_3CH_2CH_2COOCH_3$
2 $CH_3CH_2CH_2CH_2CN$
3 $CH_3CH_2CH_2CH_2Cl$
A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

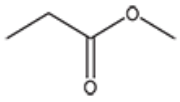
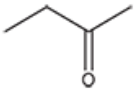
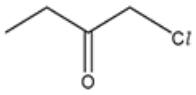
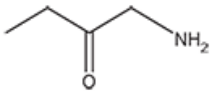
Your answer ☐ **[1]**

9. Which ion(s) contain(s) bond angles of approximately 120º?

1 CH_3COO^-
2 $C_6H_5O^-$
3 $(CH_3)_3C^+$
A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer ☐ **[1]**

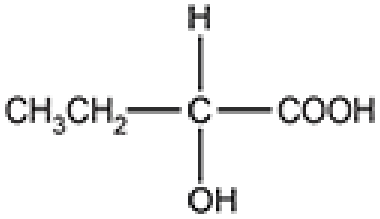
10. Which compound reacts with ethanoyl chloride?

A	
B	
C	
D	

Your answer ☐ **[1]**

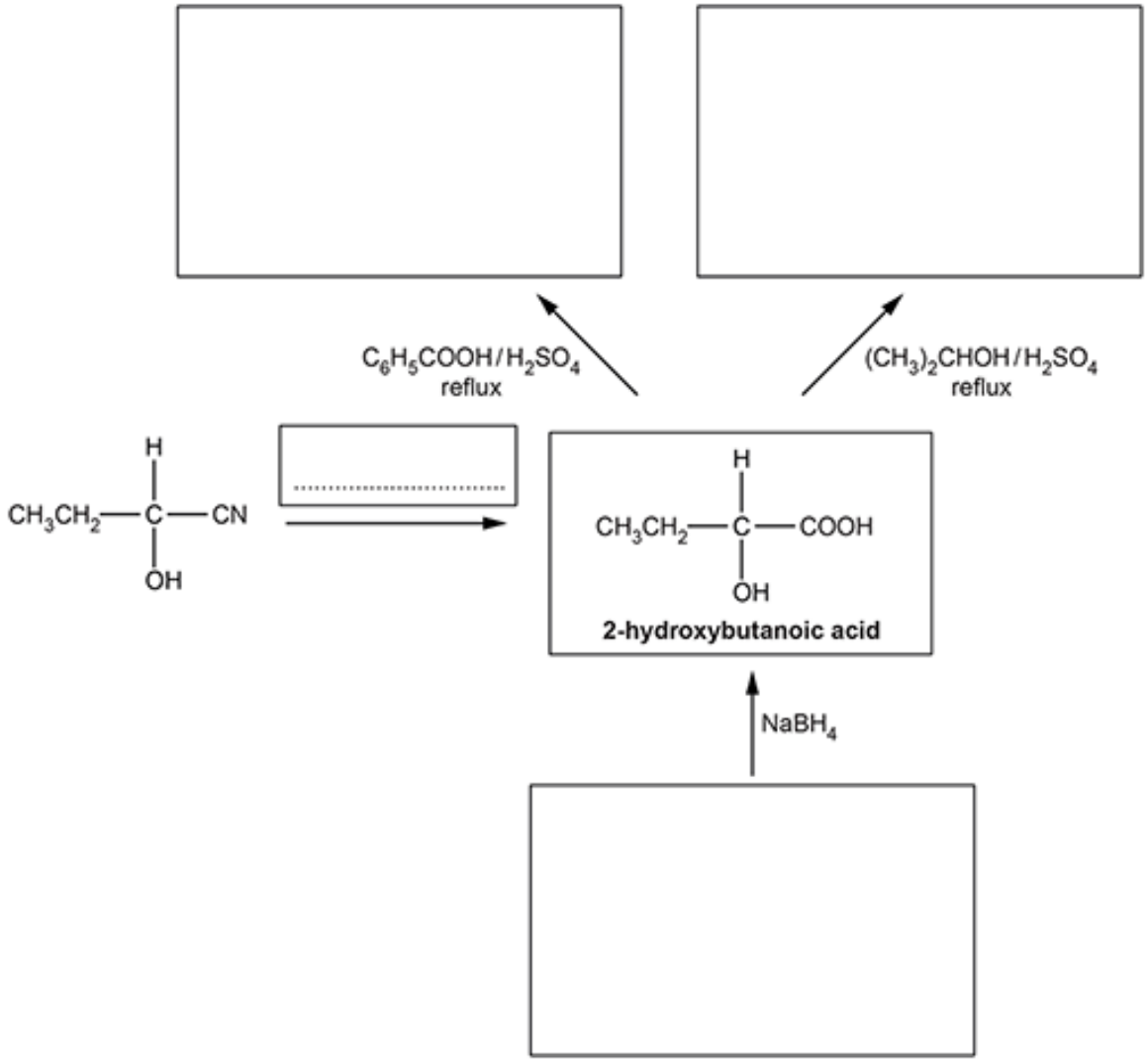
11(a). This question is about compounds that contain the carboxylic acid functional group.

The structure of 2-hydroxybutanoic acid is shown below.



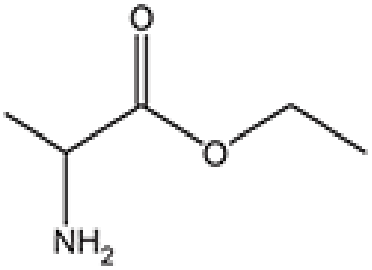
2-hydroxybutanoic acid

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, $CH_3CHClCOOH$. 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]

12. Acid anhydrides react in a similar way to acyl chlorides with phenols.

Benzoic anhydride is the acid anhydride of benzoic acid, C_6H_5COOH.

Benzoic anhydride reacts with butan-2-ol to form an ester.

Suggest an equation for this reaction. Show structures for organic compounds. Use C_6H_5 for any phenyl groups.

[2]

13. This question is about compounds that contain the carboxylic acid functional group.

Carboxylic acids react with alkalis, metals and carbonates to form salts.

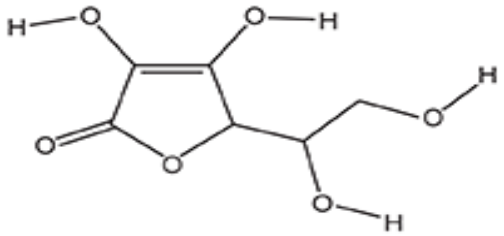
Write full equations for the following **three** reactions. Show structures for organic compounds.

- the reaction of propanoic acid with aqueous potassium hydroxide:
- the reaction of aqueous methanoic acid with magnesium:
- the reaction of the α−amino acid, aspartic acid ($R=CH_2COOH$), with an excess of aqueous sodium carbonate, Na_2CO_3:

[4]

14(a). A student carries out an investigation on vitamin C, $C_6H_8O_6$.

The structure of vitamin C is shown below. Vitamin C is an optical isomer.



Vitamin C

What is the total number of optical isomers with the structure of vitamin C?

total number of optical isomers = ... **[1]**

(b). Vitamin C is extremely soluble in water. This means that vitamin C is removed rapidly from the body. 'Vitamin C ester' is available in tablet form as a less soluble source of vitamin C which stays in the body for longer.

i. Suggest why vitamin C is extremely soluble in water.

[1]

ii. A 'vitamin C ester' tablet contains an ester with the molecular formula $C_{22}H_{38}O_7$.

This ester can be prepared by reacting vitamin C with a long chain carboxylic acid, C_xH_yCOOH, in the presence of an acid catalyst.

Vitamin C and the long chain carboxylic acid react in a 1:1 molar ratio.

Determine *x* and *y* in the formula of this carboxylic acid.

x = ... *y* = ... **[2]**

END OF QUESTION PAPER