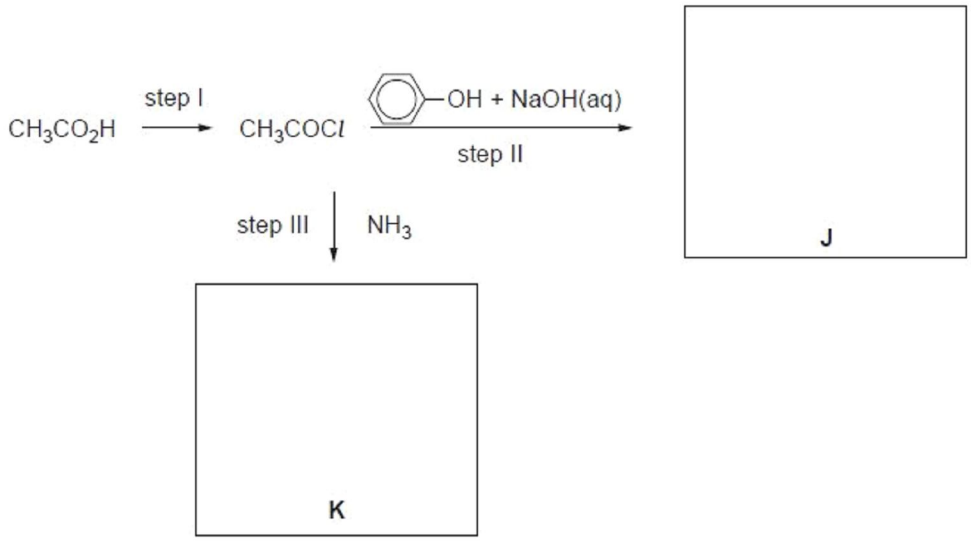
Q1.

5 **(a)** Acyl chlorides are useful intermediates for making various acid derivatives. The following reaction scheme shows some of the reactions of ethanoyl chloride.



(i) Suggest a reagent for step I.

.....

(ii) Write an equation showing the reaction between phenol and NaOH(aq), the reagents in step II.

.....

(iii) Draw the structural formulae of products **J** and **K** in the boxes above.

[4]

Use

(b) The diacid **L** occurs naturally and is used as a food additive to enhance the acidic flavour in some fruit drinks.

$HO_2CCH_2CH_2CO_2H$
L

When the diacyl chloride of **L** is reacted with $HOCH_2CH_2OH$, a polymer is formed.

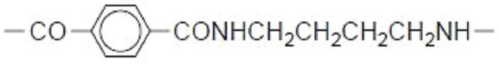
(i) What type of polymerisation is occurring here?

.....

(ii) Write an equation showing the reaction between **one** mole of the diacyl chloride of **L** and **two** moles of $HOCH_2CH_2OH$.

[3]

(c) The following formula represents a section of another polymer.



(i) What type of polymer is this?

.....

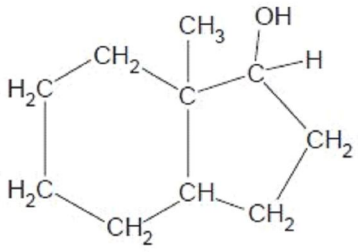
(ii) Draw the structural formula of each of the monomers that make up this polymer.

[3]

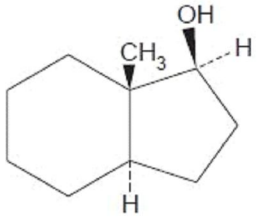
[Total : 10]

Q2.

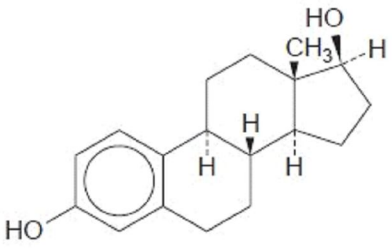
6 Chemists use skeletal or partial-skeletal formulae to represent larger structures. For example the structure



may also be represented as follows.



Oestradiol is one of the hormones that controls the reproductive cycle in female mammals.



oestradiol

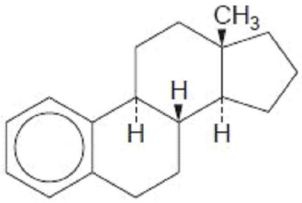
(a) **(i)** On the above structure of oestradiol, circle **one** chiral centre.

(ii) What is the total number of chiral centres in the oestradiol molecule? .....

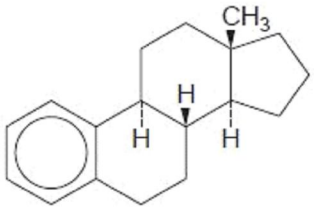
[2]

(b) Complete the following part-structures (which have the -OH groups removed) to show the products obtained when oestradiol (above) is reacted with the stated reagents.

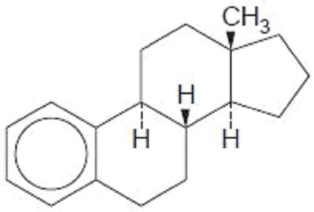
(i) sodium metal



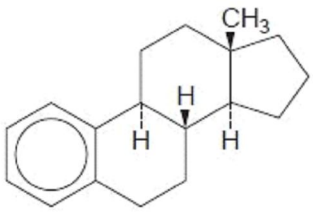
(ii) $Br_2(aq)$



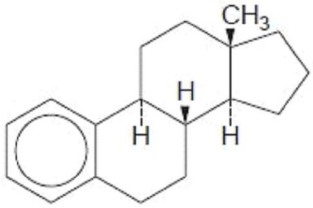
(iii) NaOH(aq)



(iv) CH_3COCl



(v) hot acidified $K_2Cr_2O_7$



[7]

[Total: 9]

Q3.

5 **(a)** In the following boxes draw the structural formulae of **three** alcohols having straight (i.e. unbranched) chains, with the molecular formula $C_5H_{12}O$.

For Examiner's Use

A	B	C

[2]

Use the letters **A**, **B** or **C** as appropriate when answering the following questions. Each letter may be used once, more than once or not at all.

(b) Which of the alcohols are chiral?.....[1]

(c) **(i)** Which of these alcohols react with alkaline aqueous iodine? .....

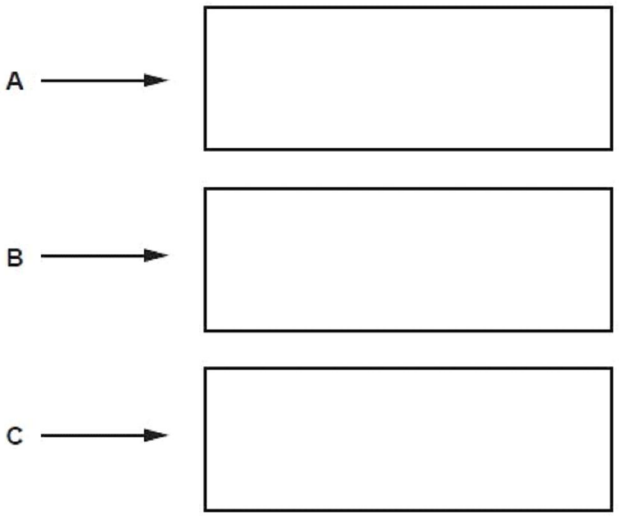
(ii) Describe the observation you would make during this reaction.

.....

(iii) Draw the structural formulae of the products of this reaction.

[4]

(d) Draw the structural formula of the product obtained when **each** of the alcohols **A**, **B** and **C** is heated with an excess of acidified $K_2Cr_2O_7(aq)$.



[3]

(e) One of the many suggestions for converting biomass into liquid fuel for motor transport is the pyrolysis (i.e. heating in the absence of air) of cellulose waste, followed by the synthesis of alkanes.

For Examiner's Use

(i) In the first reaction, cellulose, $(C_6H_{10}O_5)_n$, is converted into a mixture of carbon monoxide and hydrogen. Some carbon is also produced.

Complete and balance the equation for this reaction.

$(C_6H_{10}O_5)_n \longrightarrow$ _____ + _____ + _____

(ii) The second reaction involves the combination of CO and H_2 to produce alkanes such as heptane.

$$7CO + 15H_2 \longrightarrow \underset{\text{heptane}}{C_7H_{16}} + 7H_2O$$

Using the value of 1080 kJ mol^{-1} as the value for the C≡O bond energy in CO, and other relevant bond energies from the *Data Booklet*, calculate the ΔH for this reaction.

ΔH = ... kJ mol^{-1}
[5]

[Total: 15]

Q4.

6 Acyl chlorides are useful intermediates in organic syntheses.

For Examiner's Use

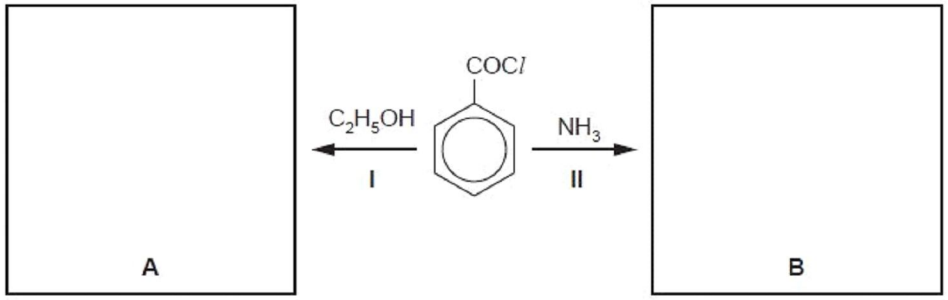
(a) **(i)** State a suitable reagent for converting carboxylic acids into acyl chlorides.

.....

(ii) Construct an equation for the reaction between ethanoic acid, CH_3CO_2H, and the reagent you have stated in **(i)**.

.....
[2]

(b) **(i)** In the boxes provided draw the structures of the compounds formed when benzoyl chloride undergoes the following reactions.



(ii) Name the functional group in

- compound **A** .....
- compound **B** .....

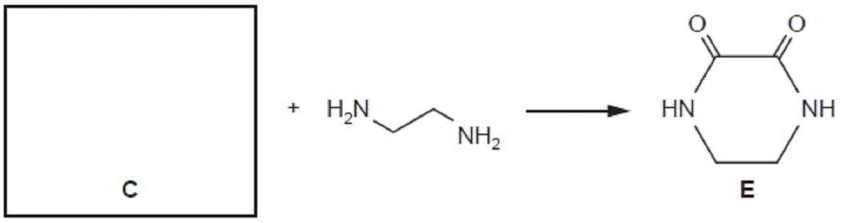
(iii) What *type of reaction* is reaction **II**?

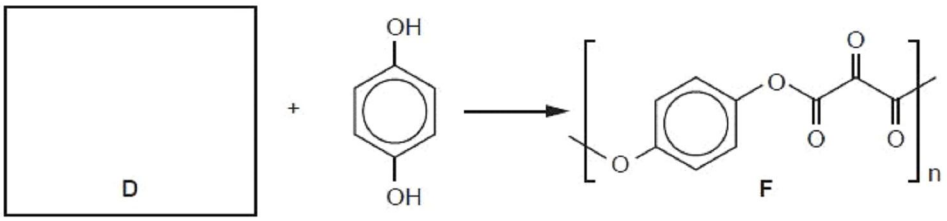
.....

[5]

(c) **(i)** Suggest suitable acyl chlorides to use in the following reaction. Draw their structures in the boxes provided.

For Examiner's Use





Compound **E** dissolves in, but does not react with, cold water.

(ii) Suggest the major type of intermolecular interaction that occurs between **E** and water.

.....

(iii) A solution of the diamine $H_2NCH_2CH_2NH_2$ in water has pH = 11 but a solution of **E** in water has pH = 7. Suggest why this is the case.

.....

.....

(iv) What type of polymer is compound **F**?

.....

[5]

[Total: 12]

Q5.

6 **(a)** The reaction producing tri-iodomethane (iodoform) can be used as a test for the presence of certain groups within a molecule.

For Examiner's Use

(i) State the reagents and conditions used for this reaction.

.....

(ii) Write the structural formula of **one** functional group that would give a positive result with this iodoform reaction.

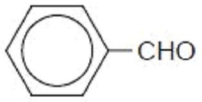
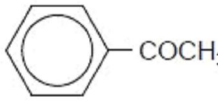
.....

(iii) What do you observe in a positive test?

.....

.....

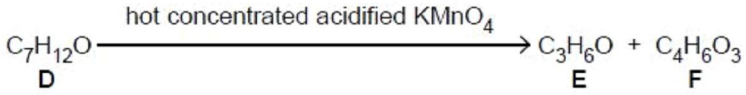
(iv) In the following table place a tick (✓) in the column against each compound that would give a positive result with this test, and a cross (✗) against each compound that would give a negative result.

compound	result
CH_3OH	
CH_3CH_2OH	
CH_3CHO	
CH_3CO_2H	
	
	

[6]

(b) The iodoform test can be used, along with other reactions, to work out the structures of unknown compounds.
Use the information in the table below to deduce the structures of the compounds in the following scheme, and draw these structures in the boxes provided.

For Examiner's Use



Results of tests (✓ indicates a positive result; ✗ indicates a negative result)

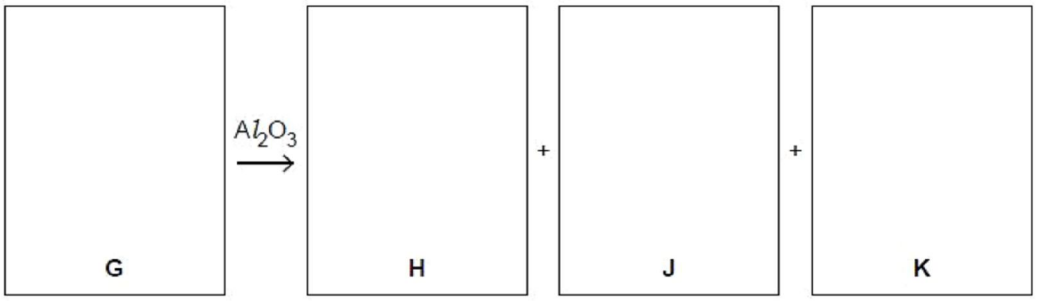
test	results of tests with each compound		
	D	**E**	**F**
iodoform	✗	✓	✓
Fehling's solution	✓	✗	✗
2,4-dinitrophenyl-hydrazine reagent	✓	✓	✓
Na_2CO_3(aq)	✗	✗	✓

structures

D($C_7H_{12}O$)	**E**(C_3H_6O)	**F**($C_4H_6O_3$)

[3]

(c) Treatment of compound **F** with $NaBH_4$ gives compound **G**, $C_4H_8O_3$. Heating **G** with Al_2O_3 gives a mixture of three isomeric unsaturated carboxylic acids **H**, **J** and **K**, $C_4H_6O_2$, two of which are stereoisomers of each other.
Suggest structures for **G**, **H**, **J**, and **K**, and name the type of stereoisomerism shown.



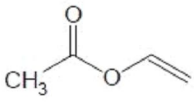
type of stereoisomerism .....[5]

[Total: 14]

Q6.

4 **(a)** Polyvinyl acetate, PVA, is a useful adhesive for gluing together articles made from wood, paper or cardboard. The monomer of PVA is ethenyl ethanoate, **B**.

For Examiner's Use

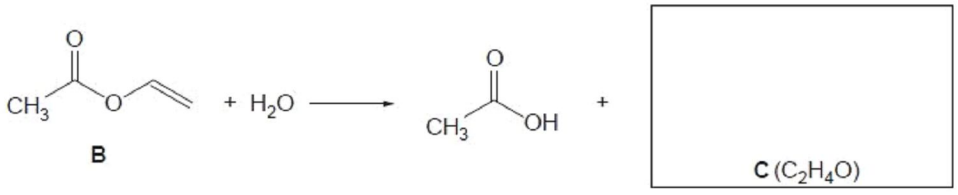


B

PVA is formed from **B** by the process of addition polymerisation.

(i) Draw a section of the PVA molecule containing at least 2 monomer molecules, and identify clearly the repeat unit.

The ester **B** can be hydrolysed in the usual way, according to the following equation.



(ii) Use this information to suggest a possible structure for **C** and draw it in the box above.

When substance **C** is extracted from the product mixture, it is found that it does **not** decolourise $Br_2(aq)$, but it **does** form a pale yellow precipitate with alkaline aqueous iodine.

(iii) Suggest a structure for **C** that fits this new information.

(iv) Suggest a confirmatory test for the functional group in the structure you have drawn in **(iii)**. Your answer should include the reagent you would use and the observation you would make.

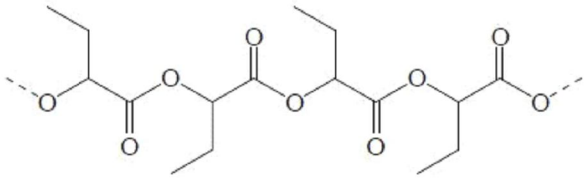
.....

.....

[6]

(b) The following diagram represents a section of another polymer.

For Examiner's Use



D

(i) On the above formula draw brackets, [ ], around the atoms that make up the repeat unit of this polymer.

(ii) Name the functional group in polymer **D**.

.....

(iii) Suggest and draw the structure of the monomer, **E**, that could form this polymer.

(iv) What *type of polymerisation* is involved in making polymer **D** from its monomer?

.....

(v) What is the relationship between the repeat unit of polymer **D** and the repeat unit of PVA?

.....

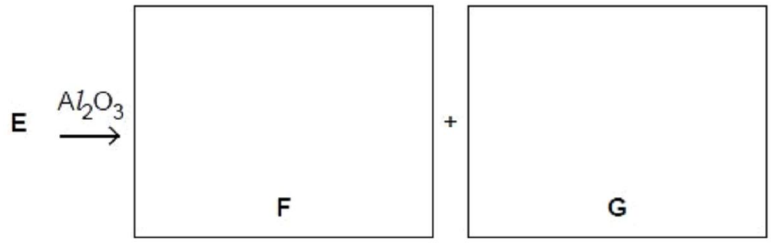
[5]

(c) Monomer **E** exists as two stereoisomers. Heating either isomer with Al_2O_3 gives a mixture of two unsaturated carboxylic acids **F** and **G**, which are stereoisomers of each other.

(i) Name the *type of stereoisomerism* shown by compound **E**.

.....

(ii) Suggest structures for **F** and **G**, and name the type of stereoisomerism they show.



type of isomerism .....

[4]

[Total: 15]

Q7.

5 **(a)** Describe and explain how the acidities of $CHCl_2CO_2H$ and CH_2ClCO_2H compare to each other, and to the acidity of ethanoic acid.

Ex

.....

.....

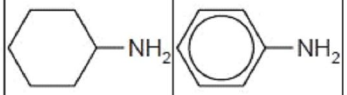
.....

.....

.....

[3]

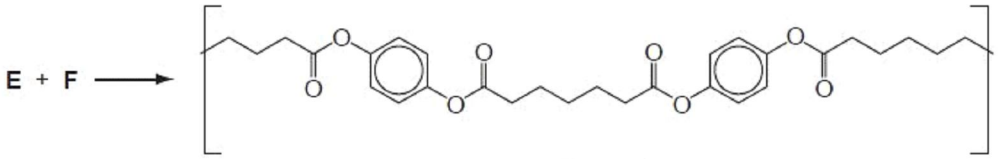
(b) For each of the following pairs of compounds, suggest one chemical test (reagents and conditions) that would distinguish between them.
State the observations you would make with each compound, writing 'none' if appropriate.

first compound	second compound	test (reagents and conditions)	observation with first compound	observation with second compound
				
CH_3CH_2COCl	CH_3COCH_2Cl			
CH_3CH_2CHO	CH_3COCH_3			

[7]

For Examine Use

(c) The following diagram shows a section (not a repeat unit) of a polymer, **G**, that can be made from the two monomers **E** and **F**.



polymer **G**

(i) What *type of polymerisation* made this polymer?

.....

(ii) Draw the structures of the two monomers **E** and **F**.

E

F

(iii) Suggest the conditions needed to make polymer **G** from **E** and **F** in the laboratory.

.....

.....

.....

(iv) One of the monomers, **E** or **F**, could be changed to make a more rigid polymer of a similar chemical type to **G**.
Suggest which of your two monomers could be changed, and suggest a structure for the new monomer.

Monomer to be changed (**E** or **F**) .....

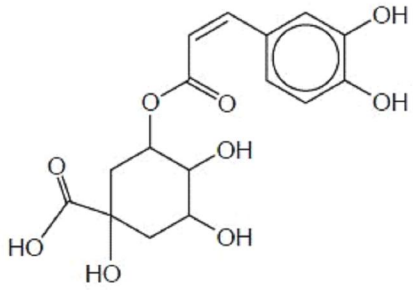
Structural formula of the new monomer

[6]

[Total: 16]

Q8.

5 Coffee beans contain chlorogenic acid.



chlorogenic acid

(a) (i) Draw circles around any chiral centres in the above structure.

(ii) Write down the molecular formula of chlorogenic acid.

.....

(iii) How many moles of $H_2(g)$ will be evolved when 1 mol of chlorogenic acid reacts with an excess of sodium metal?

.....

(iv) How many moles of NaOH(aq) will react with 1 mol of chlorogenic acid under each of the following conditions?

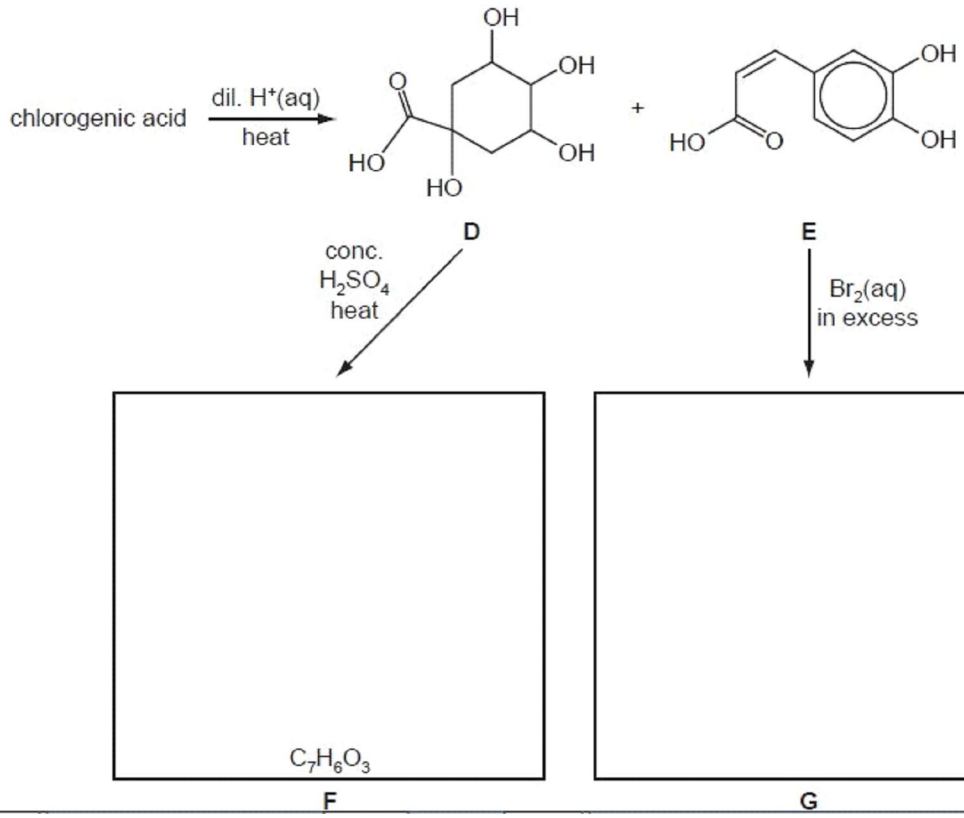
in the cold .....

on heating .....

[6]

(b) On heating with dilute aqueous acid, chlorogenic acid produces two compounds, **D** and **E**.

For Examine Use



(i) What *type of reaction* is chlorogenic acid undergoing when **D** and **E** are formed?

.....

When compound **D** is heated with concentrated H_2SO_4, compound **F**, $C_7H_6O_3$, is formed.

Compound **F** evolves $CO_2(g)$ when treated with $Na_2CO_3(aq)$, and decolourises $Br_2(aq)$, giving a white precipitate. It does not, however, decolourise cold dilute acidified $KMnO_4$.

When compound **E** is treated with an excess of $Br_2(aq)$, compound **G** is produced.

(ii) If the test with cold dilute acidified $KMnO_4$ had been positive, which functional group would this have shown to be present in **F**?

.....

(iii) **Name** the functional groups in compound **F** that would react with the following.

$Na_2CO_3(aq)$ ..... $Br_2(aq)$ .....

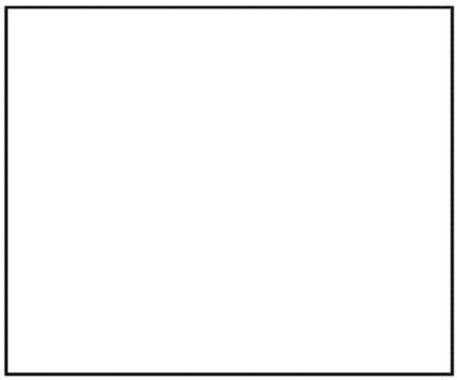
(iv) Suggest structures for compounds **F** and **G** and draw them in the relevant boxes above.

(v) Compound **E** is one of a pair of stereoisomers.

What type of stereoisomerism is shown by compound **E**?

.....

(vi) Draw the structure of the other stereoisomer in the box below.



[8]

(c) Calculate the volume of 0.1 mol dm^{-3} NaOH that is needed to react completely with 0.1 g of compound **E**.

volume = ... cm^3

[3]

[Total: 17]

Q9.

6 Amides can be made by reacting amines with acyl chlorides, as in the example below.

$$CH_3CH_2COCl + H_2NCH_2CH_2CH_3 \longrightarrow CH_3CH_2CONHCH_2CH_2CH_3 + HCl$$

(a) What type of reaction mechanism is this?

.....[1]

(b) What compound could CH_3CH_2COCl be made from, and what reagent would you use?

.....

.....[2]

(c) The amine $CH_3CH_2CH_2NH_2$ can be made from CH_3CH_2Br in two steps.

(i) Draw the structural formula of the intermediate in the box provided.

.....

(ii) State the reagents and conditions for step I.

.....

(iii) State the reagents and conditions for step II.

.....

[4]

(d) *Kevlar* is a low weight, high strength polyamide used as a reinforcement in car tyres, aircraft wings and in bullet-proof vests. A portion of its chain is shown below.

(i) What type of polymerisation produces *Kevlar*?

.....

(ii) Draw the structural formulae of the monomers from which *Kevlar* is made.

(iii) Suggest a reason why *Kevlar* is much stronger than most other polyamides.

.....

(iv) What reaction conditions are needed to break the amide bonds in *Kevlar*?

.....

[4]

[Total: 11]

Q10.

5 The amino acid alanine, **K**, can be obtained from 2-hydroxypropanoic acid, **H**, by the following route.

$$\underset{\textbf{H}}{CH_3CH(OH)CO_2H} \xrightarrow{\text{I}} \underset{\textbf{J}}{CH_3CHClCO_2H} \xrightarrow{\text{II}} \underset{\textbf{K}}{CH_3CH(NH_2)CO_2H}$$

(a) Suggest a test you could use to distinguish **H** from its isomer 3-hydroxypropanoic acid, **L**.

$$\underset{\textbf{L}}{HOCH_2CH_2CO_2H}$$

reagents .....

observation with **H** .....

observation with **L** .....[2]

(b) How would the acidity of chloropropanoic acid, **J**, compare with that of propanoic acid? Briefly explain your answer.

.....

.....

.....[2]

(c) Alanine reacts with both acids and bases.

Write an equation for the reaction between alanine and sodium hydroxide, drawing the displayed formula of the organic product.

[2]

(d) In solution, alanine exists as a zwitterion. Draw the structure of this ion.

[1]

(e) Alanine is one of about 20 amino acids that make up proteins.

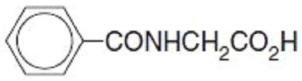
(i) What type of bond joins amino acids together in proteins?

.....

(ii) Draw the displayed formula of the compound formed when two alanine molecules are joined by this bond.

[2]

(f) An excess of benzoic acid in the body (present as a preservative in many foodstuffs, or formed by oxidation of aromatic compounds present in food) is excreted as hippuric acid, **M**.



M

(i) Suggest a reagent that could be reacted with glycine in the laboratory to form hippuric acid.

.....

(ii) Suggest the reagents and conditions needed to re-form glycine from hippuric acid.

.....

.....

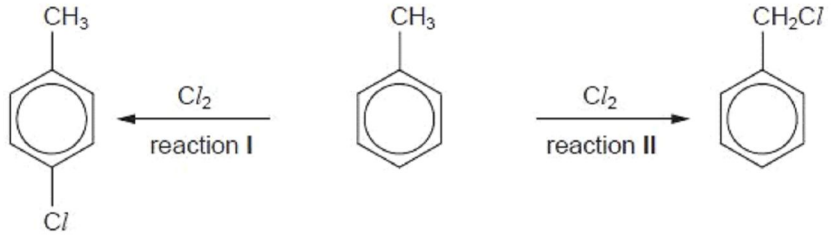
[3]

[Total : 12]

Q11.

5 This question is concerned with organochlorine compounds.

(a) State the conditions needed to produce the two compounds **A** and **B.**



A **B**

(i) conditions for reaction **I**

.....

(ii) conditions for reaction **II**

..... [2]

(b) State the reagent needed to carry out the following reaction.

C

reagent for reaction **III**: ..... [1]

Use

(c) The three chloro-compounds **A**, **B** and **C** vary in their ease of hydrolysis.

(i) Place a tick in the box corresponding to the correct relative rates of hydrolysis. [the symbol '>' means 'faster than']

	place **one** tick only in this column
A > **B** > **C**	
A > **C** > **B**	
B > **A** > **C**	
B > **C** > **A**	
C > **B** > **A**	
C > **A** > **B**	

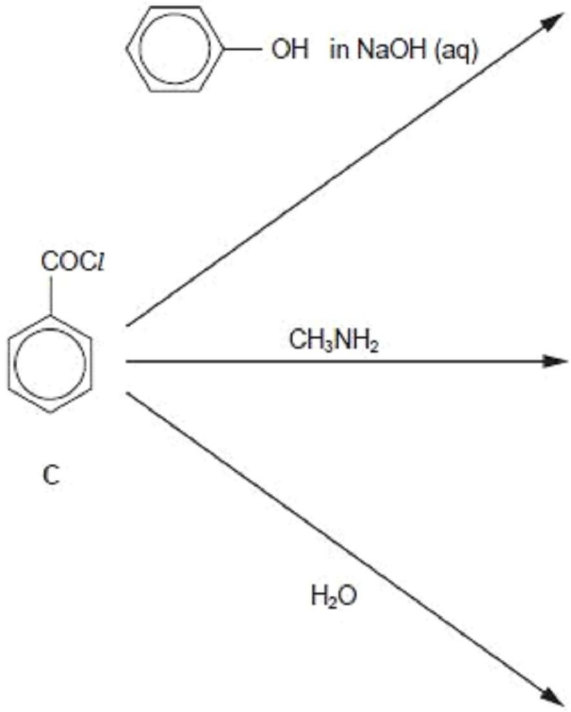
(ii) Suggest an explanation for these differences in reactivity.

.....

.....

..... [3]

(d) Draw the structural formulae of the organic products of the following reactions of compound C.



[3]

[Total: 9]

Q12.

Use

6 Compounds **D** and **E** are both ketones.

$CH_3CH_2COCH_2CH_3$ **D**

$CH_3CH_2CH_2COCH_3$ **E**

(a) State which one of these compound reacts with alkaline aqueous iodine, and draw the structural formulae of the products formed during this reactions.

(i) compound (**D** or **E**) .....

(ii) products

..... [3]

(b) The reduction of **D** with $NaBH_4$ produces just one alcohol, but a similar reduction of **E** produces two isomers in equal amounts. Explain these observations, drawing structures where appropriate.

.....

.....

[3]

[Total: 6]

Q13.

6 Suggest a test or simple reaction you could carry out on each of the following pairs of compounds to enable them to be distinguished.

(a) $CH_3COCH_2CH_2CH_3$ **J** $CH_3CH_2COCH_2CH_3$ **K**

(i) description of test or reaction

.....

.....

(ii) observation with compound **J**

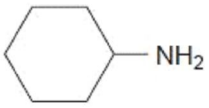
.....

(iii) observation with compound **K**

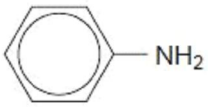
.....

[2]

(b)



L



M

(i) description of test or reaction

.....

.....

(ii) observation with compound **L**

.....

(iii) observation with compound **M**

.....

[2]

(c) CH_3CH_2COCl **N** $CH_3CH_2CH_2Cl$ **P**

(i) description of test or reaction

.....

.....

(ii) observation with compound **N**

.....

(iii) observation with compound **P**

.....

[2]

(d) $CH_3CH_2CONH_2$ **Q** $CH_3CH_2CH_2NH_2$ **R**

(i) description of test or reaction

.....

.....

(ii) observation with compound **Q**

.....

(iii) observation with compound **R**

.....

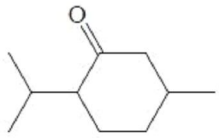
[2]

[Total: 8]

Q14.

For Examiner's Use

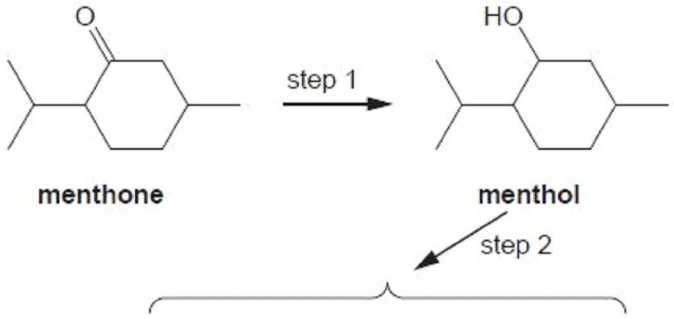
6 Menthone, $C_{10}H_{18}O$, is a cyclic ketone that occurs in oil of peppermint.



menthone

(a) Use asterisks (*) on the formula above to identify any chiral centres in the molecule of menthone. [2]

(b) Menthone can be reduced to menthol, which can be dehydrated to a mixture of two alkenes, **L** and **M**.



menthone **menthol**

step 2

L	+	**M**

(i) Suggest reagents for

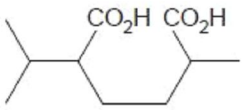
step 1, ...

step 2. .....

(ii) Suggest structures for **L** and **M** and draw them in the boxes above. [4]

(c) When heated with concentrated, acidified $KMnO_4(aq)$, one of the two alkenes **L** or **M** produces the dicarboxylic acid **N**.

For Examiner's Use



N

(i) Give the letter of the alkene that produced **N** by this reaction.

.....

(ii) Suggest the structure of the product, **P**, of the reaction between the other alkene you have drawn and hot concentrated acidified $KMnO_4$.

P

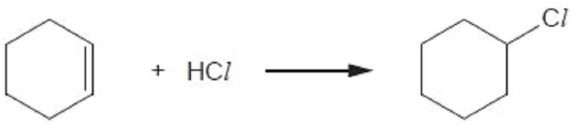
(iii) Suggest **one** chemical test that would enable you to distinguish between **N** and **P**.

reagent(s).....

observation.....

[3]

(d) Chlorocyclohexane can be prepared by bubbling HCl(g) through a solution of cyclohexene.



Suggest the mechanism of this 2-stage reaction by means of a diagram. Include all whole or partial charges, and represent the movements of electron pairs by curly arrows.

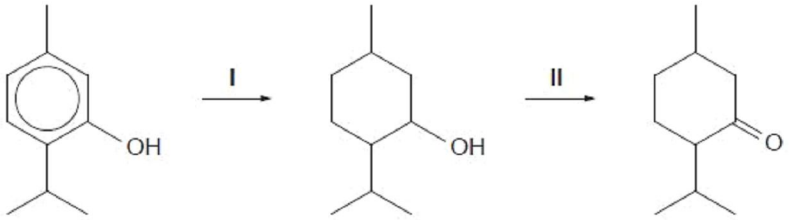
[3]

[Total: 12]

Q15.

3 Menthol and menthone, the main constituents of oil of peppermint, can be made synthetically from thymol by the following route.

For Examiner's Use



thymol menthol menthone

(a) State the *type of reaction* of

- reaction **I**, ...
- reaction **II**. .....

[2]

(b) Suggest **one** test for **each** of the three compounds that would give a positive result with the stated compound but a negative result with **both** the other two compounds.

thymol

test .....

observation .....

menthol

test .....

observation .....

menthone

test .....

observation .....[6]

[Total: 8]

Q16.

5 Compound **C** has the molecular formula $C_7H_{14}O$. Treating **C** with hot concentrated acidified $KMnO_4(aq)$ produces two compounds, **D**, C_4H_8O, and **E**, $C_3H_4O_3$. The results of four tests carried out on these three compounds are shown in the following table.

For Examiner's Use

test reagent	result of test with		
	compound **C**	compound **D**	compound **E**
$Br_2(aq)$	decolourises	no reaction	no reaction
Na(s)	fizzes	no reaction	fizzes
$I_2(aq) + OH^-(aq)$	no reaction	yellow precipitate	yellow precipitate
2,4-dinitrophenylhydrazine	no reaction	orange precipitate	orange precipitate

(a) State the functional groups which the above four reagents test for.

(i) $Br_2(aq)$

.....

(ii) Na(s)

.....

(iii) $I_2(aq) + OH^-(aq)$

.....

(iv) 2,4-dinitrophenylhydrazine

.....

[4]

(b) Based upon the results of the above tests, suggest structures for compounds **D** and **E**.

D, C_4H_8O **E**, $C_3H_4O_3$

[2]

(c) Compound **C** exists as two stereoisomers.

For Examiner's Use

Draw the structural formula of **each** of the two isomers, and state the type of stereoisomerism involved.

type of stereoisomerism .....

[3]

[Total: 9]

Q17.

5 Alkanes are generally considered to be unreactive compounds, showing an inertness to common reagents such as NaOH, H_2SO_4, and $K_2Cr_2O_7$.

For Examiner's Use

(a) Suggest a reason why these reagents **do not** attack an alkane such as CH_4.

.....

[1]

(b) When a mixture of chlorine and ethane gas is exposed to strong sunlight, an explosion can occur due to the fast exothermic reaction.
Under more controlled conditions, however, the following reaction occurs.

$$C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$$

(i) What is the name of this type of reaction?

.....

(ii) Use equations to describe the mechanism of this reaction, naming the steps involved.

.....

.....

.....

.....

.....

.....

(iii) This reaction can produce organic by-products, in addition to C_2H_5Cl.
Draw the structural formulae of three possible organic by-products. Two of your by-products should contain 4 carbon atoms per molecule.
Briefly describe how each by-product could be formed.

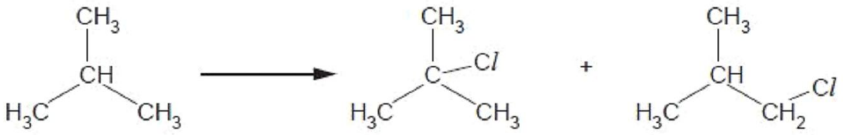
structural formula of by-product	formed by

(iv) It is found by experiment that, during this type of reaction, primary, secondary and tertiary hydrogen atoms are replaced by chlorine atoms at different rates, as shown in the following table.

For Examiner's Use

reaction	relative rate
$RCH_3 \rightarrow RCH_2Cl$	1
$R_2CH_2 \rightarrow R_2CHCl$	7
$R_3CH \rightarrow R_3CCl$	21

Using this information, and considering the number of hydrogen atoms of each type (primary, secondary or tertiary) within the molecule, predict the relative ratio of the two possible products **J** and **K** from the chlorination of 2-methylpropane. Explain your answer.



2-methylpropane **J** **K**

ratio **J** / **K** = ...

explanation:

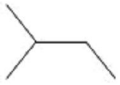
.....

.....

.....

[10]

(c) In the boxes below draw the **skeletal** formulae of **four** different structural isomers of $C_5H_{11}Cl$ that could be obtained from the chlorination of 2-methylbutane. Indicate any chiral centres in your structures by an asterisk (*).



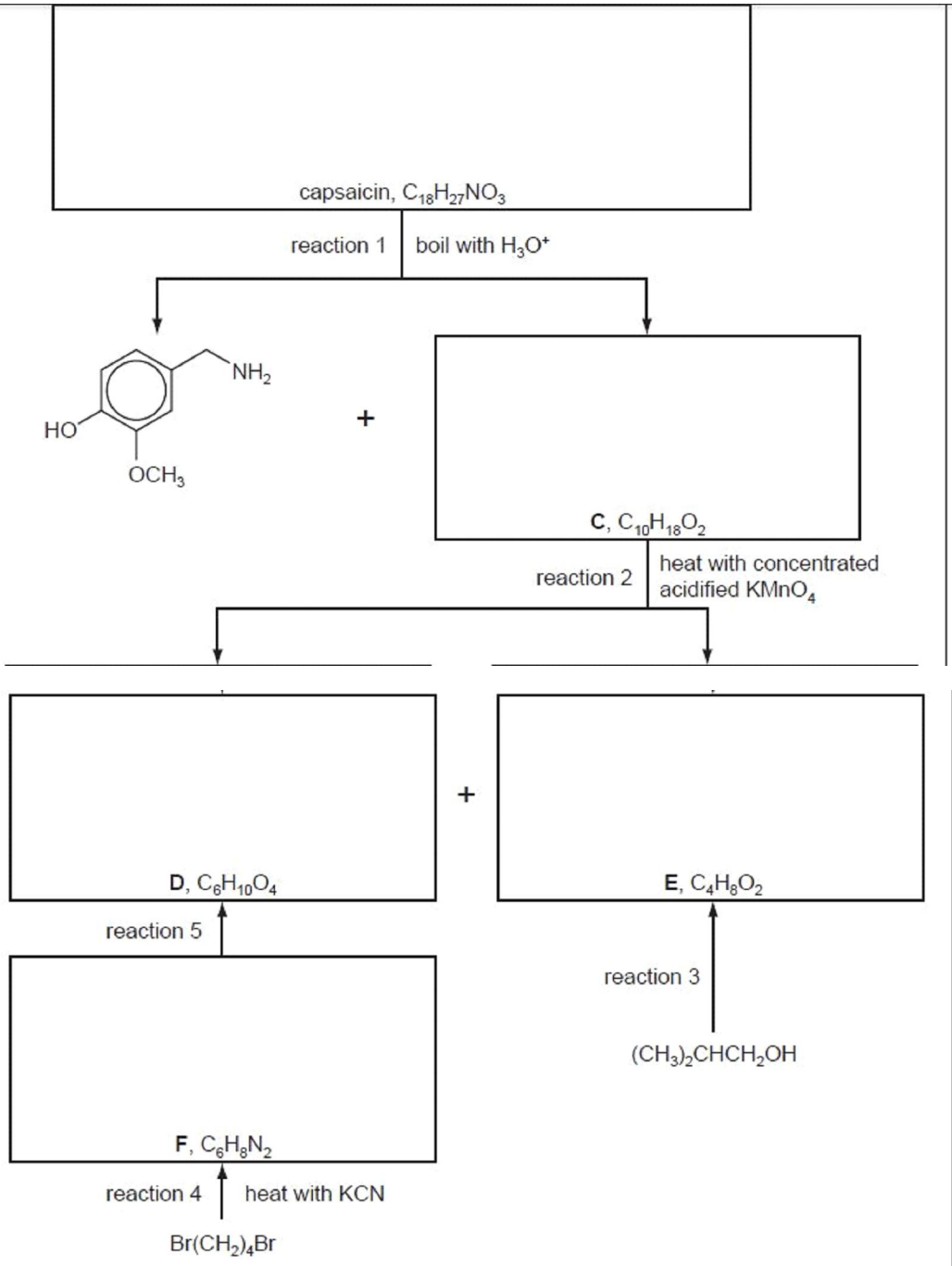
2-methylbutane + Cl_2 $\rightarrow$ $C_5H_{11}Cl$ + HCl

[5]

[Total: 16]

Q18.

4 The compound responsible for the hot taste of chilli peppers is capsaicin. Its molecular structure can be deduced by the following reaction scheme.



Compounds **C**, **D** and **E** all react with $Na_2CO_3(aq)$.

Answer the following questions.

For Examiner Use

(a) Suggest reagents and conditions for reaction 3.

..... [1]

(b) What *type of reaction* is reaction 4?

..... [1]

(c) Suggest reagents and conditions for reaction 5.

..... [1]

(d) Name the functional group in **C** that has reacted with hot concentrated acidified $KMnO_4$.

..... [1]

(e) Suggest the name of the functional group in capsaicin that has reacted in reaction 1.

..... [1]

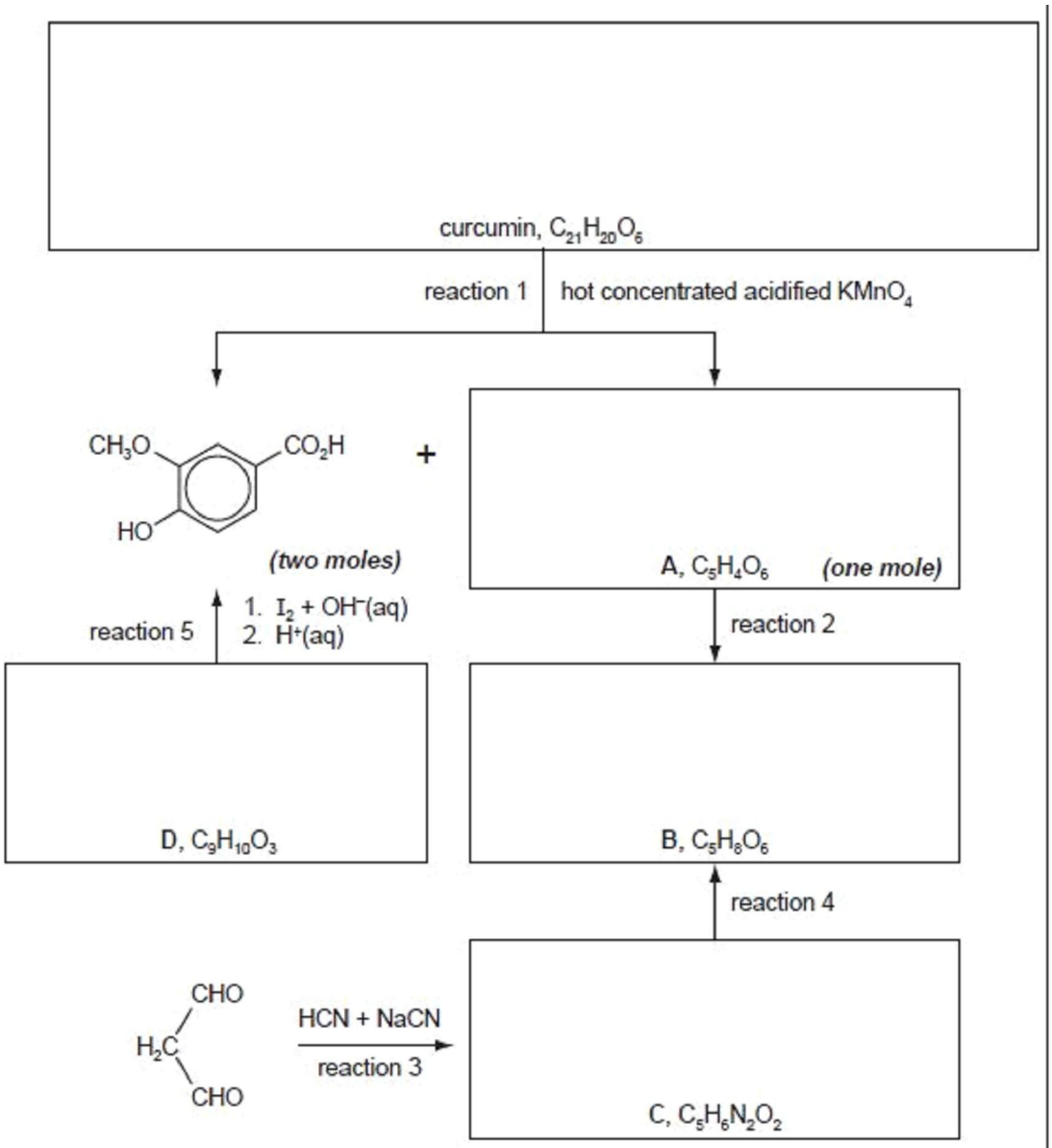
(f) Work out structures for compounds **C**–**F** and capsaicin, and draw their structural formulae in the boxes opposite. [5]

[Total: 10]

Q19.

4 The compound responsible for the yellow colour of the spice turmeric is curcumin. Its molecular structure can be deduced from the following series of reactions. The CH_3O- group that is present in curcumin may be regarded as unreactive.

For Examiner's Use



Curcumin and compounds **A** and **D** all react with 2,4-dinitrophenylhydrazine reagent.

Compounds **A** and **B** effervesce with Na_2CO_3(aq), but curcumin, and compounds **C** and **D**, do not.

Curcumin reacts with Br_2(aq) and with cold dilute acidified $KMnO_4$

(a) (i) Name the functional group common to curcumin and compounds **A** and **D**.

.....

(ii) Name the functional group common to compounds **A** and **B**.

.....

[2]

(b) (i) Suggest the structures of compounds **B**, **C** and **D**, and draw their structural formulae in the relevant boxes opposite.

(ii) Suggest suitable reagents and conditions for reaction 4.

.....

[4]

(c) (i) Name the *type of reaction* for reaction 2.

.....

(ii) Suggest a reagent for reaction 2.

.....

(iii) Suggest the structure of compound **A**, and draw its structural formula in the relevant box opposite.

[3]

(d) (i) **Name** the functional group in curcumin that reacts with cold dilute acidified $KMnO_4$.

.....

(ii) **Name two** functional groups in curcumin that react with $Br_2(aq)$.

.....

[2]

(e) Suggest a structure for curcumin and draw its structural formula in the relevant box opposite. [2]

[Total: 13]