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Level: CIE AS and A Level (9701)
Subject: Chemistry
Topic: CIE Chemistry
Type: Mark Scheme

Chemistry CIE AS & A Level
To be used for all exam preparation for 2025+

CHEMISTRY AS and A

This to be used by all students studying CIE AS and A level Chemistry (9701) But students of other boards may find it useful

Mark Scheme

Answer 1.

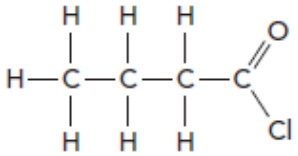
a) The completed table is:

Structural formula	IUPAC name
$C_6H_5CH_3$	methylbenzene; [1 mark]
$CH_3CH_2CH_2CH_2CHO$	pentanal; [1 mark]
CH_3NHCH_3	dimethylamine; [1 mark]
$CH_3CH(NH_2)CO_2H$	2-aminopropanoic acid; [1 mark]

[Total: 4 marks]

- $C_6H_5CH_3$
  - C_6H_5 tells us that this is a benzene ring
  - The 5 hydrogen atoms in the structure tells us that 1 hydrogen atom has been substituted, in this case for a CH_3 group
  - Therefore it is methylbenzene
- $CH_3CH_2CH_2CH_2CHO$
  - The CHO group at the end of the molecule indicates the compound is an aldehyde
  - There are 5 carbon atoms in the straight chain, therefore the name is pentanal
- CH_3NHCH_3
  - The NH atom indicates that this is an amine
  - There are two CH_3 groups bonded to the nitrogen atom, dimethyl- should be in the name
  - Therefore the name is dimethylamine
- $CH_3CH(NH_2)CO_2H$
  - This compound is an amino acid
  - There are 3 carbon atoms in the chain with a carboxylic acid group, CO_2H
    - This group takes priority so is named last -propanoic acid
  - There is also a NH_2 group, amine group bonded to the second carbon
    - Therefore the name is 2-aminopropanoic acid

b) The fully displayed formula for butanoyl chloride is:



- Correct displayed formula of butanoyl chloride; [1 mark]

[Total: 1 mark]

- Butanoyl chloride is an acyl chloride molecule so will contain COCl group at the end of the chain
- The carbon in the COCl group is part of the carbon chain so take note of this when drawing or naming acyl chlorides

c) The type of mechanism is:

- Addition-elimination; [1 mark]

[Total: 1 mark]

- You are asked for the type of **mechanism** that occurs in this reaction
- A water molecule adds across the C=O bond
- A hydrochloric acid (HCl) molecule is eliminated
  - Therefore the mechanism is addition-elimination
- The reaction overall is hydrolysis

Answer 2.

a) The systematic name of compounds **K**, **L** and **M** are:

- compound **K** = phenol; [1 mark]
- compound **L** = ethanoyl chloride; [1 mark]
- compound **M** = 2–phenylpropylamine; [1 mark]

[Total: 3 marks]

- You should know that compound **K** is phenol
- Compound **L** is an acyl chloride
  - These have the suffix -oyl chloride
  - The carbon chain:
    - Is 2 carbons long, which means that the name is eth- based
    - Contains only single bonds, which means that the name contains -an-
  - Overall, you have eth + an + oyl chloride = ethanoyl chloride
- Compound **M** is more complicated
  - There is a phenyl ring attached to carbon-2 of a carbon chain, which means that the name contains 2–phenyl
  - The carbon chain is 3 carbons long **AND** has an amine group at the end, which means that the name contains propylamine
  - Overall, you have 2–phenyl + propylamine = 2–phenylpropylamine

b) The completed table identifying whether compounds **K**, **L** and **M** are aliphatic or aromatic is:

	Aliphatic	Aromatic
compound **K**	x	✓
compound **L**	✓	x
compound **M**	✓	✓

- Compounds **L** and **M** identified as aliphatic; [1 mark]
- Compounds **K** and **M** identified as aromatic; [1 mark]

[Total: 2 marks]

- **Remember:** Aromatic compounds contain a benzene ring
  - Aliphatic compounds do not contain benzene rings
  - Aliphatic compounds are most commonly carbon chains although they can sometimes be cyclic as well, e.g. cyclohexane

c)

i) **Structural isomerism** is:

- Where compounds have the same molecular formula but different structural formulae; [1 mark]

Three specific types of structural isomerism are:

- (Branched) Chain
  AND
  Positional
  AND
  Functional group; [1 mark]

ii) **Stereoisomerism** is:

- Where compounds have the same molecular formula and structural formulae but a different arrangement of atoms in space; [1 mark]

Two specific types of structural isomerism are:

- Geometric(al)
  AND
  Optical; [1 mark]

[Total: 4 marks]

- You need to know the definitions of structural isomerism and stereoisomerism as well as be able to work with each type of isomer that they describe

Answer 3.

a) The IUPAC names of the compounds **A**, **B** and **C** are:

- Compound **A** - butanoyl chloride; [1 mark]
- Compound **B** - propanamide; [1 mark]
- Compound **C** - 4–aminobutanoic acid; [1 mark]

[Total: 3 marks]

- Naming compound **A**:
  - Determine the primary functional group: acyl chloride, -COCl
    - Suffix of name -oyl chloride
  - Determine the primary chain: 4 carbons with only single bonds
    - Stem of name butan-
  - The acyl chloride can only go on an end carbon so it does not need to be numbered
  - This gives the name butanoyl chloride
- Naming compound **B**
  - Determine the primary functional group: amide, $-CONH_2$
    - Suffix of name -amide
  - Determine the primary chain: 3 carbons with only single bonds
    - Stem of name propan-
  - The amide can only go on an end carbon so it does not need to be numbered
  - This gives the name propanamide
- Naming compound **C**
  - Determine the functional groups: amino, $-NH_2$ and carboxylic acid, -COOH
    - Prefix of name, amino-
    - Suffix of name -oic acid
  - Determine the primary chain: 3 carbons with only single bonds
    - Stem of name propan-
  - The carboxylic acid can only go on an end carbon so it does not need to be numbered but the position of the amino group needs to be given in relation to the carboxylic acid
    - The carbon of the -COOH is given position 1, so the $-NH_2$ group is on carbon 4
  - This gives the name 4–aminobutanoic acid

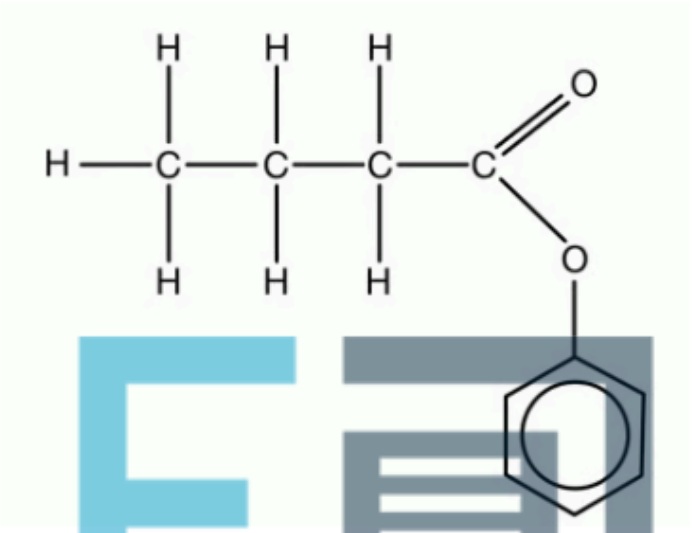
b) This is an example of an addition-elimination reaction because:

- Water adds across the C=O bond; [1 mark]
- HCl is eliminated; [1 mark]

[Total: 2 marks]

- You need to understand the terminology associated with various mechanisms:
  - free-radical substitution
  - electrophilic addition
  - nucleophilic substitution
  - nucleophilic addition
  - electrophilic substitution
  - addition-elimination
- An addition-elimination reaction is a reaction in which 2 molecules join together with the loss of a small molecule, in this case, HCl

c) The displayed formula of phenyl butanoate is:



- Correct ester link -COO-; [1 mark]
- Rest of structure correct; [1 mark]

[Total: 2 marks]

- 'Butan-' tells you that the carbon chain has 4 carbon atoms with single bonds between each carbon atom
- '-oate' tells you that it is an ester, so draw the -COO- group on one of the end carbon atoms, remembering that there is a double bond to one oxygen and a single bond to the other
- The first part of the name of an ester comes from the alcohol
  - Phenyl indicates that phenol was used
  - The H in the OH group of phenol is lost, leaving the O
  - This is the O of the C-O of the ester link, so you need to draw a benzene ring from this O

d) Stating whether any of the compounds, **A**, **B** or **C**, can form optical isomers and why:

- None of the compounds form optical isomers; [1 mark]
- Because none have a chiral centre; [1 mark]

[Total: 2 marks]

- Compounds with a chiral centre exist as two optical isomers which are also known as enantiomers
- A carbon atom that has four different atoms or groups of atoms attached to it is called a chiral carbon or chiral centre
- None of these compounds has a carbon atom which is attached to four different atoms or groups of atoms

Answer 4.

Give the name of compounds **W** and **X**

- **W** is propene; [1 mark]
- **X** is 2-chloropropane; [1 mark]

[Total: 2 marks]

- As Step 1 gives the major product from the reaction, the chloro group, -Cl, must be on the middle carbon atom
- The mechanism for Step 1 would be electrophilic addition of the alkane and so a primary and secondary carbocation would be produced
- Secondary carbocations are more stable than primary carbocations so the chloro group, -Cl, would bond more favourably to this forming 2-chloropropane

Give a suitable reagent and reaction equation for step 2 given in Fig. 2.1

- Ammonia / NH_3; [1 mark]
- Propanoyl chloride; [1 mark]

[Total: 2 marks]

- Nucleophilic substitution of a haloalkane using ammonia produces a primary amine
- Acyl chlorides will react with amines to form N-substituted amides such as compound **Z**
  - It must be propanoyl chloride to ensure compound **Z** contains 6 carbon atoms

i) Calculate the mass of **X** in grams and give your answer to 1 decimal place

- $\frac{5}{42}$ = 0.119 moles; [1 mark]
- 0.119 x 78.5 = 9.34 g; [1 mark]
- 9.34 x 0.64 = 6.0 g
  OR
  $\frac{9.34 \times 64}{100}$ = 6.0 g; [1 mark]

ii) Give two reasons why the percentage yield of the reaction is not 100%:

Any **two** from the following

- By-products are formed in this reaction; [1 mark]
- Reaction has not gone to completion; [1 mark]
- Alternative chemical pathways; [1 mark]
- Formation of intermediates; [1 mark]

[Total: 5 marks]

- Percentage yield is defined as the actual yield divided by the theoretical yield times 100
- It is very rare for a reaction to produce 100% yield
- **Careful**: make sure that you give your answer to the number of decimal places specified in the question **AND** that you round correctly!
  - It would be easy to write 5.9 as your answer to this question by mistake

Answer 5.

a) The completed table is:

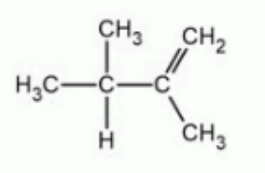
formula	name
$(CH_3)_2C(OH)CH(CH_3)_2$	2,3-dimethylbutan-2-ol; [1 mark]
CH_3COCl	ethanoyl chloride; [1 mark]
$CH_3CONHCH_3$	*N*-methylethanamide; [1 mark]
CH_3CN	ethanenitrile; [1 mark]

[Total: 4 marks]

- There are a mix of different types of compounds here, so take your time with naming them.
- It can help to draw out the skeleton of the structure so you can see the number of carbon atoms and any functional groups present
- $(CH_3)_2C(OH)CH(CH_3)_2$
  - There are 4 carbon atoms in the main chain and an -OH group on the 2nd carbon atom (butan-2-ol)
  - There are also 2 methyl groups, one on the 2nd and 3rd carbons (2,3-dimethylbutan-2-ol)
- CH_3COCl
  - This should be instantly recognisable as a acyl chloride and there are 2 carbon atoms in the main chain (ethanoyl chloride
- $CH_3CONHCH_3$
  - This compound contains the RONHR so must be an amide
  - One of the H atoms on the nitrogen has been substituted by an R group so it is an *N*-substituted amide
  - Therefore we start the name with N- followed by the substituted R group, in this case methyl (*N*-methyl)
  - The other group which is bonded to the C=O group will give the ending (*N*-methylethanamide)

b) The structure of the isomer is:

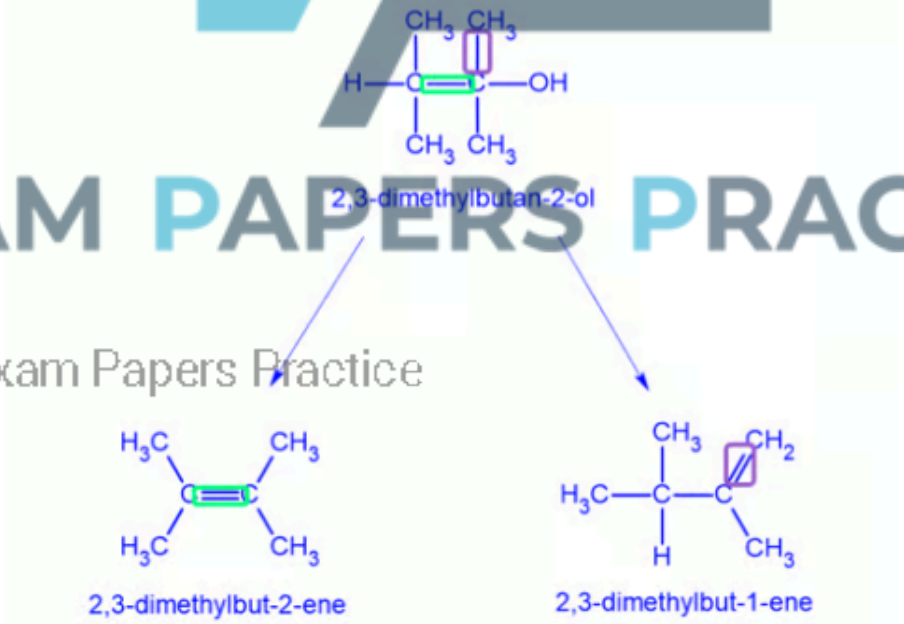
- 2,3-dimethylbut-1-ene; [1 mark]



- Correct structure; [1 mark]
- Loss of hydrogen atom from the end carbon also possible; [1 mark]

[Total: 3 marks]

- The isotopes are formed by the elimination occurring in a slightly different place in the alcohol



c)

i) The reaction of $CH_3COCl + H_2O$ is:

- $CH_3COCl + H_2O \rightarrow CH_3COOH + HCl$; [1 mark]

ii) The formation of $CH_3CONHCH_3$ is:

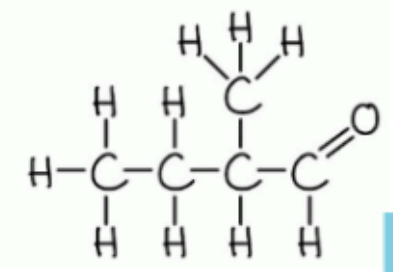
- $CH_3COCl + CH_3NH_2 \rightarrow CH_3CONHCH_3 + HCl$; [1 mark]

[Total: 2 marks]

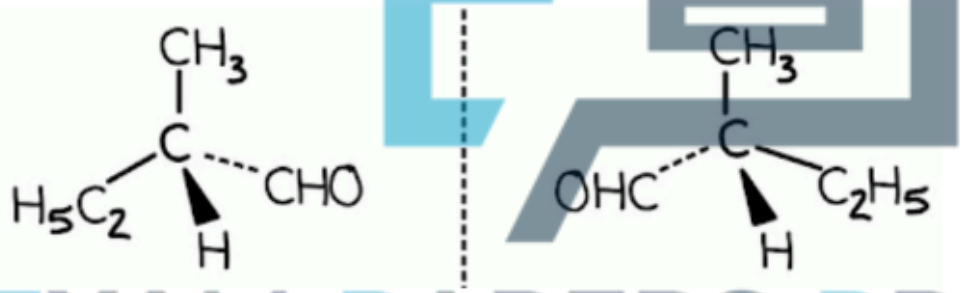
- You need to know some of the the reactions of acyl chlorides
- Make sure you know how they undergo hydrolysis, form amides and form esters
- They are highly reactive and the common feature of these two reactions is they form steamy fumes of HCl
- For the formation of $CH_3CONHCH_3$ make sure you pick the correct amine
    - It must contain a methyl group to form the *N*-substituted amide

Answer 6.

a) The displayed formula and 3D representations of the smallest aldehyde that can form optical isomers are:



- Correct displayed formula; [1 mark]



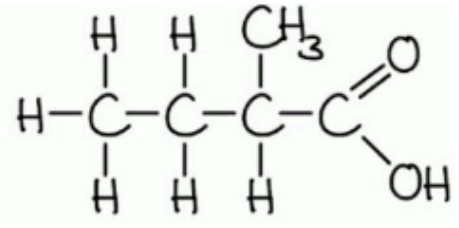
- Correct 3-dimensional structure of the left-hand isomer; [1 mark]
- Correct 3-dimensional structure of the right-hand isomer; [1 mark]

[Total: 3 marks]

- You need a carbon with four different atoms or groups of atoms to form optical isomers
  - Therefore, the aldehyde carbon **cannot** be the chiral carbon
- The chiral carbon must have an aldehyde group attached, which leaves 3 bonds for other atoms or groups of atoms
- To create the smallest aldehyde with optical isomer, you should add a hydrogen, methyl group and ethyl group to the chiral carbon so that you are adding different hydrocarbon functional groups
- **Careful:** Do not add other functional groups because the question asks for the smallest aldehyde

b)

i) The displayed formula of the oxidation product of the aldehyde identified in part **(a)** is:

-  ; [1 mark]

ii) A suitable reagent, including observations, for the oxidation of the aldehyde identified in part **(a)** is:

Alternative 1

- Reagent = Fehling's solution
  AND
  Observation = blue solution to brick red precipitate; [1 mark]

Alternative 2

- Reagent = Tollens' reagent
  AND
  Observation = formation of a silver mirror; [1 mark]

Alternative 3

- Reagent = Acidified potassium dichromate(VI) solution under reflux
  AND
  Observation = orange solution to green solution; [1 mark]

[Total: 2 marks]

- **Remember:** Aldehydes oxidise to carboxylic acids
- The wording of this question can be a bit off-putting but it is basically asking "what is formed when you oxidise an aldehyde?"
- You are expected to know this along with the reagents and observations as one of the more basic points of organic chemistry
- Although reagents and their associated observations are typically for 2 marks, you may sometimes see them for one combined mark where you have to get the combined reagent and observation matching and correct

c)

i) The balanced symbol equation to show the reduction of the aldehyde identified in part **(a)** is:

- $C_2H_5CH(CH_3)CHO + 2[H] \rightarrow C_2H_5CH(CH_3)CH_2OH$; [1 mark]

ii) A suitable reagent is:

- Sodium tetrahydridoborate(III) / sodium borohydride / $NaBH_4$

  OR

  Lithium tetrahydridoaluminate(III) / lithium aluminium hydride / $LiAlH_4$; [1 mark]

[Total: 2 marks]

- **Remember:** Aldehydes reduce to primary alcohols
- You are expected to know this along with the reagents required for this reduction as part of your organic chemistry as well as being able to apply your equation writing skills to questions such as these

d) The organic compound formed by the reaction of the oxidation product in part **(b)** and the reduction product in part **(c)**:

- 2–methylbutyl-2–methylbutanoate; [1 mark]

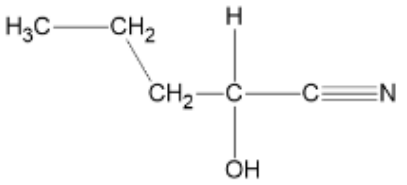
[Total: 1 mark]

- In part (b), you drew the structure of 2–methylbutanoic acid
- In part (c), you write the structural formula of 2–methylbutan-1–ol
- If you think about the reaction of ethanol and ethanoic acid:
  - Ethanol + ethanoic acid → ethyl ethanoate + water
- Then apply this principle but substituting the names for the alcohol and acid in this question
  - 2–methylbutanol + 2–methylbutanoic acid → **2–methylbutyl–2–methylbutanoate** + water

Answer 7.

a)

i) The name and structure of the product of the reaction between $CH_3CH_2CH_2CHO$ and HCN is:

- Name = 2–hydroxypentanenitrile; [1 mark]
- Structure =  ; [1 mark]

ii) The changes in shape and chirality that occur during the formation of the organic product / 2–hydroxypentanenitrile are:

Shape:

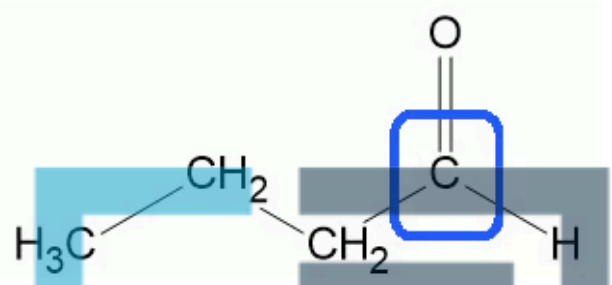
- (The -CHO / aldehyde group) changes from trigonal planar to a tetrahedral (-CHOHCN / hydroxynitrile group); [1 mark]
- (Because,) the carbonyl / C=O bond breaks, forming two single bonds (to OH and CN groups)
  AND
  This means that the carbon atom is now surrounded by 4 single bonding pairs (resulting in a tetrahedral shape); [1 mark]

Chirality:

- $CH_3CH_2CH_2CHO$ / butanal has no chiral centres / carbons
  AND
  The organic product / 2–hydroxypentanenitrile has one chiral centre / carbon; [1 mark]
- (Because,) the carbonyl / C=O bond breaks, forming two single bonds to OH and CN groups
  AND
  Which results in the carbon atom having four different atoms or groups of atoms; [1 mark]

[Total: 6 marks]

- $CH_3CH_2CH_2CHO$ is the aldehyde butanal
  - There are no chiral centres because there are no carbons that have four different atoms or groups of atoms
  - The aldehyde carbon has a trigonal planar shape due to the carbonyl double bond / C=O



- Aldehydes undergo an addition-elimination reaction with HCN to form hydroxynitrile compounds
  - This results in a change of shape and chirality
  - **Careful:** Naming hydroxynitrile compounds is often done incorrectly because students forget that a carbon atom has been added to the original chain
- The product of this reaction is 2-hydroxypentanenitrile
  - There is now a chiral centre / carbon
    - Therefore, the chirality has changed / increased
  - The original carbonyl double bond / C=O has broken during the reaction and replaced with a C-OH and a C-CN bond
    - This means that the original carbonyl bond now has four bonding pairs around it, which results in equal repulsion and a tetrahedral shape

b)

i) The mechanism involved in this reaction is:

- (Nucleophilic) addition-elimination; [1 mark]

Explanation:

- The lone pair of electrons on CH_3OH / methanol act as a nucleophile attacking the δ+ carbonyl carbon
  AND
  One of the carbonyl / C=O bonds breaks (heterolytically) giving both electrons to the oxygen atom; [1 mark]
- A lone pair of electrons from the O^- reforms the carbonyl / C=O bond
  AND
  The carbon-chlorine /C-Cl bond breaks (heterolytically) releasing a chloride ion; [1 mark]
- The OH bond breaks (heterolytically) giving both electrons to the (electron-deficient) oxygen / O^+ atom
  AND
  Resulting in the loss of H^+; [1 mark]
- Overall, a HCl molecule is lost / eliminated; [1 mark]

ii) The systematic name of the organic product of this reaction is:

- Methyl butanoate; [1 mark]

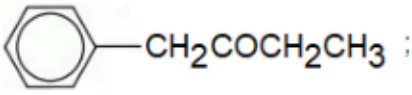
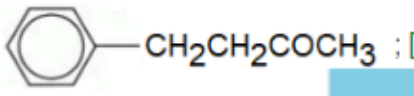
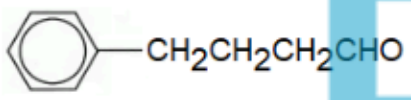
[Total: 6 marks]

- **Remember:** Alcohol + acyl chloride → ester + HCl
  - You should know this is a nucleophilic addition-elimination mechanism
- The explanation of your answer is actually a description of how the mechanism proceeds
  - This is more challenging than simply drawing the mechanism because it requires you to be specific about atoms, lone pairs and charges
  - Although it is theoretically possible that you could be asked a question like part (i), it is more likely that you would be asked to draw the mechanism
    - So, if you get full marks on part (i) it suggests that you really know your nucleophilic addition-elimination mechanism
- **Remember:** The alcohol forms the first name of an ester and the carboxylic acid / acyl chloride forms the surname
  - In this case:
    - Methanol → methyl
    - Butanoyl chloride → butanoate
  - Therefore, the overall name is methyl butanoate

i) The formula of the reactive intermediate is:

- $CH_3CH_2CH_2CO^+$; [1 mark]

ii) The **three** structural isomers of phenylbutanone are:

-  ; [1 mark]
-  ; [1 mark]
-  ; [1 mark]

Explanation of which, if any, form optical isomers:

- No isomers form optical isomers
  AND
  Because there are no chiral centres / carbons **OR** because there are no carbons with four different atoms or groups of atoms; [1 mark]

[Total: 5 marks]

- The reaction of benzene with butanoyl chloride requires an $AlCl_3$ / halogen carrier catalyst
  - The catalyst forms the reactive intermediate / electrophile according to the following equation:
    $CH_3CH_2CH_2COCl + AlCl_3 \rightarrow CH_3CH_2CH_2CO^+ + AlCl_4^-$
- The three structural isomers can be drawn by moving the CO one carbon down the chain each time
  - Each isomer has carbon atoms with either two hydrogens attached **OR** a double bond to an oxygen atom
  - Therefore, there can be no optical isomers
  - **Careful:** It is easy to decide that 4–phenylbutanal has a chiral centre because it does not appear to have two of the same atom attached