Chemistry AS 91391
C3.5 Organic Chemistry
Achievement Criteria

This achievement standard involves describing the structure, physical properties, and reactions of organic compounds.

- Organic compounds will be limited to those containing one or more of the following functional groups: alkene, haloalkane, amine, alcohol, aldehyde, ketone, carboxylic acid, ester (including triglycerides), acyl chloride, amide.

Reactivity of organic compounds will be limited to

- substitution reactions using the following reagents: concentrated HCl, HBr, ZnCl₂/HC₂l, SOCl₂, PCl₃, NaOH, KOH (in alcohol or aqueous solution), concentrated NH₃, primary amines, primary alcohols/H⁺, primary alcohols, H₂O/H⁺, H₂O/OH⁻ (Substitution reactions include esterification, condensation, hydrolysis, and polymerisation.)
- oxidation reactions using the following reagents: MnO₄⁻/H⁺, Cr₂O₇²⁻/H⁺, Tollens’, Fehling’s and Benedict’s. Reduction of aldehydes and ketones with NaBH₄
- elimination reactions using the following reagents: KOH in alcohol and concentrated H₂SO₄ (includes major and minor products from asymmetric alcohols and haloalkanes)
- polymerisation reactions of formation of polyesters and polyamides including proteins
- addition reactions of alkenes (used for the identification of the products of elimination reactions).
Appropriate information relating to other oxidants or reductants will be provided.

Physical properties of organic compounds will be limited to

- solubility
- melting point and boiling point
- rotation of plane-polarised light.

Special notes
Constitutional isomers are those that have the same molecular formula, but a different structural formula.
Systematic naming of amines is restricted to primary amines.
Candidates will not be expected to recall the common names of amino acids.
Knowledge of principles of organic chemistry covered in Chemistry Level 2 AS 91165 will be assumed.
1. **Functional groups – Naming and properties:** Alkanes, alkenes, haloalkanes (primary, secondary, tertiary), alcohol, amines, carboxylic acids, Aldehydes, ketones, acids chlorides, amides and esters

2. **Isomers:** cis/trans and optical isomers (enantiomers)

3. **Addition reactions** of alkenes: to alcohol (H₂O/H⁺) or haloalkane (PCl₅) using Markovnikov’s rule / major (2°) minor (1°)

Comparing Addition (Oxidation) of alkenes: alkene + MnO⁴⁻ → -dol OR alkene + H₂O/H⁺→ -ol

4. **Elimination reactions** of alcohol (conc H₂SO₄) /haloalkanes (alc KOH) : to alkenes Saytzeff’s rule (poor get poorer) major (-2-) /minor (-1-)

5. **Substitution reactions:**
   alcohols (SOCl₂) ⇌ haloalkanes (aq KOH)
   carboxylic acids → acids chlorides (PCl₅ or SOCl₂) reflux
   acid chlorides + ammonia → 1° amide + HCl (HCl + NH₃ → NH₄Cl)

6. **Oxidation reactions of alcohols:** 1° alcohol (+ MnO₄⁻) → aldehyde (distillation)
   aldehyde → carboxylic acids (reflux)
   2° alcohol (+ MnO₄⁻) → ketone

7. **Reduction reactions of aldehydes/ketones:** (NaBH₄) aldehyde → 1° alcohol / ketone → 2° alcohol

8. **Distinguishing tests/redox equations:** aldehyde positive for Tollens/Benedicts/permanganate
9. Acid/base reactions with Amines:  amine + water → conjugate + OH⁻  
amine + acid → salt + water

10. Acids base reactions with Carboxylic acids: carboxylic acid + base → salt + water (+ CO₂ if carbonate)

11. Esterification reactions: alcohol + carboxylic acid → ester (conc H₂SO₄) reflux with Na₂CO₃ and anhydrous MgSO₄

12. Esterification reactions of acid chlorides: acid chloride + alcohol → Ester + HCl

13. Hydrolysis reactions of esters: acid: ester → alcohol + carboxylic acid  
   base: (NaOH) ester → alcohol + salt

   base: amide + OH → carboxylate ion + + NH₃

15. Condensation polymerization: dicarboxylic + diol → polyester + water  
dicarboxylic + diamides → polyamide + water

16. Amino acids: forming dipeptides
Carbon has four valence electrons. The electronegativity of carbon is too small for carbon to gain electrons from most elements to form $C^{4-}$ ions, and too large for carbon to lose electrons to form $C^{4+}$ ions. Carbon therefore forms covalent bonds with a large number of other elements, including the hydrogen, nitrogen, oxygen, phosphorus, and sulfur. 

Organic chemistry is the chemistry of compounds that contain both carbon and hydrogen.
**Molecular Formula** – type and number of each atom.

i.e. Propane \( \text{C}_3\text{H}_8 \)

**Structural Formula** – placement of each atom.

**Condensed Structural Formula**

\[
\text{CH}_3-\text{CH}_2-\text{CH}_3
\]

Structural **isomers** are molecules with the same molecular formula but **different** structural formula.
Functional Groups – Alkene Derivatives

Alkanes

Alkenes

Alcohols

Primary | Secondary | Tertiary

Haloalkanes

1° Amines

2° and 3° Amines
Functional Groups – Carboxylic Derivatives

- **Carboxylic Acids**
  \[
  RCOOH
  \]

- **Ketones**
  \[
  R'CR
  \]

- **Esters**
  \[
  RCOOR'
  \]

- **Acid Chlorides**
  \[
  RCOCl
  \]

- **Aldehydes**
  \[
  RCHO
  \]

- **Amino Acid**
  \[
  \text{H} \quad \text{H} \quad \text{N} - \text{C} - \text{C} - \text{O} - \text{H}
  \]

- **Carboxylic salt**
  \[
  RCOO^-\]

- **Amide**
  \[
  RCONH_2
  \]
Compounds that contain only carbon and hydrogen are known as hydrocarbons. Those that contain as many hydrogen atoms as possible are said to be saturated. The saturated hydrocarbons are also known as alkanes.

Straight-chain hydrocarbons, in which the carbon atoms form a chain that runs from one end of the molecule to the other, i.e. butane.

Alkanes also form branched structures. The smallest hydrocarbon in which a branch can occur has four carbon atoms. This compound has the same formula as butane (C₄H₁₀), but a different structure, known as a structural isomer.
Chemical properties of Alkanes

1. **Non reactivity of alkanes** (in relation to acids, alkalis, metals, water, because they are non-polar molecules).
2. **Low melting and boiling points** – intermolecular forces are weak van der Waal forces.
3. **Odour** – hydrocarbons are volatile because they have weak intermolecular forces and they have characteristic smells.
4. Do not conduct heat or electricity.
5. As the C chain gets longer the hydrocarbons change from gas to liquid to solid.
6. Combustion of alkanes. Alkanes are very good fuels.
Prefixes are used to indicate number of carbon atoms in the longest carbon chain.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Number</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>meth</td>
<td>1</td>
<td><img src="image1" alt="meth" /></td>
</tr>
<tr>
<td>eth</td>
<td>2</td>
<td><img src="image2" alt="eth" /></td>
</tr>
<tr>
<td>prop</td>
<td>3</td>
<td><img src="image3" alt="prop" /></td>
</tr>
<tr>
<td>but</td>
<td>4</td>
<td><img src="image4" alt="but" /></td>
</tr>
<tr>
<td>pent</td>
<td>5</td>
<td><img src="image5" alt="pent" /></td>
</tr>
<tr>
<td>hex</td>
<td>6</td>
<td><img src="image6" alt="hex" /></td>
</tr>
<tr>
<td>hept</td>
<td>7</td>
<td><img src="image7" alt="hept" /></td>
</tr>
<tr>
<td>oct</td>
<td>8</td>
<td><img src="image8" alt="oct" /></td>
</tr>
<tr>
<td>non</td>
<td>9</td>
<td><img src="image9" alt="non" /></td>
</tr>
<tr>
<td>dec</td>
<td>10</td>
<td><img src="image10" alt="dec" /></td>
</tr>
</tbody>
</table>
Naming Alkanes

Write name as –

1. Identify the longest C chain
2. Identify any branches
3. Number the C atoms in longest chain
4. so branches are on the lowest numbers

5. Write the name
   1. Location of branch
   2. Name of branch
   3. Prefix of long chain
   4. -ane
IUPAC Rules for Alkane Nomenclature
1. Find and name the longest continuous carbon chain.
2. Identify and name groups attached to this chain.
3. Number the chain consecutively, starting at the end nearest a substituent group.
4. Designate the location of each substituent group by an appropriate number and name.
5. Assemble the name, listing groups in alphabetical order.
   The prefixes di, tri, tetra etc., used to designate several groups of the same kind, are not considered when alphabetising.

<table>
<thead>
<tr>
<th>methyl</th>
<th>ethyl</th>
<th>propyl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>-CH₃</td>
<td>-CH₂CH₃</td>
<td>-CH₂CH₂CH₃</td>
</tr>
</tbody>
</table>
Always make sure the longest possible chain of carbons – and therefore the shortest possible branches – is used.

3-ethyl-4-methylhexane

2,3-diethylpentane (incorrect)
Alkanes can also form cyclic molecules. These are named by placing cyclo- in front of the longest chain.

- cyclopropane
- cyclobutane
- cyclohexane
Alkanes are non-polar molecules and are bonded together by weak intermolecular forces. As the number of carbons increase so does the Molar Mass of the molecule. The larger the molar mass the more total valence electrons are available. These valance electrons can randomly cluster on one side or the other creating an instantaneous polar end – thereby creating a bond to another molecules instantaneous polar end. The greater the number of carbons, the stronger the bond between molecules therefore the higher the melting and boiling point.
**Functional Group** – One double carbon-carbon bond C=C
A *functional* group is the part of the molecule responsible for reactions typical of the homologous series.

**Alkene Nomenclature**
Alkenes are named in a similar way to alkanes, *but the longest continuous carbon chain is numbered to give the carbon atoms in the double bond the lowest possible numbers.*
The position of the double bond is given by the smaller number of the two carbon atoms involved.

After numbering the longest chain C1-C2=C3-C4, the compound is named 2-butene or but-2-ene, but not 3-butene nor but-3-ene.

**generic formula**
\[ C_nH_{2n} \]
Number carbons so double bond has the lowest number.

The Alkene shown above is found to be 4-methylhex-2-ene by numbering the chain C1-C2=C3-C4-C5-C6.
Alkanes and Alkenes: **Not soluble in water.** These molecules are non-polar (there is no negative or positive ends to the molecule) compared with water which is polar (having a negative area near the oxygen atom and positive area near the hydrogen atoms) so they are not attracted to each other. Alkanes and alkenes are **immiscible** (two or more liquids that will not mix together to form a single homogeneous substance) and form a distinct layer from the water. Smaller C chained alkanes and alkenes are less dense than water and float on top.

If either an Alkane or Alkene is mixed into water eventually the two liquids will form separate *immiscible* layers.
Named as a chloroalkane or bromoalkane etc, with the position of the halogen given by the appropriate number of the carbon that it is attached to in the chain.

The haloalkanes can be classified as

**Primary** $R\text{CH}_2\text{X}$ - the C atom to which X is attached is only attached to one other C atom

**Secondary** $R_2\text{CHX}$ - the C atom to which X is attached, is attached to two other C atoms

**Tertiary** $R_3\text{CX}$ - the C atom to which X is attached, is attached to three other C atoms.
Haloalkanes are classified according to the position of the halogen atom bonded in the molecule.

This leads to the existence of:

- primary (1°) – bonded to a C that is bonded to only 1 other C
- secondary (2°) – bonded to a C that is bonded to 2 other C
- tertiary (3°) – bonded to a C that is bonded to 3 other C

1-chlorobutane (1° haloalkane)

2-chlorobutane (2° haloalkane)

2-chloro-2-methylpropane (3° haloalkane)
<table>
<thead>
<tr>
<th>Atom</th>
<th>Name used in haloalkane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromine</td>
<td>Bromo</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Chloro</td>
</tr>
<tr>
<td>Fluorine</td>
<td>Fluoro</td>
</tr>
<tr>
<td>Iodine</td>
<td>iodo</td>
</tr>
</tbody>
</table>

2-bromo-2-methylpropane
**Background Knowledge**

**Naming Alkynes**

The Alkyne shown below is found to be 4-methylhex-1-yne by numbering the chain C1-C2-C3-C4-C5-C6.

Addition reactions of Alkynes are similar to Alkene

1. Location of branch
2. Name of branch
3. Prefix of long chain
4. Location of C=C
5. -yne

**First** break triple bond to double bond - adding atoms and forming Alkene

**Next** break double bond – adding atoms and forming Alkane
Alcohols are not considered hydrocarbons as they have one or more oxygen atoms attached in addition to the hydrogen and carbon atoms. Alcohols are organic substances however and share many of the same chemical and physical properties of the alkanes and alkenes. Alcohols are used as solvents and fuels and ethanol (a two carbon alcohol) is used as a drink.
Functional group is the hydroxyl group –OH (not a hydroxide)

**Naming alcohols**

1. Location of branch
2. Name of branch
3. Prefix of long chain
4. an-
5. Location of OH (if multiple di, tri, tetra)
6. -ol

**Alcohols** are classified according to the position of the hydroxyl group bonded in the molecule.

This leads to the existence of

- primary (1°) – bonded to a C that is bonded to only 1 other C
- secondary (2°) – bonded to a C that is bonded to 2 other C
- tertiary (3°) – bonded to a C that is bonded to 3 other C
Small alcohol molecules are polar and the presence of the OH group means they are able to undergo intermolecular **hydrogen bonding**. The large difference in electronegativity between the O and H atoms means the O-H bond is very polar and the slightly positive charge on this H atom is attracted to the non-bonding electron pairs of the oxygen on another molecule. This means small alcohol molecules are highly soluble in water. However as the length of the non-polar hydrocarbon chain increases this solubility in water decreases. Aqueous solutions are neutral. The presence of the OH group in this molecule is **NOT** the same as the OH- in sodium hydroxide, NaOH (an ionic compound).
Alcohols: **Soluble in water.** These molecules are polar (due to the –OH end) and water, also being polar, will bond with the alcohol. The alcohol molecules will therefore disperse and mix within the water molecules.

At the instant ethanol and water are mixed the ethanol floats on top of the water.

Because the attractions between their molecules are similar, the molecules mix freely, allowing each substance to disperse into the other.

Hydrogen bonds between ethanol molecules.

Hydrogen bonds between water molecules.

Hydrogen bonds between ethanol and water molecules.

Ethanol and water mix.
Summary of Boiling points

**Alkanes:** The smaller the alkane molecule the lower the boiling point and the more volatile (easier to combust) the alkane. As the molar mass (Mass number of all the atoms combined) increases, the boiling points also increase as the strength of the intermolecular (between molecules) attractions increases.
The alkanes methane to butane (C1 – C4) are all gases at room temperature
Alkanes with between 5C and 15C atoms are all liquids
Alkanes with over 15 C atoms are soft solids

**Alkenes:** The boiling point trend is similar to alkanes where the larger the number of C atoms in the chain the higher the boiling point. The equivalent length C chain alkene has a slightly higher point than that of the alkanes.

**Alcohols:** The boiling point trend is similar to both alkanes and alkenes where the larger the number of C atoms in the chain the higher the boiling point. The boiling point is higher than both alkanes and alkenes as the intermolecular bonding is stronger due to being a polar molecule— which creates a positive and negative end and hold the individual alcohol molecules together stronger and thus needs more energy to break them (heat energy)
Even small chain alcohols are liquid at room temperature
Amines are named as substituents e.g. aminomethane, CH$_3$NH$_2$. These may be classed as primary, secondary or tertiary, but their classification depends on the number of C atoms attached to the N atom. Primary RNH$_2$, secondary R$_2$NH, tertiary R$_3$N.

Amines have an unpleasant “ammonia” smell. The smaller amines, up to C5, are soluble in water but larger amino alkanes are insoluble, as the size of the non-polar hydrocarbon chain cancels out the effect of the polar amino (mainly due to lone pair of electrons on the N) functional group.
Naming Primary Amines

1. Write name as –
   1. Identify the longest C chain - Identify any branches
   2. Number the C atoms in longest chain so number Carbon 1 attached to amino group (NH₂)
   3. Write the name
      1. Location of branch
      2. Name of branch
      3. Amino-
      4. Prefix of long chain
      5. -ane
      e.g. 1-aminobutane (4C)

Alternative naming method

1. Identify the longest C chain - Identify any branches
2. Number the C atoms in longest chain so number Carbon 1 attached to amino group (NH₂)
3. Write the name
   1. Location of branch
   2. Name of branch
   3. Prefix of long chain
   4. -amine
   e.g. butanamine (4C)

Either will be accepted in NCEA assessments
Amines can be classified as $1^o$, $2^o$ or $3^o$ according to the number of R groups on the nitrogen. The N is a placeholder for a number as it is not off a carbon.

<table>
<thead>
<tr>
<th>$1^o$</th>
<th>1 R group on amino nitrogen (and 2H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2^o$</td>
<td>2 R groups on amino nitrogen (and 1H)</td>
</tr>
<tr>
<td>$3^o$</td>
<td>3 R groups on amino nitrogen (and no H)</td>
</tr>
</tbody>
</table>

If the amino group – NH$_2$ is not on the end carbon then name the compound as you would a branch. For example 2-amino ...

If the groups off the N are different then name each separately. For example N-ethyl – N-methyl

Systematic naming of amines is limited to primary amines.
**Bonding and physical properties**

**Intermolecular bonding** results from hydrogen bonding between the N-H groups as well as ID-ID attractions from the molecule.

**States**
- aminomethane and aminoethane are **gases**.
- Aminopropane and aminobutane are volatile **liquids** with fishy smells.
- Heavier aminoalkanes are **solids**.

**Solubility in water**
Lower molecular mass aminoalkanes are soluble in water due to hydrogen bonding. Solubility in water decreases as hydrocarbon portion increases.
Carboxylic Acids

Functional group is the carboxyl group –COOH

**Naming carboxylic acids**

1. Longest –C chain with -COOH
2. Identify branches
3. No. 1 C is the C in -COOH
4. Location of branches
5. Name branch
6. Prefix
7. -anoic acid

- polar molecules as short chains ~ non-polar molecules as long chains
- boiling points and melting points decrease with chain length
- turn blue litmus red (weakly acidic)
- conduct electricity
- react with metal to form salt and H₂
- react with metal oxides to form salt and H₂O
- react with metal carbonates to form salt and H₂O and CO₂
All the simple, straight-chain carboxylic acids up to ten carbons are liquids at room temperature. The liquids have sharp pungent odours and all have high boiling points. Smaller molecules, less than 10 carbons, are completely miscible in water due to the formation of hydrogen bonds with the water. The highly polar carboxylic acids dimerise in the liquid phase and in non-aqueous solvents (CCl₄) and form two hydrogen bonds between each pair. This extra degree of hydrogen bonding causes carboxylic acids to have higher boiling points compared to their corresponding alcohols.
Aldehydes are a class of organic compounds that are important in the manufacture of plastics, dyes, food additives, and other chemical compounds. Aldehydes have the general formula \(-\text{RCHO}\)

Where R is either a hydrogen atom, as in the case of formaldehyde, or an aromatic hydrocarbon group. Formaldehyde is used extensively in the chemical industry in the synthesis of organic compounds. Its most important use is in the manufacture of synthetic resins. Recent tests have indicated that it is a carcinogen.

\[
\begin{align*}
\text{C} & \quad \text{H} & \quad \text{O} \\
\text{O} & \quad \text{HCH} & \quad \text{CH}_3\text{CH} \\
\text{Formaldehyde} & \quad \text{Acetaldehyde (methanal)} & \quad \text{Acetaldehyde (ethanal)}
\end{align*}
\]
Functional group is the group – RCHO

Aldehydes are named by changing “-e” at the end of the alkane to “-al”.

The aldehyde group does not need to be numbered when naming an aldehyde as it must always be on the end carbon (carbon number 1). If there are other substituents in the molecule, then numbering is always from the aldehyde end of the chain.
Functional group is the group – (alkanones - RCOR')

Ketones are named by changing “-e” on alkanes to “-one”.

Ketones (apart from propanone and butanone where there is no choice) need a number to indicate the position of the carbonyl (C=O) group.

pentan-2-one
Ketones are a class of organic compounds of the general structure RCOR’, in which R and R’ represent organic radicals. The simplest ketone is acetone (CH₃COCH₃). Acetone is a product of the metabolism of fats, but under ordinary conditions, it oxidizes quickly to water and carbon dioxide. In diabetes mellitus, however, acetone accumulates in the body. Other ketones are camphor, many steroids, some fragrances, and some sugars. Ketones are relatively reactive organic compounds and thus are invaluable in synthesizing other compounds; they are also important intermediates in cell metabolism.
Carvone is a ketone that forms two optical isomers or enantiomers: (−) carvone smells like spearmint. Its mirror image, (+) carvone, smells like caraway. Humans have olfactory receptors in their noses, which can distinguish between the chiral ketones, allowing them to notice significant differences in smell between spearmint and caraway.
Summary of Alcohols, aldehydes, ketones and carboxylic acids

- **Primary alcohol**
  - Oxidant /distillation

- **Secondary alcohol**
  - Oxidant

- **Tertiary alcohol**
  - No Reaction

- **Aldehyde**
  - Oxidant /reflux

- **Ketone**
  - Oxidant /reflux

- **Carboxylic acid**
  - Oxidant /

Elements:
- C
- H
- O
Formed from carboxylic acids, with a -Cl replacing the –OH

Functional Group: -COCl

Naming
- suffix is “-oyl chloride”
- prefix is alkyl group including the carbon on the -COCl group
  e.g. “butan-”

Acid Chloride Properties
- low MPs and BPs as there is no H bonding on the functional group.
- liquids which fume in moist air and have an irritating smell (due to rapid hydrolysis reaction)
- They are very reactive with water
**Functional Group**  
-CONH$_2$ Formed from carboxylic acids with a –NH$_2$ substituting the -OH.

**Naming**
- suffix is “-anamide”
- prefix is alkyl group including the carbon on the –CONH$_2$ group e.g. “but-”

**Physical Properties**
- methanamide is liquid, the rest are odourless solids.
  (impure ethanamide smells like mice)
- The higher melting points are due to dimerisation caused by hydrogen bonding.

A **dimer** is a chemical entity consisting of two structurally similar subunits called monomers joined by bonds that can be either strong or weak.
Classification as $1^o$, $2^o$, $3^o$

1. **$1^o$** no alkyls and 2 hydrogens on N

\[
\text{R} - \text{C} \quad \text{NH}_2
\]

2. **$2^o$** 1 alkyl and 1 hydrogen on N

\[
\text{R} - \text{C} \quad \text{NH} - \text{R}'
\]

3. **$3^o$** 2 alkyls and no hydrogen on N

\[
\text{R} \quad \text{R}' 
\]

Amide classification
1. Indicate whether 1° - The N is only attached to one C group (no N in front of name)
2. Indicate whether 2° - The N is attached to 2 C groups (place an ‘N’ in front of the name)
3. Indicate whether 3° - The N is attached to 3 C groups (place an ‘N,N’ in front of the name)
4. Name the groups off the N (not the long ‘parent C chain’) as branches
5. Name the longest C chain
6. Suffix - anamide

\[ \text{N,N-dimethylethanamide} \]
Functional group is –COO–

**Naming esters**
1. Split between C-O bond
2. Identify name for side with –O–
3. Prefix of C chain
4. -yl
5. Identify name for side with C=O
6. Prefix of C chain
7. -anoate

Ethyl propanoate

Esters often have fruity or distinctive smells
Prepared by the process of esterification
Esters are chemical compounds responsible for the fruity smells present in processed food. Many natural flavours and smells are due to the presence of esters in flowers and fruits. The higher the molecular weight, the weaker the odours they carry are.

<table>
<thead>
<tr>
<th>alcohol</th>
<th>organic acid</th>
<th>ester made</th>
<th>smell of ester</th>
</tr>
</thead>
<tbody>
<tr>
<td>pentanol</td>
<td>ethanoic acid</td>
<td>pentyl ethanoate</td>
<td>pears</td>
</tr>
<tr>
<td>octanol</td>
<td>ethanoic acid</td>
<td>octyl ethanoate</td>
<td>bananas</td>
</tr>
<tr>
<td>pentanol</td>
<td>butanoic acid</td>
<td>pentyl butanoate</td>
<td>strawberries</td>
</tr>
<tr>
<td>methanol</td>
<td>butanoic acid</td>
<td>methyl butanoate</td>
<td>pineapples</td>
</tr>
</tbody>
</table>
**Question 1a:** Complete the table below by giving the IUPAC systematic name or the structural formula for each compound.

<table>
<thead>
<tr>
<th>Structural formula</th>
<th>IUPAC systematic name</th>
</tr>
</thead>
<tbody>
<tr>
<td>HO–CH₂–CH₂–C=O</td>
<td>3-hydroxy propanal / 3-hydroxyl propanal</td>
</tr>
<tr>
<td>CH₃CH₂C(\text{NH₂})=O</td>
<td>propanamide</td>
</tr>
<tr>
<td>CH₃C–CH₂–CH–CH₃(\text{O})</td>
<td>4-methyl pentan-2-one</td>
</tr>
</tbody>
</table>
**Question 1c:** Draw the structural formulae of three different isomers of which show the following properties:
- Isomer 1 turns moist blue litmus paper red.
- Isomer 2 is an ester.
- Isomer 3 is a ketone.

<table>
<thead>
<tr>
<th>Property</th>
<th>Structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>turns moist blue litmus paper red</td>
<td>( \text{CH}_3\text{CH}_2\text{C} = \text{O} )</td>
</tr>
<tr>
<td>is an ester</td>
<td>( \text{CH}_3\text{C} - \text{O} - \text{CH}_3 )</td>
</tr>
<tr>
<td>is a ketone</td>
<td>( \text{HO} - \text{CH}_2\text{C} - \text{CH}_3 )</td>
</tr>
</tbody>
</table>

\[ \text{HO} - \text{CH}_2\text{H} - \text{C} - \text{C} \text{H}_3 \]
The three alcohols are (structural) isomers / they have the same molecular formula but different structural formula.
Methyl propan-2-ol is a tertiary alcohol
Butan-2-ol is a secondary alcohol
Butan-1-ol is a primary alcohol
**Question 1(a):** Complete the table below giving the IUPAC systematic name or the structural formula for each compound.

<table>
<thead>
<tr>
<th>Structural formula</th>
<th>IUPAC systematic name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃ – CH – C – CH₃</td>
<td>3-chlorobutanone</td>
</tr>
<tr>
<td>CH₃ – CH₂ – CO – NH₂</td>
<td>propanamide</td>
</tr>
<tr>
<td>CH₃ – O – C – CH₂ – CH₂ – CH₃</td>
<td>methylbutanoate</td>
</tr>
</tbody>
</table>
**Question 1(a):** The structure of aspartame is given below. Aspartame is often used as an artificial sweetener in drinks. Identify the FOUR different functional groups within the aspartame molecule that are circled and numbered below:

**Answer:**
1. Carboxylic acid or carboxyl
2. Amine or aminoalkane
3. Amide
4. Ester
**Question 1(b):** Complete the table below by drawing the structural formula for the named compounds.

<table>
<thead>
<tr>
<th>IUPAC systematic name</th>
<th>Structural formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>propanoyl chloride</td>
<td>( \text{H}_3\text{CCH}_2\text{C} = \text{O} \text{Cl} )</td>
</tr>
<tr>
<td>3-bromopentan-2-one</td>
<td>( \text{H}_3\text{CCCHCH}_2\text{CH}_3 )</td>
</tr>
<tr>
<td>2-methylbutanal</td>
<td>( \text{H}_3\text{CCH}_2\text{CHC} = \text{O} \text{H} \text{CH}_3 )</td>
</tr>
</tbody>
</table>
**Question 1(c) (i):** In the boxes below, draw the three structural isomers of \( \text{C}_4\text{H}_9\text{Cl} \) that represent a primary, secondary and tertiary haloalkane.

<table>
<thead>
<tr>
<th>Primary haloalkane</th>
<th>Secondary haloalkane</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_3\text{C}–\text{CH}_2–\text{CH}_2–\text{CH}_2–\text{Cl} ) or ( \text{H}_3\text{C}–\text{CH}_2–\text{CH(\text{CH}_3)}–\text{Cl} )</td>
<td>( \text{H}_3\text{C}–\text{CH(\text{\text{Cl})}}–\text{CH}_2–\text{CH}_3 )</td>
</tr>
<tr>
<td><strong>Tertiary haloalkane</strong></td>
<td></td>
</tr>
<tr>
<td>( \text{H}_3\text{C}–\text{CCl(\text{\text{CH}_3})CH}_3 )</td>
<td></td>
</tr>
</tbody>
</table>
**Question 1a:** Complete the table below by drawing the structural formula for the named compounds.

<table>
<thead>
<tr>
<th>IUPAC systematic name</th>
<th>Structural Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>butylethanoate</td>
<td>![Structural formula for butylethanoate]</td>
</tr>
<tr>
<td>2-hydroxybutanal</td>
<td>![Structural formula for 2-hydroxybutanal]</td>
</tr>
<tr>
<td>ethanamide</td>
<td>![Structural formula for ethanamide]</td>
</tr>
</tbody>
</table>
**Question 1b:** The structure of amoxycillin is given below. It is an antibiotic used in the treatment of bacterial infections.

Name the four different functional groups circled within the amoxycillin molecule above.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hydroxyl (alcohol).</td>
</tr>
<tr>
<td>2</td>
<td>Amine / amino.</td>
</tr>
<tr>
<td>3</td>
<td>Amide / peptide.</td>
</tr>
<tr>
<td>4</td>
<td>Carboxylic acid.</td>
</tr>
</tbody>
</table>
**Question 2b:**
The structures of four different organic substances are shown in the table below. (i) Name the organic substances A to D.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Structure</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CH₃CH₂CH₂−NH₂</td>
<td>Propan-1-amine. (1-propanamine)</td>
</tr>
<tr>
<td>B</td>
<td>CH₃CH₂−C=H</td>
<td>Propanal.</td>
</tr>
<tr>
<td>C</td>
<td>CH₃CH₂−C=O</td>
<td>Propanoyl chloride.</td>
</tr>
<tr>
<td>D</td>
<td>CH₃−C−CH₃</td>
<td>Propan-2-one. (propanone)</td>
</tr>
</tbody>
</table>
**Question 1a:** Complete the table below to indicate the IUPAC name, functional group, and/or the structural formula for organic compounds that contain only four carbon atoms. The first row has been completed for you.

<table>
<thead>
<tr>
<th>Functional group</th>
<th>Structural formula</th>
<th>IUPAC (systematic) name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkene</td>
<td>CH₃CH₂CH=CH₂</td>
<td>but-1-ene</td>
</tr>
<tr>
<td>Amine</td>
<td>CH₂CH₂CH₂-N-H</td>
<td>2-methylpropan-1-amine</td>
</tr>
<tr>
<td></td>
<td>CH₃</td>
<td></td>
</tr>
<tr>
<td>Acyl chloride</td>
<td>CH₃CH₂CH₂Cl</td>
<td>butanoyl chloride 2-methylpropanoyl chloride</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Ester</td>
<td>H-C-O-CH₂CH₂CH₃</td>
<td>propyl methanoate</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Ketone</td>
<td>CH₃CH₂-C-CH₃</td>
<td>Butanone Butan-2-one</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Aldehyde</td>
<td>CH₃CH₂CH₂-C-H</td>
<td>Butanal 2-methylpropanal</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Amide</td>
<td>CH₃CH₂CH₂-C-NH₂</td>
<td>butanamide</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>
Two molecules are described as stereoisomers of each other if they consist of the same atoms, that are connected in the same sequence, but the atoms are positioned differently in space. The difference between two stereoisomers can only be seen from the three dimensional arrangement of the molecules. Stereoisomers are a type of isomer (variety). Stereoisomers can be subdivided into geometric isomers and optical isomers.

Examples: cis-Dichloroethene  trans-Dichloroethene  L-(+)
Lactic acid  D-(-)-Lactic acid
Alkenes can exist as geometrical or cis-trans isomers, a form of stereoisomerism. A simple example is but-2-ene.

To exist as geometrical isomers the C atoms at both ends of the double bond must each have two different groups (or atoms) attached. It is impossible for a 1-alkene to have geometric isomers since the first C atom in the chain has two identical H atoms.

NOTE:
(i) The cis or trans prefix must be included when naming these alkenes.
(ii) Bond angles around a double bonded C are 120°; and the shape is trigonal planar
(iii) Bond angles around the triple bonded C found in an alkyne are 180°, shape is linear.
Optical Isomers or Enantiomers
Optical isomers (like geometric isomers) are examples of stereoisomers. The enantiomer and its mirror image are non-identical. All amino acids, (except the simplest amino acid, glycine), are optically active. This means they contain an asymmetric, or chiral, carbon atom. This is a carbon atom, which has four different groups attached.
To show the different enantiomers of a molecule it is necessary to draw a 3-dimensional structure.
For any enantiomer, the structure of the mirror image can be drawn by swapping any two groups.
A chiral molecule is a type of molecule that lacks an internal plane of symmetry and has a non-superimposable mirror image. The feature that is most often the cause of chirality in molecules is the presence of an asymmetric carbon atom. The term chiral (pronounced in general is used to describe an object that is non-superimposable on its mirror image.

Achiral (not chiral) objects are objects that are identical to their mirror image. In chemistry, chirality usually refers to molecules. Two mirror images of a chiral molecule are called enantiomers or optical isomers. Pairs of enantiomers are often designated as "right-" and "left-handed."
Enantiomers have identical physical properties (melting point, solubility etc.) BUT differ in that they **rotate** plane polarised light in opposite directions.
Drawing Optical isomers

Optical isomers cannot be superimposed. If two of the groups are the same around the chiral carbon then the molecule can be turned 180° and be superimposed therefore it is not an optical isomer.

(a) Bromochlorofluoromethane

(b) Dichlorofluoromethane
Question 1b: (i) The alcohol below can exist as two enantiomers (optical isomers).

\[
\text{CH}_3\text{CHCH}_2\text{CH}_3
\]

\[
\text{OH}
\]

(i) Draw three-dimensional structures for the two enantiomers.

```

<table>
<thead>
<tr>
<th>Enantiomer 1</th>
<th>Enantiomer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (\text{C} \text{H}_3\text{C} \text{H}_2\text{OH} )</td>
<td>H (\text{C} \text{H}_5\text{C} \text{H}_3\text{OH} )</td>
</tr>
</tbody>
</table>
```

Question 1b: (ii) Link the structure of enantiomers to a physical property that can be used to distinguish them from non-optically active molecules.

Enantiomers exist for atoms containing a carbon atom with 4 different groups attached / Non-optically active substances do not have any carbon with 4 different groups attached. Enantiomers rotate (plane) polarised light in opposite directions.
Question 1c: (i) Glycine, alanine, and serine are three amino acids shown below.

Draw the 3-D structures of the enantiomers (optical isomers) of serine in the boxes below.
Question 1c: (ii) Which amino acid below does NOT display optical isomerism: Explain your answer

Glycine.
It does NOT have a chiral C, i.e. it needs four different groups around the central C atom, glycine only has three
**Question 1c: (i)** Some organic compounds can exist as enantiomers (optical isomers). An example is a secondary alcohol with the molecular formula $C_4H_9OH$. (i) Draw the enantiomers of $C_4H_9OH$ below.

![Diagram of enantiomers of $C_4H_9OH$]

**Question 1c: (ii)** Explain what is meant by the term enantiomers (optical isomers). In your answer, you should:
- identify the structural requirement for a molecule, such as $C_4H_9OH$, to exist as enantiomers
- explain how enantiomers can be distinguished from each other.

There must be a carbon atom that has **four different species (groups)** attached to it. This creates two molecules that are **mirror images** of each other that are **nonsuperimposable**. The different isomers will **rotate (plane)-polarised light in opposite directions**. This will distinguish the isomers.
**Reaction types (1)**

**Substitution** reactions are characterized by replacement of an atom or group (Y) by another atom or group (Z). Aside from these groups, the number of bonds does not change.

**Addition** reactions increase the number of bonds to the Carbon chain by bonding additional atoms, usually at the expense of one or more double bonds.

**Elimination** reactions decrease the number of single bonds by removing atoms and new double bonds are often formed.
**Reaction types (2)**

**Acid Base Reactions** involve the transfer of a proton from the acid to the base which produces a salt.

**Oxidation** reactions involve a loss of electrons from the organic molecule or a gain of oxygen. An oxidant such as dichromate or permanganate is used to make a diol (2 OH) or dilute acid to make an alcohol (1 OH).

**Polymerisation** reactions join monomers together to form a polymer. **Condensation polymerisation** removes a small molecule and joins monomers.
Alkene reactions

- **Dibromoalkane**
  - Addition halogenation

- **Alkenes**
  - Addition fast
  - Heat 300°C
  - Addition
  - Polymerisation
  - Addition

- **Alcohols**
  - Primary
  - Secondary
  - Tertiary

- **Haloalkanes**

- **Combustion**
  - O₂

- **Addition hydrogenation**
  - H₂ (N₂)

- **CO₂**
  - H₂O
Alkenes are **unsaturated** molecules, where not every carbon atom has the maximum amount of atoms bonded to it because it has one or more double bonds. If another atom is added to an alkene, the double bond can be broken down to a single bond and another atom can occupy the available site.

This reaction is known as an **addition** reaction. This reaction has a lower activation energy requirement than substitution, therefore it requires less energy to break a double bond than break a C-H bond, and it can proceed easier than a substitution reaction.
1. **Hydrogenation**
   \[ \text{Alkene} + \text{H}_2 \rightarrow \text{Alkane} \]

2. **Hydration**
   \[ \text{Alkene} + \text{H}_2\text{O} \rightarrow \text{Alcohol} \]

3. **Reaction with HCl**
   \[ \text{Alkene} + \text{HCl} \rightarrow \text{Haloalkane} \]

4. **Halogenation** (Bromine/Chlorine)
   \[ \text{Alkene} + \text{Halogen} \rightarrow \text{Haloalkane} \]

5. **Oxidation** (oxidant)
   \[ \text{Alkene} + \text{Halogen} \rightarrow \text{Haloalkane} \]
Asymmetric molecules such as HCl and H₂O can also be added to alkenes resulting in the formation of two possible products.

Markovnikov’s rule - sometimes called the “rich get richer” rule. The **major** product is the one in which the H atom of HBr attaches to the C atom with the **most** H atoms already.

As an easy way to remember: The Major is 2° product (larger) and minor is 1°.
Addition reactions increase the number of bonds to the Carbon chain by bonding additional atoms, usually at the expense of one or more double bonds.
Addition reactions increase the number of bonds to the Carbon chain by bonding additional atoms, usually at the expense of one or more double bonds.
Alkenes and alkynes undergo **addition** reactions - this means they can undergo addition of a halogen across the double (or triple) bond to form a di-haloalkane (or tetra-haloalkane).

The common test for an unsaturated hydrocarbon is therefore the **rapid** decolourisation of an orange solution of bromine. This occurs both in the presence or absence of sunlight (c.f. reaction of alkanes).

\[
\text{CH}_3\text{CH}=\text{CH}_2 + \text{Br}_2 \rightarrow \text{H}_3\text{C} - \text{C} - \text{CH}_2
\]

1,2-dibromopropane

An alternative test to distinguish alkenes from alkanes is the reaction of alkenes with potassium permanganate. In acid solution the purple permanganate ion, \(\text{MnO}_4^-\), is reduced to colourless manganese ion, \(\text{Mn}^{2+}\), while in neutral solution it is reduced to brown manganese dioxide, \(\text{MnO}_2\). Alkanes have no reaction with potassium permanganate so the solution remains purple.
Alkenes can also undergo an oxidation reaction (this could also be classified as an addition reaction). The reagent is an oxidant, potassium permanganate (acidified), $\text{MnO}_4^-/\text{H}^+$, performed under reflux conditions. The reaction creates a diol. Two hydroxyl groups join onto the carbons on either end of the broken double bond.

Compare this to the addition reaction that occurs with dilute acid added to an alkene. Only a single hydroxyl group is added to make an alcohol.
Addition (Oxidation) Reaction of Alkenes

Oxidation reactions involve a loss of electrons from the organic molecule or a gain of oxygen. An oxidant such as dichromate or permanganate is used to make a diol (2 OH) or dilute acid to make an alcohol (1 OH).

Oxidant

MnO$_4^-$ or Cr$_2$O$_7^{2-}$

Dilute

H$_2$SO$_4$ (H$_2$O/H$^+$)

C H O

Diol

Alcohol
Elimination Reactions decrease the number of single bonds by removing atoms and new double bonds are often formed. In **alcohols** the elimination reaction, using concentrated H₂SO₄ and heat, removes a H₂O molecule and forms an alkene. In **haloalkanes** the Halogen atom is removed and a double bond forms between the two carbon atoms. Elimination of Haloalkanes is favoured when the solvent used is less polar e.g. alcoholic (rather than aqueous) KOH. The reagent may be referred to as either ethanolic KOH, KOH / CH₃CH₂OH or OH⁻ in alcohol. The reaction also occurs more favourably with tertiary haloalkanes rather than primary.
When an elimination reaction occurs on a secondary haloalkane (with more than 3 carbons in the longest chain) then the H removed along with the halogen (Cl/Br) can come from either side. This produces 2 types of products; major or minor.

**Minor product** as the H is taken from the Carbon with the most hydrogen atoms.

**Major product** as the H is taken from the Carbon with the least hydrogens atoms (can be cis or trans).
Elimination of unsymmetrical Halo alkanes to form alkenes

Elimination reactions decrease the number of single bonds by removing atoms and new double bonds are often formed.

C H Br or Cl

KOH alcoholic

Minor

Major
Elimination reactions occur when the hydroxyl group (OH) plus a hydrogen from an adjacent (beside) carbon atom is removed. The OH and the H removed form a water molecule. The two carbons with the OH and H taken off join to form a double one. A concentrated sulphuric acid is used as the reagent. This type of elimination reaction is also known as a dehydration reaction because water is removed.
When an elimination reaction occurs on an *asymmetrical secondary* alcohol (with more than 3 carbons in the longest chain) then the H removed along with the OH can come from either side. This produces 2 types of products; major or minor.

**Minor product** as the H is taken from the Carbon with the most hydrogen atoms.

**Major product** as the H is taken from the Carbon with the least hydrogens atoms (can be cis or trans)
Elimination in secondary alcohols to form alkenes

Elimination reactions decrease the number of single bonds by removing atoms and new double bonds are often formed.

Concentrated $\text{H}_2\text{SO}_4$

minor

major
Question 2a: (ii) Butan-2-ol is converted to a mixture of but-1-ene and but-2-ene.

Reagent: conc H₂SO₄ / conc H₃PO₄ / Al₂O₃
Type of reaction – elimination / dehydration / condensation

Discuss the reaction occurring in (ii) above, with reference to the structures of the organic reactant and products.

Explanation:
- An elimination reaction occurs because the molecule has changed from saturated to unsaturated / a (C=C) double bond forms.
- Because water is removed / H and OH have been removed (from adjacent C atoms).
- The but-2-ene is the major product / but-1-ene is the minor product.
- A mixture of products is formed, because the two carbons adjacent to the carbon-bearing OH have different numbers of H atoms attached / it is asymmetric. (Zaitsev’s (Saytzeff’s) rule – the major product has the more substituted double bond)
Question 1(b) When butan-2-ol undergoes a reaction with concentrated $\text{H}_2\text{SO}_4$, three possible organic products form, which are isomers of each other.

\[
\text{CH}_3\text{CH}_2\text{CHCH}_3 \xrightarrow{\text{conc. } \text{H}_2\text{SO}_4, \text{heat}} \text{organic products}
\]

(i) Draw the three isomers formed during this reaction.
(ii) Which of the three isomers from part (i) will be formed in the smallest amount?

Answer: The minor product is but-1-ene.
Saytzeff’s rule: the minor product will have the least substituted double bond OR Saytzeff’s rule is explained.
Eg: the minor product is formed by the removal of the OH group and a hydrogen atom is removed from the carbon adjacent to the C-OH that has the most hydrogens.

in lowest concentration
Question 1(c) (ii) : Elaborate on the reactions occurring when each of the haloalkane isomers from (c)(i) reacts with KOH in alcohol.
In your answer you should include:
• the identification of ALL organic products formed
• an explanation of the type of reaction taking place
• reasons for the formation of any major and minor products.

Answer: Cl–CH₂–CH₂–CH₂–CH₃ → H₂C=CH–CH₂–CH₃

H₃C–CH(Cl)–CH₂–CH₃ → two possibilities:
1. Minor H₂C=CH–CH₂–CH₃ but-1-ene
H₃C–CCl(CH₃)CH₃ → C(CH₃)(CH₃)=CH₂

All reactions are **ELIMINATION** reactions as the Cl functional group and the hydrogen atom from the adjacent carbon atoms are removed.
(The molecule changes from saturated to unsaturated).
The secondary haloalkane produces major and minor products because the molecule is asymmetric OR it has two adjacent C atoms with different numbers of H atoms attached. The major product is formed when the H atom is removed from the adjacent C atom with the fewest H atoms attached, OR the major product has the most substituted double bond.
Substitution reactions do not change the number of single bonds. In haloalkanes the Halogen atom is removed and a hydroxyl (OH) group is substituted to form an alcohol. Substitution of Haloalkanes is favoured when the solvent used is polar eg. aqueous (rather than alcoholic) KOH.

The OH bonds with the same carbon that the halogen is removed from. A primary halogen will become a primary alcohol and a secondary halogen will become a secondary alcohol.

\[
\text{CH}_3\text{CH}_2\text{CHCH}_3 + \text{KOH} \rightarrow \text{CH}_3\text{CH}_2\text{CHCH}_3 + \text{KBr} \\
\text{Br} \quad \text{OH}
\]
Substitution reactions are characterized by replacement of an atom or group (Y) by another atom or group (Z). Aside from these groups, the number of bonds does not change.
Substitution - of the OH by a Cl\(^{-}\) or Br\(^{-}\) to form a haloalkane. This substitution removes the hydroxyl group (plus one hydrogen to form water) and replaces the bonding sites on the carbon with a halogen. This is called a nucleophilic substitution as the Br/Cl is attracted to the nucleus of the carbon atom.

An H\(^{+}\) ion is attracted to the polar OH end to create a greater positive charge. The negative Br\(^{-}\) or Cl\(^{-}\) now attacks and replaces the H\(_2\)O molecule removed forming a haloalkane.

Substitution Reactions

Alcohol Substitution to form haloalkane (nucleophilic substitution)
Lucas’ Reagent and substitution

**Lucas’ reagent** is a solution of zinc chloride in concentrated HCl, used to classify alcohols of low molecular weight. The reaction is a substitution in which the chlorine replaces the hydroxyl (OH) group.

The reagent dissolves the alcohol, removing the OH group, forming a carbocation. The speed of this reaction is proportional to the energy required to form the carbocation, so tertiary alcohols react quickly, while smaller, less substituted, alcohols react more slowly. The cloudiness observed is caused by the carbocation immediately reacting with the chloride ion creating an insoluble chloroalkane.

We can use these to identify whether an alcohol is primary, secondary or tertiary

The time taken for turbidity to appear is a measure of the reactivity of the class of alcohol with Lucas reagent, and this is used to differentiate between the three classes of alcohols:
- no visible reaction: **primary alcohol**
- solution turns cloudy in 3-5 minutes: **secondary alcohol**
- solution turns cloudy immediately: **tertiary alcohol**
Substitution (Nucleophilic) - of the OH (hydroxyl) by a Cl\(^{-}\) to form a chloroalkane. This substitution is faster for tertiary alcohols than for secondary, and slowest for primary alcohols. It is the basis of the **Lucas test** for distinguishing between small molecules of primary, secondary and tertiary alcohols. The reagent used is conc HCl and anhydrous ZnCl\(_2\) (called Lucas Reagent), and it is shaken with alcohol in a test tube at room temperature. The haloalkane formed is nonpolar and insoluble in the aqueous solution so forms a cloudy emulsion that separates out as two layers. For **tertiary alcohols** - solution rapidly goes cloudy and two layers form.

The ZnCl\(_2\) ‘pulls’ the OH\(^{-}\) away leaving the more positive C (carbocation) to attract the Cl\(^{-}\).
For **secondary alcohols** - solution slowly goes cloudy as the chloroalkane slowly forms and separates.

For **primary alcohols** - reaction is so slow a single layer containing unreacted alcohol remains.

Substitution of alcohols can also be carried out using PCl$_5$, PCl$_3$ and SOCl$_2$.

The haloalkane formed is nonpolar and insoluble in the aqueous solution so forms a cloudy emulsion that separates out as two layers.
Substitution reactions are characterized by replacement of an atom or group (Y) by another atom or group (Z). Aside from these groups, the number of bonds does not change.
Substitution reaction to form acid chlorides
Using SOCl₂ (not conc HCl), carboxylic acids undergo a substitution reaction under reflux conditions.

\[
\begin{align*}
\text{H}_3\text{C} & \quad \text{H}_3\text{C} \\
\text{C} & \quad \text{C} \\
\text{O} & \quad \text{O} \\
\text{OH} & \quad \text{Cl}
\end{align*}
\]

ethanoic acid \quad \text{ethanoyl chloride}

The acid chloride is named using the name of the parent alkane, but changing the final “-e” to “-oyl chloride”. The acid chloride formed reacts violently with water to produce the corresponding carboxylic acid. It is for this reason that conc HCl cannot be used to make an acid chloride as the concentrated acid consists of at least 60% water.
Substitution reactions are characterized by replacement of an atom or group (Y) by another atom or group (Z). Aside from these groups, the number of bonds does not change.

This reaction takes place under reflux conditions.
Reactivity
The C-Cl bond is highly polar. The carbon is $\delta^+$ and is readily attacked by nucleophiles causing substitution of the Cl. For this reason, acyl chlorides are useful for producing many chemicals. Addition of water to acyl chlorides results in a vigorous exothermic reaction.

$$\text{RCOCI} + \text{H}_2\text{O} \rightarrow \text{RCOOH} + \text{HCl}$$
Acid chloride react readily with Ammonia to form Amides

Acyl chlorides react readily with ammonia to form 1° amides.

\[
\text{RCOCl} + \text{NH}_3 \rightarrow \text{RCONH}_2 + \text{HCl}
\]

ammonia          1° amide

As HCl is produced in the reaction it reacts with unreacted NH\(_3\)

\[
\text{HCl} + \text{NH}_3 \rightarrow \text{NH}_4\text{Cl}
\]

Adding these two we find the overall reaction.

\[
\text{RCOCl} + 2\text{NH}_3 \rightarrow \text{RCONH}_2 + \text{NH}_4\text{Cl}
\]
Acyl chlorides react readily with 1º amines to produce 2º amides

\[
\text{RCOCl} + \text{R'NH}_2 \rightarrow \text{RCONHR'} + \text{HCl}
\]

acyl chloride  amine  2º amide

As HCl is produced in the reaction it reacts with unreacted amine.

\[
\text{HCl} + \text{R'NH}_2 \rightarrow \text{R'NH}_3\text{Cl}
\]

Adding these two reactions together we find the overall reaction.

\[
\text{RCOCl} + 2\text{R'NH}_2 \rightarrow \text{RCONHR'} + \text{R'NH}_3^+ \text{Cl}^- 
\]

acyl chloride  2º amide
Question 3c: When ammonia reacts with 

\[
\text{CH}_3\text{CHCH}_2\text{C}^\text{O} \quad \text{CH}_3\text{CH}_2\text{Cl}
\]

two products are formed.

Complete the equation below by naming compounds or drawing the structure.

Name: 3 methyl butanoyl chloride.

Ammonia + \[\text{CH}_3\text{CHCH}_2\text{C}^\text{O} \quad \text{CH}_3\text{CH}_2\text{Cl}\] → Structural formula of organic product:

Name of inorganic product:

\[\text{CH}_3\text{CHCH}_2\text{C}^\text{O} \quad \text{CH}_3\text{CH}_2\text{NH}_2\] + Hydrogen chloride / HCl / ammonium chloride / NH\(_4\)Cl
Question 2(b) Instructions for the preparation of 2-chloro-2-methylpropane are given below.
Read the instructions carefully and answer the questions that follow.
1. Shake 10 mL of 2-methylpropan-2-ol with 30 mL of concentrated hydrochloric acid in a separating funnel for 10 minutes.
2. Run off the bottom acid layer and discard it. Add saturated sodium hydrogen carbonate to the organic product. Shake, releasing the tap every few seconds to relieve the pressure.
3. Run off the bottom aqueous layer and discard it. Transfer into a conical flask and add some anhydrous sodium sulfate, and stir thoroughly.
4. Transfer the organic product into a round-bottom flask, and collect the fraction boiling within 2°C of the boiling point of 2-chloro-2-methylpropane.

(i) Explain why the solution of sodium hydrogen carbonate is added in instruction 2. Name the gas produced in this step.

Answer:
Gas = Carbon dioxide / CO₂
NaHCO₃ is used to remove any remaining acid mixed with the liquid product.
Question 2(b) (ii) Explain why anhydrous sodium sulfate is added in instruction 3.

Answer:
Na₂SO₄ is added to remove any remaining water mixed with the liquid product.

Question 2(b) (iii – v) Name the process used in instruction 4 to purify the organic product. Identify which piece of the equipment that a student would use to perform this process from the diagrams below.

Answer: *Fractional Distillation*. Equipment 1.
The purpose of the process is to purify the chemical / remove impurities / separate product. This is achieved by separating liquids according to their **boiling points**. Chemicals are boiled then condensed / liquid-gas then gas-liquid. The fraction at the desired boiling point is kept / other fractions are discarded.
Primary Alcohol Oxidation to form aldehyde and carboxylic acid

Aldehydes must always be prepared from Primary alcohols. Primary alcohols can be oxidized by mild oxidising agents, such as potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$), or potassium permanganate ($\text{KMnO}_4$) and distilled to yield aldehydes.

Further reacting with an oxidant under reflux conditions will yield a carboxylic acid.
Oxidation - using acidified KMnO₄ or acidified K₂Cr₂O₇. The type of product formed depends on whether the alcohol used in the oxidation reaction is primary or secondary.

Primary alcohols are oxidised to form aldehydes, which are then easily oxidised further to form carboxylic acids.

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{OH} & \rightarrow \text{CH}_3\text{CH} = \text{H} \rightarrow \text{CH}_3\text{C}-\text{O} = \text{H} \\
\text{ethanol} & \rightarrow \text{ethanal} & \rightarrow \text{ethanoic acid}
\end{align*}
\]

When using acidified dichromate in this redox reaction, the Cr₂O₇²⁻ is reduced to Cr³⁺, and the colour changes from orange to green. This colour change was the basis for the chemical reaction in the old “blow in the bag” breathalyser test.

When using acidified permanganate in this redox reaction, the MnO₄⁻ is reduced to Mn²⁺, and the colour changes from purple to colourless.
Oxidation reactions involve a loss of electrons from the organic molecule or a gain of oxygen. An oxidant such as dichromate or permanganate is used to make an aldehyde.
A primary alcohol is oxidised to an aldehyde. The aldehyde can be further oxidised by exactly the same reagent to a carboxylic acid, so it is important to remove it from the reaction vessel immediately. This is possible as the aldehyde has a much lower boiling point than both the alcohol and carboxylic acid. The reaction is performed in a distillation flask above the boiling point of the aldehyde and below the boiling point of the other compounds and the aldehyde is allowed to distil off as it is formed.
An Aldehyde can be further oxidised to produce Carboxylic acid. (the Carboxylic acid can also be prepared directly from the primary alcohol). The process requires the use of reflux apparatus. The aldehyde (or alcohol solution) is heated until it forms the carboxylic acid but the water jacket condenser prevents the aldehyde escaping as vapour – which has a lower boiling point than the Carboxylic acid that has Hydrogen bonding.
Oxidation - using acidified KMnO$_4$ or acidified K$_2$Cr$_2$O$_7$

Secondary alcohols are oxidised to form ketones, which do not oxidise further.

Tertiary alcohols do not oxidise
Oxidation reactions involve the loss of electrons from the organic molecule or a gain of oxygen. An oxidant such as dichromate or permanganate is used to make a ketone.
Question 2b: Discuss the laboratory procedures used to convert butan-1-ol into butanal, and butan-1-ol into butanoic acid. In each discussion, you should:
• outline the process for each conversion
• state and justify the type of reaction occurring
• identify the reagents used, and explain any observations made.

Aldehyde (Butanal) is obtained by distillation of butan-1-ol with acidified (potassium) dichromate / (acidified potassium) permanganate solution. (Distillation) is used because the aldehyde has a lower boiling point (than butan-1-ol and the carboxylic acid formed) / to prevent it from being oxidised further. (Both) reactions are oxidation–reduction because butan-1-ol has lost electrons/lost hydrogen/gained oxygen/oxidation number (of C) has increased.

Carboxylic acid (butanoic acid) is obtained by reacting a mixture of butan-1-ol with acidified potassium dichromate solution (under reflux conditions) until all of the reactant has been converted to butanoic acid.

Observations: orange \( \text{Cr}_2\text{O}_7^{2-} \) to green /, purple \( \text{MnO}_4^- \) to colourless / aldehyde condensed in the condenser.
Reduction of Aldehydes and Ketones - NaBH₄ (sodium borohydride) - reduce aldehydes to primary alcohols and ketones to secondary alcohols. This is considered a reduction reaction because the amount of Hydrogen increases. Sometimes LiAlH₄ (lithium aluminium hydride) can also be used as a reductant.
Reduction of Aldehydes and Ketones with NaBH\(_4\)

In this Reduction reaction we are breaking a C-O bond and replacing it with a C-H bond. This is what helps us classify the reaction as a reduction. Note that we also form an O-H bond. In order to make the alcohol, the oxygen needs to pick up a proton (H\(^+\)) (called pronation) from either water or acid that is added after the reaction is complete.
Question 2a: (i) What reagent can be used to reduce aldehydes and ketones?

Sodium borohydride / NaBH₄ (accept LiAlH₄)

<table>
<thead>
<tr>
<th></th>
<th>Structure of the product:</th>
<th>Functional group:</th>
</tr>
</thead>
<tbody>
<tr>
<td>pentanal</td>
<td>CH₃CH₂CH₂CH₂CH₂CH₂OH</td>
<td>Pentanal will produce a primary alcohol / pentan-1-ol.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pentan-2-one</td>
<td>CH₃CH₂CH₂CH₃CHCH₃OH</td>
<td>Pentan-2-one will produce a secondary alcohol / pentan-2-ol.</td>
</tr>
</tbody>
</table>
Oxidation of aldehydes
Aldehydes are readily oxidised by even mild oxidising agents such as Ag+ and Cu²⁺, which are too weak to oxidise alcohols. Like alcohols they are also oxidised by acidified potassium dichromate and acidified potassium permanganate. In contrast, ketones are not oxidised, and this means that they can readily be distinguished by observing the reaction with an oxidising agent.

Tollens’ test
If Tollens’ reagent (a colourless solution [Ag(NH₃)₂]⁺ ) is heated with an aldehyde a redox reaction occurs, which produces a silver mirror on the inner surface of the test tube. The aldehyde is oxidised to a carboxylic acid.

The reduction half-equation is
\[
\text{Ag}^+ (aq) + e^- \rightarrow \text{Ag}(s)
\]

If Tollens’ reagent is heated with a ketone or an alcohol no reaction occurs. This means there would be no observed colour change and no formation of a silver mirror.
Tests to distinguish between Aldehydes and Ketones

**Benedict's test** - Benedict’s reagent is an alkaline solution containing a copper(II) citrate complex ion. When Benedict’s solution is heated with an aldehyde, the \( \text{Cu}^{2+} \) complex ion acts as an oxidising agent, and the blue complex of \( \text{Cu}^{2+} \) is reduced to a **brick red precipitate of \( \text{Cu}_2\text{O} \)**. When heated with a ketone (or an alcohol), Benedict’s solution does not react and remains blue.

**Fehling's test** - Fehling's solution is an alkaline solution containing a deep blue complex ion of \( \text{Cu}^{2+} \) (copper(II) tartrate complex ion). It is also reduced to red \( \text{Cu}_2\text{O} \) when heated with an aldehyde, but has no reaction with ketones (or alcohols).
Distinguishing tests - Aldehyde/Ketone Reactions

We can use these to identify whether the molecule is an Aldehyde or Ketone.

<table>
<thead>
<tr>
<th>Testing Reagent</th>
<th>observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium permanganate</td>
<td>Oxidises into carboxylic acid Purple to colourless</td>
</tr>
<tr>
<td>Tollens’ reagent [Ag(NH$_3$)$_2$]$^+$</td>
<td>Oxidise aldehydes (but not alcohols) Silver ‘mirror’ forms</td>
</tr>
<tr>
<td>Benedict’s solution</td>
<td>Oxidises aldehydes (but not alcohols) to form Cu$^+$ ions Red/brown ppt forms</td>
</tr>
</tbody>
</table>
Identify whether each reactant is a ketone or aldehyde and the expected observations in each of the following reactions. In some cases there will be no reaction.

(a) Methanal is heated with Tollens reagent. Aldehyde so Silver mirror forms around the outside of the test tube. (aldehyde oxidises to a Carboxylic acid)

(b) Hexan-2-one is heated with Benedict’s reagent. Ketone so no reaction

(c) Propanone is reacted with acidified potassium permanganate. Ketone so no reaction

(d) 2-methylpropanal is heated with $\text{Cr}_2\text{O}_7^{2-}/\text{H}^+$. Aldehyde so solution reduces from Orange dichromate into green chromium ions ($\text{Cr}^{3+}$). (aldehyde oxidises to a Carboxylic acid)

(e) 3-methylpentanal is reacted with Benedict’s reagent. Aldehyde so blue solution turns orange. (aldehyde oxidises to a Carboxylic acid)

(f) Butanone is heated with Tollens reagent. Ketone so no reaction.
Question 3a:(ii) Describe how you could distinguish between the alcohols in (i) above, using chemical tests on the alcohols and / or their oxidation products.

- Butan-1-ol is oxidised using permanganate / acidified dichromate, 
  EITHER
  forming an aldehyde which can be identified using Tollens’, silver mirror forms / Benedict’s or Fehling’s solution.
  OR
  forms brick red precipitate / forming a carboxylic acid, which can be identified turning (moist) blue litmus paper red.
- Butan-2-ol is oxidised to a ketone with permanganate / acidified dichromate, but this does not give a positive test using Tollens’ or Benedict’s.
- Methyl propan-2-ol does not react with oxidising agents, permanganate remains purple / dichromate remains orange.

*Lucas test may be accepted with correct explanation. (anhydrous) ZnCl₂ and conc HCl
Solution goes cloudy / layers form: Tertiary in seconds
:Secondary in minutes
:Primary in hours / no reaction.*
**Question 2c:** Devise a method for distinguishing between the three liquid compounds, butan-1-ol, butanoic acid, and butanoyl chloride, using only blue litmus paper and water. Explain each of the observations in your method, with reference to the structure of the organic compounds.

Add to water then test with blue litmus paper

The butan-1-ol will not react with water nor change the colour of the moistened litmus paper.

The butanoic acid will change the moistened blue litmus paper to red.

The butanoyl chloride will react violently with the water.

Carboxylic acids react with water to form hydronium ions / equation

\[
\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^- + \text{H}_3\text{O}^+
\]

Acyl chlorides react with water to form carboxylic acids and hydrogen chloride / equation

\[
\text{CH}_3\text{CH}_2\text{CH}_2\text{COCl} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} + \text{HCl}
\]
Question 2(a): (iv) Explain why the equipment to the right is used for hydrolysis of the triglyceride.

(i) Aqueous solutions of propanamine and propanamide.

**Answer:** *Damp red* litmus.

Propanamine will change the colour of *red* litmus blue.

Propanamide will not change the colour of *red* litmus.

(ii) Propanone and propanal.

**Answer:** Tollens’ reagent (Fehling’s or Benedict’s or Cr$_2$O$_7^{2-}$/H$^+$ or MnO$_4^-$/H$^+$). Propanal will form a silver mirror when *warmed* with Tollens’ reagent. Propanone will not react with Tollens’ reagent.

(iii) Propanoyl chloride and propyl propanoate.

**Answer:** Water.

Propanoyl chloride will react violently with water.

Propyl propanoate with not react with water / it will form layers.
Question 2b: Explain how you would identify each of the organic substances, A to D, from the table in (b)(i), using only moist litmus paper, water, and Benedict’s solution. In your answer, you should include:
• a description of any tests carried out and any observations you would make
• equations to show the organic products formed, if applicable.
A: Propan-1-amine. (1-propanamine)
B: Propanal.
C: Propanoyl chloride.
D: Propan-2-one. (propanone)

A: Propan-1-amine (a primary amine)
CH₃CH₂CH₂NH₂ (propan-1-amine) will turn moist red litmus paper blue as it is basic.
CH₃CH₂CH₂NH₂ + H₂O → CH₃CH₂CH₂NH₃⁺ + OH⁻
Water: Dissolves in water.
Benedict’s solution will stay blue as primary amines do not react with Benedict’s reagent.
NCEA 2016 Distinguishing tests Continued...

**B: Propanal (An aldehyde)**
Damp Litmus: No colour change.
Water: Dissolves in water.
Propanal will react with Benedict’s reagent, with the blue solution forming a (copper mirror) / brick red precipitate. Propanoic acid is formed.
\[ \text{CH}_3\text{CH}_2\text{CHO} \rightarrow \text{CH}_3\text{CH}_2\text{COOH} \]

**C: Propanoyl chloride (An acyl chloride)**
Damp Litmus: Turn blue litmus red
Water: Propanoyl chloride will react vigorously with water to produce propanoic acid and hydrogen chloride.
\[ \text{CH}_3\text{CH}_2\text{COCl} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{COOH} + \text{HCl} \]
Benedict’s solution will stay blue as the acyl chloride does not react with the Benedict’s, but instead reacts with the water present in the Benedict’s solution.

**D: Propan-2-one (A ketone)**
CH₃COCH₃ (propan-2-one)
Damp Litmus: No colour change.
Water: Dissolves in water.
Benedict’s solution: No reaction, so stays blue.
Question 2b (i): Adding an acidified potassium dichromate solution to propan-1-ol can produce either propanal or propanoic acid. Explain the laboratory procedure used to convert propan-1-ol to propanal. In your answer, you should:
• outline the procedure for the conversion, and describe any colour changes linked to the species involved
• state the type of reaction occurring
• explain how the procedure ensures only propanal is collected.
Aldehyde (propanal) is obtained by distillation of propan-1-ol with acidified (potassium) dichromate (Cr₂O₇²⁻ / H⁺). The orange colour of the Cr₂O₇²⁻ / H⁺ changes to (blue) green (Cr³⁺ ions). The reaction is an oxidation reaction. Distillation is a way to separate the aldehyde (propanal) from the reactant alcohol (propan-1-ol) which has a higher boiling point. The aldehyde (propanal) can react further to form a carboxylic acid (propanoic acid). This reaction is prevented if the aldehyde is removed as it is formed – distillation achieves this by evaporating the aldehyde and then allowing it to condense for collection.
Question 2b (ii) : Explain how Benedict’s solution can be used to distinguish between propanone and propanal.
In your answer, you should include:
• any observations made linked to the organic compounds involved
• the type of reaction occurring
• relevant equations showing any organic reactants and products involved.
Question 2b (ii): Explain how Benedict’s solution can be used to distinguish between propanone and propanal.
In your answer, you should include:
• any observations made linked to the organic compounds involved
• the type of reaction occurring
• relevant equations showing any organic reactants and products involved.

Adding blue Benedict’s solution to a warmed / heated sample of propanal will cause a (brick) red colour to form. This happens because the propanal has been oxidised to propanoic acid / carboxylic acid (red colour is copper(I) oxide).

\[
\text{CH}_3\text{CH}_2\text{CH} + \text{Benedict’s reagent} \xrightarrow{[\text{O}]} \text{CH}_3\text{CH}_2\text{COH}
\]

No change will occur when blue Benedict’s solution is added to propanone, as it cannot be further oxidised / won’t react.
With water - Amines behave like ammonia due to a lone pair of e- proton acceptors (i.e. bases)
Like ammonia itself, water soluble amines form alkaline solutions. They react with water by proton transfer to form OH- ions. This means aqueous solutions of amines turn litmus blue.

\[
\text{RNH}_2 + \text{H}_2\text{O} \rightarrow \text{RNH}_3^+ + \text{OH}^-
\]

With an acid - Amines also react with acids to form salts.

\[
\text{CH}_3\text{NH}_2 + \text{HCl} \rightarrow \text{CH}_3\text{NH}_3^+ \text{Cl}^-
\]

aminomethane
methyl ammonium chloride
Acid/base reactions in Amines

The formation of an ionic salt increases the solubility of the amine in acidic solutions (compared to their solubility in water). This change in solubility can be used to separate amines from other organic compounds. The formation of the salt also results in the disappearance of the obnoxious smell of the amine, which explains why lemon juice is often provided with fish meals.

Amines are made by the substitution reaction between $\text{NH}_3$ and haloalkanes, but the reaction is carried out using alcohol as a solvent rather than water.

This reaction can occur in solution, or in the air as vapours given off solutions of both chemicals meet and combine to form a smoke. This smoke is made of the salt in solid form.
Act as ligands, forming complex ions with transition metal ions.
e.g. \( \text{Cu}^{2+}(aq) + 4\text{NH}_3(aq) \leftrightarrow [\text{Cu(NH}_3)_4]^{2+}(aq) \)
   pale blue
tetraamminecopper(II)
   complex ion

\( \text{Cu}^{2+}(aq) + 4\text{CH}_3\text{NH}_2(aq) \leftrightarrow [\text{Cu(CH}_3\text{NH}_2)_4]^{2+}(aq) \)
   pale blue
depth blue
tetra
   aminomethanecopper(II)

Nucleophiles (due to lone pair of e-)
They attack the \( \delta^+ \) carbon of a haloalkane.
Carboxylic Acids are Weak Acids and are **proton donors in water**

Carboxylic acids act as a weak acid by partially dissociating and **neutralising** bases:

For example

\[ \text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COO}^-\text{Na}^+ + \text{H}_2\text{O} \]
Acid/base reactions with Carboxylic Acids

Carboxylic Acids

\[ RCOOH \]

Carboxylic ion

\[ RCOO^- \]

Acid + Base → Carboxylic salt + \( NH_4^+ \)

Carboxylic acid also have similar reactions to other acids

- Carboxylic acid + carbonate → carboxylic salt + water + carbon dioxide
- Carboxylic acid + metal → carboxylic salt + hydrogen gas
- Carboxylic acid + oxide → carboxylic salt + water

React with magnesium to give hydrogen gas (a useful test)

\[ CH_3COOH + Mg \rightarrow Mg(CH_3COO)_2 + H_2(g) \]

React with calcium carbonate to give \( CO_2(g) \) (a useful test)

\[ CH_3COOH + CaCO_3 \rightarrow Ca(CH_3COO)_2 + CO_2(g) + H_2O \]
Naming salts.
The amine ion effectively becomes an ammonium ion – and acts as the cation in forming the ionic salt. The organic group attached to it becomes a “branch” and is named as such. i.e. CH₃NH₃⁺ becomes methyl ammonium

The carboxylic ion becomes the anion and takes on the suffix -anoate. i.e CH₃COO⁻ becomes methanoate

Therefore a salt made of the 2 ions CH₃NH₃⁺ CH₃COO⁻ is called methyl ammonium methanoate
Acid Chloride reactions

Choice of chlorinating agent. By choosing the correct chlorinating agent, the products will be easier to separate by fractional distillation. e.g. If PCl₅ was used to chlorinate butanoic acid, the products butanoyl chloride (B.P. 102°C) and phosphorous oxychloride POCl₃ (B.P. 103°C) would be difficult to separate.

Condensation (or dehydration) reactions are a type of elimination reaction where a molecule of water is removed) – in esterification OH is removed from alcohol and O from a carboxylic acid and they are joined to form an ester.

Substitution reactions are characterized by replacement of an atom or group (Y) by another atom or group (Z). Aside from these groups, the number of bonds does not change.
Esterification is a *condensation* reaction that combines a carboxylic acid and an alcohol, where a water molecule is removed.

The carboxylic acid and alcohol are *refluxed* with concentrated sulphuric acid.

After reflux, *sodium carbonate* is added to neutralise any excess acid and *anhydrous magnesium sulfate* MgSO$_4$ is added to remove water.

Because of the volatility of esters, they are then readily separated from the reaction mixture by fractional distillation.
Esterification with Carboxylic Acid and alcohols to form Esters

Condensation (or dehydration) reactions are a type of elimination reaction where a molecule of water is removed) – in esterification OH is removed from alcohol and O from a carboxylic acid and they are joined to form an ester

This reaction takes place under reflux conditions
Ester Reactions - Esterification (Acid)

Carboxylic Acid + alcohol \xrightarrow{\text{Heating and H}_2\text{SO}_4} \ Ester + water
Acid Chlorides React readily with alcohols to produce esters

$$\text{RCOCI} + \text{R’OH} \rightarrow \text{RCOOR’} + \text{HCl}$$

The acid chloride is dropped into pure alcohol, (in fume cupboard, because $\text{HCl}_{(g)}$ is produced). Reaction is fast, yield is high, no heat or catalyst required.
Hydrolysis reactions involve water as a reactant and becomes part of the reaction product. Hydrolysis ‘spits’ the ester bond (C-O-C) and the ester breaks into the ‘original’ alcohol and the carboxylic acid. These two products will remain if under acid conditions. When under base conditions then the carboxylic undergoes a further reaction with the base to form a salt (+water)
Hydrolysis with Esters

Ester + sodium hydroxide → Alcohol + sodium carboxylic acid

Butyl propanoate + NaOH → butanol + Sodium propanoate
Triglycerides

Glycerol (triol) + 3 long carboxylic acids (fatty acids) → triglyceride

GLYCEROL

H - O - C - C - C - O - H
\(\text{propan,-1,2,3-triol}\)

Fatty acid

Fatty acid

Fatty acid

Triglycerides are naturally found in animal fats and seed and nut oils

Saponification

Triglycerides heated with NaOH produce soap + glycerol
Fats and oils are “triesters”
*e.g. glycerol tristearate*
a saturated fat found in many animal and vegetable fats such as tallow (animal fat).
Hydrolysis of fats or oils with ethanolic aqueous sodium hydroxide produces glycerol and the sodium salt of the fatty acid.
Hydrolysis Reactions of Amides

**Acid hydrolysis** produces the carboxylic acid and ammonium ions.

\[ \text{RCONH}_2 + \text{H}_3\text{O}^+ \rightarrow \text{RCOOH} + \text{NH}_4^+ \]

**Base hydrolysis** produces the carboxylate ion and ammonia.

\[ \text{RCONH}_2 + \text{OH}^- \rightarrow \text{RCOO}^- + \text{NH}_3 \]

You distinguish an amide from an amine by adding NaOH. Only the amide releases NH₃.
Question 1d: Give the structures and names of the products of the reactions below. These reactions are carried out by heating in either:
- dilute hydrochloric acid solution, or
- dilute sodium hydroxide solution.

<table>
<thead>
<tr>
<th>In acidic conditions</th>
<th>the products are:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Structure" /></td>
<td>CH$_3$CH$_2$CH$_2$OH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In basic conditions</th>
<th>the products are:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Structure" /></td>
<td>CH$_3$CH$_2$CH$_2$OH</td>
</tr>
</tbody>
</table>

Name: methanoic acid
Name: sodium methanoate / methanoate ion
**Question 1d:** Compare and contrast the reactions below. In your answer, you should include the type of reaction(s) taking place.

The ester link is hydrolysed in both acid and basic conditions. Both produce an alcohol. Acidic hydrolysis produces an acid and basic hydrolysis produces a base or salt. Following hydrolysis in sodium hydroxide, an acid-base reaction occurs to form the sodium salt and water. (No further reaction occurs in acid.)

---

<table>
<thead>
<tr>
<th>Acidic Conditions</th>
<th>Basic Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **In acidic conditions:** Products are methanoic acid and propan-1-ol.
- **In basic conditions:** Products are sodium methanoate and propan-1-ol.
**Question 1(c):** (i) The triglyceride below is shown in condensed form. Circle a functional group on the diagram above and give its name.

(ii) Compare and contrast the reaction of the triglyceride when it undergoes both acidic and basic hydrolysis. In your answer you should include:
- drawings of condensed structures of the organic products
- any reagents and conditions required for the reaction to proceed.

**Answer:** Both acidic and basic hydrolysis produce the same alcohol *propan-1,2,3-triol*. In addition, they both require heat / reflux. In contrast, acidic hydrolysis requires $\text{H}_2\text{O} / \text{H}^+$ or $\text{HCl}(aq)$ and produces the carboxylic acid, whereas basic hydrolysis requires $\text{H}_2\text{O} / \text{OH}^-$ or $\text{NaOH}(aq)$ and produces the carboxylate ion/salt.
Question 3(a): (a) A triglyceride has the following structure:

CH₂−OOC−(CH₂)₇−CH=CH−(CH₂)₇−CH₃

CH−OOC−(CH₂)₇−CH=CH−(CH₂)₇−CH₃

CH₂−OOC−(CH₂)₁₄−CH₃

(i) Circle one of the alkene groups in the triglyceride molecule.
This triglyceride is described as unsaturated.

(ii) Describe a chemical test that can be used to show that the molecule is unsaturated. Give any observations, and state the type of reaction occurring.

Answer:
Bromine water rapidly decolourised from red or orange to colourless in an addition reaction.
OR
Acidified permanganate rapidly decolourised from purple to colourless in a redox or oxidation or reduction reaction.
Question 3(a): (iii) Draw the structural formulae of the organic products formed by hydrolysis of this triglyceride using aqueous sodium hydroxide.

Answer:

\[
\text{NaOOC(CH}_2\text{)}_7\text{CH=CH(CH}_2\text{)}_7\text{CH}_3 \\
\text{NaOOC(CH}_2\text{)}_{14}\text{CH}_3
\]
**Question 3(a):** (iv) Explain why the equipment to the right is used for hydrolysis of the triglyceride.

**Answer:**
Reflux - Increases the rate of reaction; (Condensing) prevents volatile chemicals from being lost to the environment, (The mixture refluxed to increase reaction rate without loss of product through evaporation).
Question 3c: A triglyceride found in olive oil has the following structure below:

(i) Put a **circle** around one of the ester groups in the triglyceride molecule shown above.
(ii) Draw the structural formulae of the products produced by the hydrolysis of this triglyceride in basic conditions, using aqueous sodium hydroxide, NaOH.

\[ \text{CH}_2\text{OOC}-(\text{CH}_2)_7\text{CH}=\text{CH}-(\text{CH}_2)_7\text{CH}_3 \]

\[ \text{CH}_2\text{OOC}-(\text{CH}_2)_7\text{CH}=\text{CH}-(\text{CH}_2)_7\text{CH}_3 \]

\[ \text{CH}_2\text{OOC}-(\text{CH}_2)_{14}\text{CH}_3 \]

\[ \text{CH}_2\text{OH} \]

\[ \text{CHOH} \]

\[ \text{CH}_2\text{OH} \]

\[ \text{NaOOC}-(\text{CH}_2)_7\text{CH}=\text{CH}-(\text{CH}_2)_7\text{CH}_3 \]

and

\[ \text{NaOOC}-(\text{CH}_2)_{14}\text{CH}_3 \]
Condensation reactions involve the elimination of water. Polymerisation involves smaller units called monomers joining together to form larger molecules or chains called polymers. There are two main types of condensation polymers – **Polyesters** - the monomers consist of a di-carboxylic acid (a COOH at each end) and a diol (an –OH at each end). These monomers join together at each end to form an ester bond. The CA and the alcohol then continue joining in repeating patterns. **Polyamide** – the monomers consist of an amide and a di-carboxylic acid.
A carboxyl group (carbon with a double bonded oxygen such as carboxylic acid) and an amino group (with a NH₂ attached to the carbon chain such as an amide or amine) can react together to form an amide or **peptide** link (–CONH) through condensation polymerisation – as a water molecule is released to form each link.

e.g. Nylon-6,6

**Preparation:**
Condensation polymerisation of a diamine and a dicarboxylic acid

---

**Polyamide - Nylon**

![Polyamide - Nylon diagram](image_url)
A polyamide is a polymer containing monomers of amides joined by peptide bonds. They can occur both naturally and artificially, examples being proteins, such as wool and silk, and can be made artificially through step-growth polymerization or solid-phase synthesis, examples being nyons, aramids, and sodium poly(aspartate). Polyamides are commonly used in textiles, automotives, carpet and sportswear due to their extreme durability and strength.
These are formed by repeated condensation of a di-acid and a di-alcohol.

E.g. Preparation of Terylene

1,2-ethanediol + benzene-1,4-dicarboxylic acid

Repeated condensation reactions at either end produces the polymer Terylene.

$[\text{CH}_2\text{CH}_2\text{OOCPhCOO}^-]_n$
Question 2(c): A form of the polymer nylon can be made from the two monomers below.
1,6-diaminohexane  Sebacoyl chloride (decanedioyl dichloride)

\[
\begin{align*}
H_2N-(CH_2)_6-NH_2 & \quad Cl-C-(CH_2)_8-C-Cl \\
\end{align*}
\]

(i) draw the repeating unit of the polymer formed if these two monomers are used.

Answer:

\[
\begin{align*}
\begin{array}{c}
\text{H} \\
\text{N}-(CH_2)_6-N-C-(CH_2)_8-C \\
\end{array}
\end{align*}
\]
Question 2(c): Consider the formation of this form of nylon in a laboratory.

(ii) Describe the type of reaction occurring, and explain why this reaction results in a polymer.

Answer:
This is **condensation** or **substitution (polymerisation)**, whereby the two monomers are joined together and a small molecule (HCl\(_{(g)}\)) is released. Each monomer is di-functional or has a reactive site at each end (allowing polymerisation to be ongoing.)

(iii) Explain why sebacoyl chloride is dissolved in a non-polar organic solvent rather than in water.

Answer:
The sebacoyl chloride (as an acyl chloride) reacts vigorously with water forming the carboxylic acid, (however, it does not react with the non-polar solvent.)
Question 2(c): (iv) Elaborate on the reaction that will occur if a dilute aqueous solution of acid is mixed with the newly formed polymer.

**Answer:**
Dilute acid will cause hydrolysis of the amide linkage. The products formed would be (di)ammonium salt or $^+\text{H}_3\text{N(C}_\text{H}_2\text{)}_6\text{NH}_3^+$ and the (di)oic acid. HOOC(CH$_2$)$_8$COOH (Names not required)
Nomex® is a polymer used in firefighters’ suits. Nomex® is made up of two different monomers bonded together to form the polymer chain. A small portion of the structure of Nomex® is shown below.

Note: This is a benzene ring and does not change when the monomers bond together to form the polymer.

Explain the structure of the polymer, Nomex®. In your answer, you should include:
- the name of the functional group linking the monomers
- a drawing of both monomers
- a classification of the type of polymer formed, with an explanation to justify your choice. (see next slide)
Explain the structure of the polymer, Nomex®. In your answer, you should include:

- the name of the functional group linking the monomers
- a drawing of both monomers
- a classification of the type of polymer formed, with an explanation to justify your choice.

Nomex® has an amide linkage. This is a condensation polymer / polyamide, as monomers join / amide link forms and a molecule of water or HCl is released during the reaction.
Question 3c:
Polymers such as Nomex® can be hydrolysed by either aqueous acid or base. Show the products of the hydrolysis of Nomex® using:
(i) aqueous acid
(ii) aqueous base.

![Chemical structures showing the products of hydrolysis](image)
Amino acids have both the basic amino, NH₂, and acidic carboxylic acid, CO₂H, groups. In acidic solutions, the basic NH₂ group is protonated to form a positively charged amino acid.

General formula  aminoethanoic acid  2-aminopropanoic acid
Most Amino Acids form optical isomers (or enantiomers) because they have a chiral carbon with four different groups off it. Our bodies only use one type of optical isomer for each amino acid.
Polypeptide chains can be made from condensation polymerisation of amino acids. Two simple amino acids that can form polymers are glycine and alanine. Alanine has optical isomers.

Human protein is made from about 20 different amino acids.

**peptide link:** The linking bond between two amino acids. –CONH- (same as an amide link)
**dipeptide**: A dimer formed by two amino acids.
In solution the carboxylic acid can donate a proton to the amine, and form a zwitterion. (zwei = 2 in German) There are two separate charges on the ion.

Amino Acids

Zwitterion
Question 2d: Peptides are formed when amino acids combine.

(i) In the boxes below, show two possible dipeptides that can be formed by combining the amino acids:
Question 1c: (iii) Draw the two possible dipeptides formed from the amino acids glycine and alanine.

\[
\begin{align*}
\text{glycine} & : \quad \text{H} - \text{C} - \text{COOH} \\
\text{alanine} & : \quad \text{H}_3\text{C} - \text{C} - \text{COOH} \\
\text{serine} & : \quad \text{HO} - \text{CH}_2 - \text{C} - \text{COOH}
\end{align*}
\]

\[
\begin{align*}
\text{H} & \quad \text{H}_2\text{N} - \text{CH} - \text{C} - \text{OH} \\
\text{H} - \text{CH}_3 & \quad \text{H} - \text{N} - \text{CH} - \text{COOH} \quad \rightarrow \quad \text{H}_2\text{N} - \text{CH} - \text{C} - \text{N} - \text{CH} - \text{COOH} \\
\text{CH}_3 & \quad \text{H}_2\text{N} - \text{CH} - \text{C} - \text{OH} \quad \rightarrow \quad \text{H}_2\text{N} - \text{CH} - \text{C} - \text{N} - \text{CH} - \text{COOH}
\end{align*}
\]
**Question 1c: (iv)** Name the type of reaction that occurred when the dipeptides formed in (iii) above. Explain your Answer

Condensation.
Two larger molecules are joined together with the elimination of a smaller molecule.

**Question (v)** Draw the products of an **acidic hydrolysis** for ONE of the dipeptides from (iii) above. Explain why these products are formed.

Acidic hydrolysis leaves COOH group intact and NH₂ group becomes protonated to form NH₃⁺.

H₃N⁺CH(CH₃)COOH H₃N⁺CH₂COOH
**Question 3a:** Peptides are molecules that form when amino acids combine. The following structures show the amino acids cysteine and serine.

(i) In the boxes to the left, show two possible dipeptides that can be formed by combining the two amino acids shown above.

(ii) Circle the amide functional group on ONE of the dipeptides drawn in part (i).

Amide linkage group circled on one of the dipeptides.

**Dipeptide 1:**

[Diagram of dipeptide 1 with cysteine and serine indicated]

**Dipeptide 2:**

Second dipeptide the same structure above, with the CH₂SH swapped with CH₂OH.
Question 2a: For the following conversions, identify the reagent required, and state the type of reaction occurring.

(i) Pentan-2-one is converted to pentan-2-ol.

Reagent: NaBH₄ / LiAlH₄
Type of reaction – reduction / redox

(ii) Butan-2-ol is converted to a mixture of but-1-ene and but-2-ene.

Reagent: conc H₂SO₄ / conc H₃PO₄ / Al₂O₃
Type of reaction – elimination / dehydration / condensation
Question 3(a): Complete the following reaction scheme by drawing the structural formulae of the organic compounds B and C, and identifying reagent 1. Include any necessary conditions, needed to bring about the transformation from reactant A to the organic compound C, which is a base.
**Question 3(a):** Propene can be reacted with water in the presence of acid to form a major product (A) and a minor product (B).

- A is oxidised to form product C.
- B is oxidised to form product D.
- When D is reacted with SOCl₂, it forms product E.
- When D is reacted with alcohol B, it forms an ester G.
- When D is reacted with alcohol A, it forms ester H, which is an isomer of G.
- When E is reacted with alcoholic ammonia, it forms product F.
- When E is reacted with water, it forms product D.
A = Propan-2-ol
\[ \text{CH}_3\text{CH(CH}_3\text{)}\text{OH} \]
B = Propan-1-ol
\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \]

C = Propanone
\[ \text{CH}_3\text{C(=O)CH}_3 \]

D = Propanoic acid
\[ \text{CH}_3\text{CH}_2\text{COOH} \]

E = Propanoyl chloride
\[ \text{CH}_3\text{CH}_2\text{C}(\text{=O})\text{Cl} \]

F = Propanamide
\[ \text{CH}_3\text{CH}_2\text{C(=O)}\text{NH}_2 \]

G = Propyl propanoate
\[ \text{CH}_3\text{CH}_2\text{C(OCH}_2\text{CH}_2\text{CH}_3\text{)} \]

H = Methyl ethyl propanoate (not required)
\[ \text{CH}_3\text{CH}_2\text{C(OCH}_3\text{)}\text{OCH}_2\text{CH}_2\text{CH}_3\text{)} \]
Question 3(b): Complete the following reaction scheme by drawing the structural formulae of the organic compounds A to E, and identifying reagents 1 to 5.
**Structures**

A = CH₃CH₂CH₂NH₂  
B = CH₃CH₂CH₂OH  
C = CH₃CH₂CHO OR CH₃CH₂COOH  
D = CH₃CH₂COOCH₂CH₃  
E = CH₃CH₂COCl

**Reagents**

1 = NaOH(aq) OR KOH(aq)  
2 = Cr₂O₇²⁻ / H⁺ or MnO₄⁻ / H⁺  
3 = NaBH₄ OR LiAlH₄  
4 (i) = CH₃CH₂OH or ethanol  
4 (ii) = concentrated H₂SO₄  
5 = NH₃ (alcoholic / gas / conc)
Question 3a: Complete the following reaction scheme by drawing organic structures for **S1** to **S7**, and identifying reagents **1** to **3**.

**S1**: CH₃COOCH₂CH₂CH₃  
**S2**: CH₃CH₂CH₂OH  
**S3**: CH₃CH=CH₂  
**S4**: CH₃CH₂CH₂Cl  
**S5**: CH₃CH(Cl)CH₃  
**S6**: CH₃COCl  
**S7**: CH₃CONHCH₂CH₂CH₃  

Reagent **1** = H₂O / H⁺ (dilute acid)  
Reagent **2** = conc. H⁺ (H₂SO₄ or H₃PO₄)  
Reagent **3** = NH₃ (alc) or conc.
Question 3b: Draw a reaction scheme to show the conversion of butan-1-ol to butan-2-one. You should include any relevant reagents, conditions required, and the structures of all organic substances involved.

Step 1: Butan-1-ol to but-1-ene.
Dehydration reaction (elimination reaction) using conc H₂SO₄.

\[
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{conc H}_2\text{SO}_4} \text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2
\]

Step 2: But-1-ene to butan-2-ol.
Hydration reaction (addition reaction) using dil. H₂SO₄ (H⁺/H₂O)

\[
\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2 \xrightarrow{\text{dil H}_2\text{SO}_4} \text{CH}_3\text{CH}_2\text{CH(OH)CH}_3 \quad \text{Major product}
\]

Step 3: Butan-2-ol (Major product) to butan-2-one.
Oxidation reaction of secondary alcohol to from a ketone using Cr₂O₇²⁻ / H⁺ under reflux.

\[
\text{CH}_3\text{CH}_2\text{CH(OH)CH}_3 \xrightarrow{\text{Cr}_2\text{O}_7^{2-} / \text{H}^+} \text{CH}_3\text{CH}_2\text{COCH}_3
\]
Question 1b:
Complete the following reaction scheme by drawing the structural formulae of both organic compounds A and B, as well as the major and minor products C and D. Identify both reagents 1 and 2, and indicate the type of reaction occurring at each step.
Question 2a:
Compound P and compound Q are straight-chain constitutional (structural) isomers with the molecular formula C₅H₁₂O. Compound P can form optical isomers, whereas compound Q cannot.
When reacted with concentrated sulfuric acid, compound P forms two products, compounds R and S; compound Q forms only one product, compound S.
When compound Q is reacted with Reagent 1, it forms a chloroalkane, compound T. Compound T reacts with concentrated NH₃ to form compound U. Compound Q can also be oxidised to form compound V, which will turn moist blue litmus paper red.
Compound V can also be reacted with compound Q and Reagent 2, to form a sweet-smelling liquid, compound W.
Use the information above to identify compounds P to W, and reagents 1 and 2.
**Question 2a:** Complete the following tables using the information found on the previous page.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CHCH&lt;sub&gt;3&lt;/sub&gt; OH</td>
</tr>
<tr>
<td>Q</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt; OH</td>
</tr>
<tr>
<td>R</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH=CHCH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;3&lt;/sub&gt;</td>
</tr>
<tr>
<td>S</td>
<td>CH&lt;sub&gt;2&lt;/sub&gt;=CHCH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;3&lt;/sub&gt;</td>
</tr>
<tr>
<td>T</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt; Cl</td>
</tr>
<tr>
<td>U</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt; NH&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>V</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;C−OH</td>
</tr>
<tr>
<td>W</td>
<td>CH&lt;sub&gt;3&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;−O−CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;2&lt;/sub&gt;CH&lt;sub&gt;3&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
### Reaction types

<table>
<thead>
<tr>
<th>Reaction type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substitution</strong></td>
<td>Reactions are characterized by replacement of an atom or group (Y) by another atom or group (Z). Aside from these groups, the number of bonds does not change.</td>
</tr>
<tr>
<td><strong>Polymerisation</strong></td>
<td>Reactions join monomers together to form a polymer.</td>
</tr>
<tr>
<td><strong>Condensation polymerisation</strong></td>
<td>Removes a small molecule (such as a H from one monomer and OH from another) and joins the two ends of the monomers together.</td>
</tr>
<tr>
<td><strong>Oxidation</strong></td>
<td>Reactions involve a lost of electrons from the organic molecule or a gain of oxygen. An oxidant such as dichromate or permanganate is used.</td>
</tr>
<tr>
<td><strong>Condensation</strong></td>
<td>(or dehydration) reactions are a type of elimination reaction where a small molecule is removed – in esterification OH and H is removed from alcohol and carboxylic acid and they are joined to form an ester.</td>
</tr>
<tr>
<td><strong>Addition</strong></td>
<td>Reactions increase the number of bonds to the Carbon chain by bonding additional atoms, usually at the expense of one or more double bonds.</td>
</tr>
<tr>
<td><strong>Hydrolysis</strong></td>
<td>Reactions involve water as a reactant to ‘split’ a larger molecule into smaller molecules and the water becomes part of the reaction product.</td>
</tr>
<tr>
<td><strong>Elimination</strong></td>
<td>Reactions decrease the number of single bonds by removing atoms and new double bonds are often formed.</td>
</tr>
<tr>
<td><strong>Reduction</strong></td>
<td>Reactions involve a gain of electrons from the organic molecule or a loss of oxygen. A reductant such as LiAlH$_4$ is used.</td>
</tr>
</tbody>
</table>