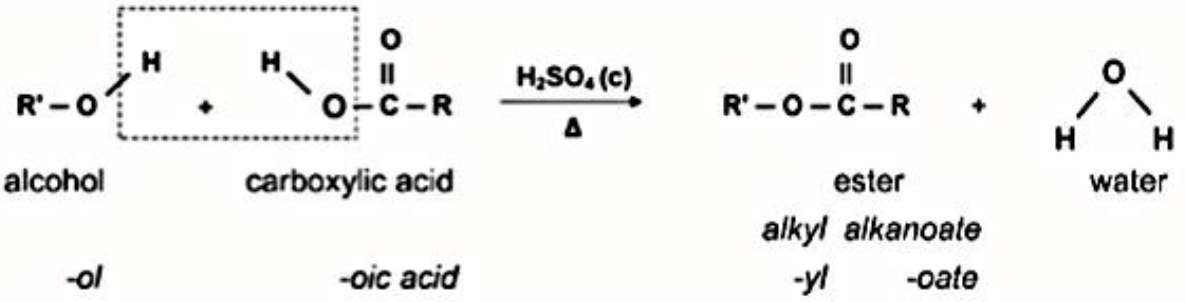
SUBJECT and GRADE	Physical Sciences Grade 12	
TERM 1	Week 7	
TOPIC	Organic Chemistry (Reactions of organic compounds)	
AIMS OF LESSON	The focus of this lesson will be on the following: • Combustion of alkanes in excess oxygen and use as fuels. • Equation & reaction conditions for the formation of an ester and IUPAC names for reactant and products. • Classify reactions as elimination, addition or substitution. • Equations and reaction conditions for addition reactions of alkenes. • Equations and reaction conditions for elimination reactions: dehydrohalogenation of haloalkanes, cracking of alkanes, dehydration of alcohols • Equations and reaction conditions for substitution reactions: hydrolysis of haloalkanes, halogenation of alkanes • Plastics & polymers	
RESOURCES	***Paper based resources***	***Digital resources***
	You are referred to the: • *Organic Chemistry topic in the textbook or study guides (e.g. Answer Series) that learners will have on hand.* • *Examination Guideline (page 17-18)* • *Mind the Gap Chemistry book (pages 29 -45)* • *Past NSC Examination papers (refer to Paper 2 question 4)*	*Refer to the relevant digital resources:* • *WCED ePortal https://wcedeportal.co.za/eresource/192856* • *Past NSC Examination papers (Paper 2 refer to question 4)* https://wcedonline.westerncape.gov.za/grade-12-question-papers • *Telematics* https://wcedonline.westercape.gov.za/edumedia/revision-dvds-telematics • *Mind the Gap* https://wcedonline.westercape.gov.za/mind-gap • *HeyScience App for Physical Sciences on Play Store* • *DBE videos* https://www.education.gov.za/secondchance/ScienceSubjects/PhysicalSciences.aspx

INTRODUCTION	*Organic compounds take part in different* ***types of reactions*** *which can be grouped into:* • Oxidation (Combustion) • Esterification • Substitution • Addition and • Elimination reactions. This lesson will also focus on *Plastics and Polymers.*
CONCEPTS AND SKILLS	***OXIDATION REACTIONS*** Oxidation of alkanes is also called the combustion of alkanes. In the complete combustion reaction of alkanes, carbon dioxide (CO_2) and water (H_2O) are released along with energy. Alkanes are our most important fossil fuels. The combustion (burning) of alkanes (also known as oxidation) is highly *exothermic*. Fossil fuels are burnt for the energy they release. *An equation for the combustion of an alkane in excess oxygen:* $$\text{Alkane} + O_2(g) \rightarrow CO_2(g) + H_2O(g) + \text{Energy}$$ The balanced equation for the complete combustion of methane is: $$CH_4 + 2O_2 \rightarrow CO_2(g) + 2H_2O(g)$$ How to write a balanced equation for the combustion of alkanes: **Step 1**: Balance the carbon atoms **Step 2**: Balance the hydrogen atoms **Step 3**: Balance the oxygen atoms **Step 4**: Make sure all numbers are whole numbers *Unbalanced equation* for the combustion of butane: $$C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$$ *Balanced equation* for the combustion of butane: $$\mathbf{2}C_4H_{10} + \mathbf{13}O_2 \rightarrow \mathbf{8}CO_2 + \mathbf{10}H_2O$$

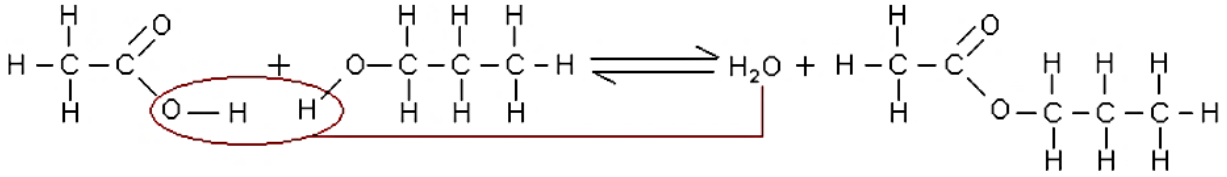
ESTERIFICATION REACTIONS

One way to form an ester is through the reaction of an alcohol and a carboxylic acid. This process is called an **esterification** or condensation.

The reaction conditions for esterification is an alcohol and a carboxylic acid must be **heated** in the presence of **concentrated H_2SO_4**. The reaction is an acid catalysed condensation reaction. An ester (organic compound) and water (inorganic compound) are produced during an esterification reaction.



• The equation, using structural formulae, for the formation of the ester **propyl ethanoate**:



Ethanoic acid *Propan-1-ol* *Water* *Propyl ethanoate*

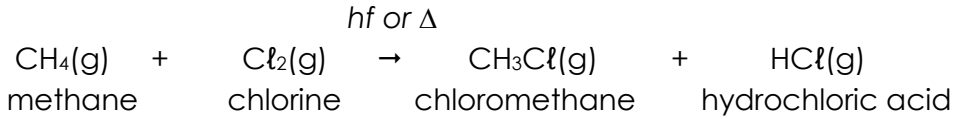
You must be able to name the alcohol and carboxylic acid used to form a specific ester.

Example: Which two compounds need to be heated in the presence of concentrated sulphuric acid in order to form butyl methanoate?

***Solution*:** butanol + methanoic acid

	You must be able to name the ester that forms from a specific alcohol and carboxylic acid **Example:** What ester will form during the acid catalysed reaction of ethanol and propanoic acid? ***Solution*:** Ethyl propanoate *Esters are used in the manufacture of*: • perfumes (pleasant smell) • solvents • artificial fruit flavours ***SUBSTITUTION REACTIONS*** Take place when saturated compounds react, and an atom bonded to the carbon chain is substituted by another atom or another group of atoms. Produce products which are also saturated. These reactions are slow and not spontaneous – additional energy (e.g. sunlight, hf or heat Δ) is needed for the reactions to take place. The different types of substitution reactions: o **Halogenation of alkanes**: The reaction of a halogen (Br_2, $C\ell_2$) with a compound o **Hydrolysis** of haloalkanes Hydrolysis: The reaction of a compound with water o Reactions of HX (X = Cℓ, Br) with alcohols to produce haloalkanes You should be able to write down, using structural formulae, equations and reaction conditions for the different types of substitution reactions. **Halogenation** Alkanes react with halogens X_2 (X = Br, Cℓ) when heated (indicated with Δ) or in the presence of light (indicated with *hf*).

Example: Write a balanced reaction for the reaction of methane with chlorine gas, using molecular formulae. Name the products.



Hydrolysis

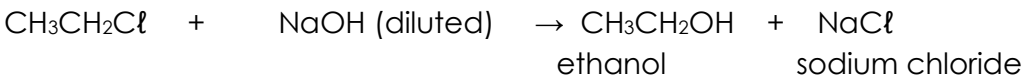
Reaction conditions:

- Reactions with **water (+ heat)** produce alcohols.
- The **haloalkane** must first be **dissolved in ethanol**
- The reaction is slower than the reaction between a haloalkane and a strong base.

Example:

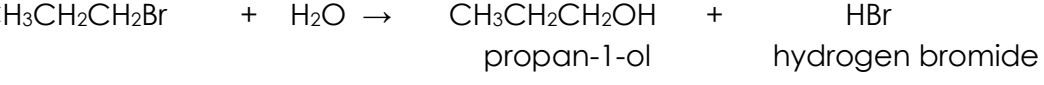
1. Write an equation for the reaction of chloroethane with a dilute sodium hydroxide solution, using condensed structural formulae. Name the products.

   Solution:

2. Write an equation for the reaction of 1-bromopropane with water, using condensed structural formulae. Name the products.

   Solution:

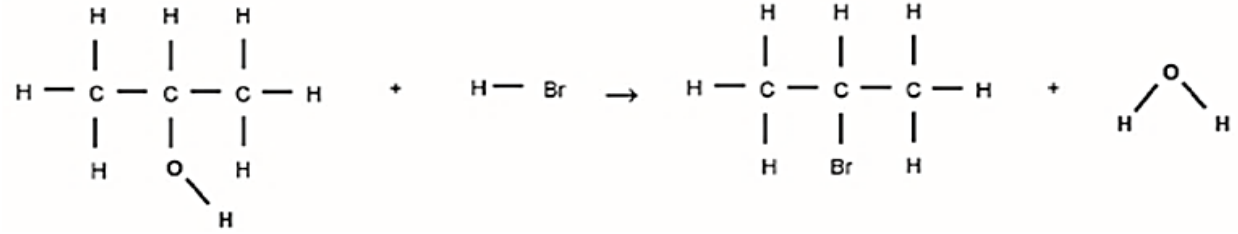
   

Reactions of HX (X = Cℓ, Br) with alcohols

alcohol + HX → haloalkane + H_2O

1. Tertiary alcohols react with HX (X = Cℓ, Br) to produce haloalkanes and water.
2. Secondary and primary alcohols react slowly and at **high temperatures**.

Example:
Write an equation for the reaction of propan-2-ol with hydrogen bromide, using structural formulae. Name the products.



2-bromopropane water

ADDITION REACTIONS

Take place when atoms attach to the double or triple bond of an unsaturated compound (alkenes or alkynes), breaking the double or triple bond during the reaction. Form products which are more saturated than the reactants. The addition reactions are faster than substitution reactions and are usually spontaneous.

The different types of addition reactions:

- **Hydrohalogenation**: The addition of a hydrogen halide to an alkene
- **Halogenation**: The reaction of a halogen (Br_2, $C\ell_2$) with a compound
- **Hydration**: The addition of water to a compound
- **Hydrogenation**: The addition of hydrogen to an alkene

You should be able to write down, using structural formulae, equations and reaction conditions for the different types of addition reactions of alkenes.

Rules to remember for when you are asked to write balanced equation using structural formulae for addition reactions:

Markovnikov's rule: Two products are formed during addition of water or of HX to an alkene.

- The major product is formed when the H-atom from the added molecule bonds to the C-atom which is already bonded to the most other H-atoms.
- The secondary product is formed when the H-atom from the added molecule bonds to the C-atom which is bonded to the least other H-atoms.

Hydrogenation

$$\text{alkene} + H_2(g) \xrightarrow[\Delta]{Pt} \text{alkane}$$

Reaction conditions:

• The alkene must first be dissolved in a non-polar solvent (e.g. $CC\ell_4$)

• Catalyst: Pt, Pd or Ni

Examples:

1. Write an equation for the hydrogenation of ethene using condensed structural formulae. Name the product.

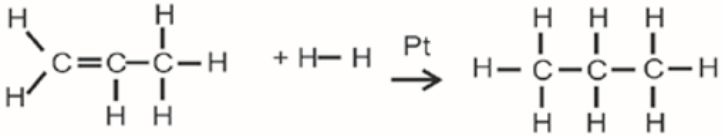
Solution:

$$CH_2{=}CH_2 + H_2 \xrightarrow[\Delta]{Pt} CH_3CH_3$$

ethane

2. Write an equation for the hydrogenation of propene, using structural formulae. Name the product.

Solution:



propane

Hydrohalogenation

alkene + HX → haloalkane (X = F, Cℓ, Br, I)

Reaction conditions:
- NO catalyst is needed – the reaction is spontaneous.
- The reaction must take place in the absence of water.

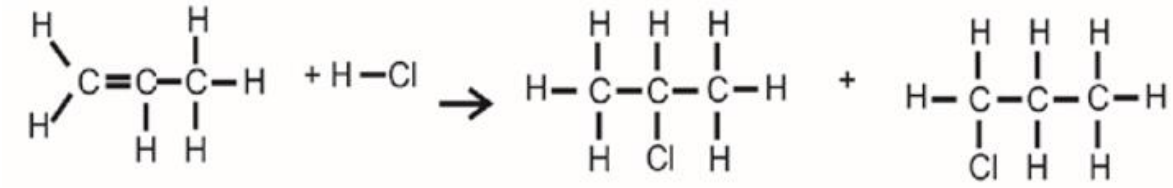
Examples:

1. Write an equation for the reaction between ethene and hydrogen fluoride, using condensed structural formulae. Name the product.

   Solution: $CH_2=CH_2 + HC\ell \rightarrow CH_3CH_2C\ell$
   chloroethane

2. Write an equation for the reaction of propene with hydrogen chloride (hydrochloric acid), using structural formulae. Name the two products and identify the major product.

   Solution:



2-chloropropane (major product) 1-chloropropane

NB! Apply Markovnikov's rule, in order to determine the major product

Halogenation

alkene + X_2 → haloalkane (X = Cℓ, Br, F, I)

Reaction condition:
- NO catalyst is needed – the reaction is spontaneous.

Examples:

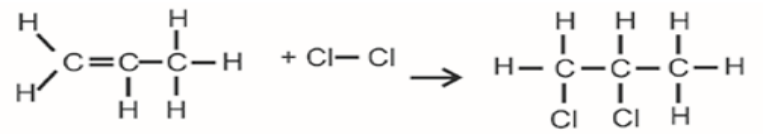
1. Write an equation for the addition of bromine to ethene, using condensed structural formulae. Name the product.

Solution: $CH_2=CH_2 + Br_2 \rightarrow CH_2Br–CH_2Br$

1,2-dibromoethane

2. Write an equation for the addition of chlorine to propene, using structural formulae. Name the product.

Solution:



1,2-dichloropropane

Hydration

$$\text{alkene} + H_2O \xrightarrow{H_2SO_4(conc)} \text{alcohol}$$

Reaction conditions:

- Catalyst used is a concentrated strong acid: H_2SO_4 or H_3PO_4
- The reaction must take place in excess H_2O

Examples:

1. Write an equation for the reaction between ethene and water, using condensed structural formulae. Name the product.

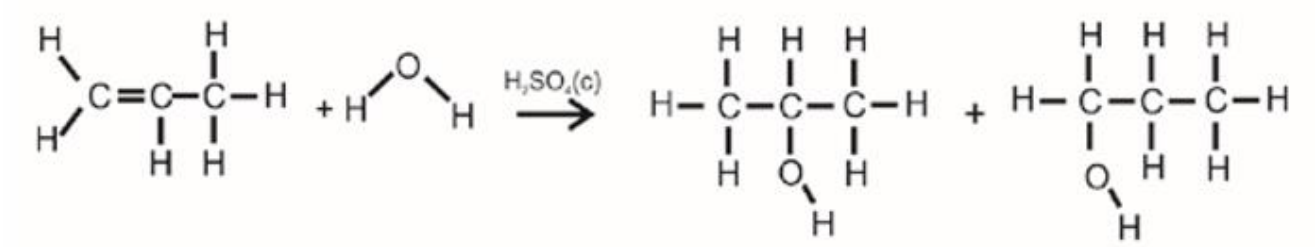
Solution:

$$CH_2=CH_2 + H_2O \xrightarrow{H_2SO_4\ (conc)} CH_3CH_2OH$$

ethanol

2. Write an equation for the hydration of propene, using structural formulae. Name the two products and identify the major product.

Solution:



propan-2-ol (major product) propan-1-ol

NB! Apply Markovnikov's rule, in order to determine the major product

ELIMINATION REACTIONS

Elimination reactions occur when two atoms or groups of atoms are removed from adjacent carbon atoms in a saturated compound (like an alkane, a haloalkane or an alcohol) to form two compounds. These reactions are always endothermic i.e. the reactants must be heated.

The different types of elimination reactions:

- **Dehydrogenation** of alkanes: Elimination of hydrogen (H_2) from an alkane.
- **Dehydrohalogenation** of haloalkanes: The elimination of hydrogen and a halogen from a haloalkane
- **Dehydration** of alcohols: Elimination of water from an alcohol
- **Cracking** of alkanes: The chemical process in which longer chain hydrocarbon molecules are broken down to shorter more useful molecules.

You should be able to write down, using structural formulae, equations and reaction conditions for the different types of elimination reactions.

Rules to remember for when you are asked to write balanced equation using structural formulae for elimination reactions:

- Zaitsev's* rule: If more than one elimination product is possible the major product is formed when the H-atom is removed from the C-atom with the least H-atoms bonded to it and
- the secondary product is formed when the H-atom is removed from the C-atom with the most H-atoms bonded to it.

* If you look this rule up online, you might find it is spelled 'Saytseff' as well.

Dehydrogenation

$$\text{alkane} \xrightarrow[\Delta]{Pt} \text{alkene} + H_2$$

Reaction condition:
Use **platinum (Pt)** as a catalyst and **heat** the alkane

Example:
Write an equation for the elimination reaction of propane in the presence of platinum and heat, using condensed structural formulae. Show the major organic product only and name it and the by-product.

$$CH_3CH_2CH_2CH_3 \xrightarrow[\Delta]{Pt} CH_2CHCHCH_3 + H_2$$

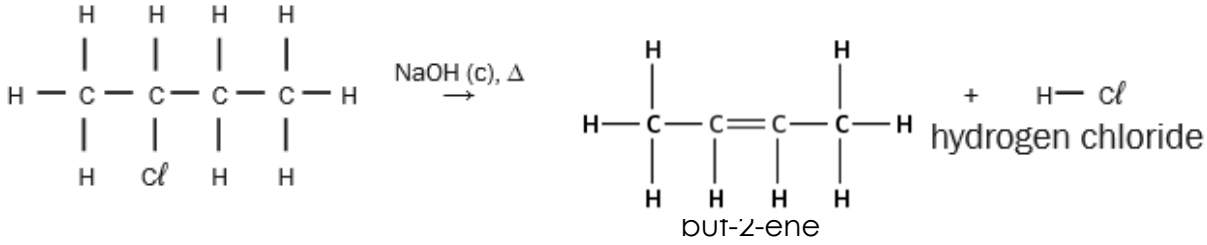
but-2-ene hydrogen

Dehydrohalogenation

$$\text{Haloalkane} \xrightarrow[\Delta]{NaOH(c)} \text{alkene} + HX \ (X = C\ell, Br, I)$$

Reaction conditions:
Heating a haloalkane under reflux in a **concentrated solution of NaOH or KOH in pure ethanol** as the solvent (hot ethanolic NaOH / KOH) to produce an alkene.

Example:
Write an equation for the reaction of 2-chlorobutane with concentrated sodium hydroxide when heated under reflux, using structural formulae. Show the major organic product only and name it and the by-product.



NB! Apply Zaitsev's rule in order to determine the major product

Dehydration

$$\text{alcohol} \xrightarrow[\Delta]{H_2SO_4(c)} \text{alkene} + H_2O$$

Reaction condition:
Acid catalysed dehydration takes place when an **alcohol is heated** in the presence of **concentrated sulphuric acid, H_2SO_4** (a dehydrating catalyst).

Example:
Write an equation for the elimination reaction of butan-2-ol, using condensed structural formulae. Show and name only the major organic product and the by-product.

$$CH_3CH_2CHOHCH_3 \xrightarrow[\Delta]{H_2SO_4(c)} CH_3CH{=}CHCH_3 + H_2O$$

but-2-ene water

NB! Apply Zaitsev's rule in order to determine the major product

Cracking

This involves breaking up large alkane molecules into smaller and more useful molecules.

Reaction conditions:
- high pressure and
- high temperature without a catalyst (**thermal cracking**), or
- lower temperatures and pressures in the presence of a catalyst (*Pt*) (**catalytic cracking**).

Examples:

- $CH_3CH_2CH_2CH_3 \xrightarrow[\Delta]{Pt} H_2 + CH_2{=}CHCH_2CH_3$
  butane → hydrogen + but-1-ene

- $CH_3CH_2CH_2CH_3 \xrightarrow[\Delta]{Pt} CH_2{=}CH_2 + CH_3CH_3$
  butane → ethene + ethane

<u>How do we distinguish between saturated and unsaturated hydrocarbons using bromine water?</u>

Bromine water has a red-brown colour. If an organic compound decolourises **bromine water**, then it will be an **unsaturated hydrocarbon** (containing a double bond or a triple bond), but **saturated hydrocarbon** (alkanes) do not decolourise bromine water.

PLASTICS and POLYMERS

Polymers are a type of macromolecule which form when monomers bond to each other chemically to produce large molecules that are built up of repeating units in chains that vary in length depending on the number of monomers that bond. Many polymers occur in nature (wood, carbohydrates, proteins etc.) while a large number are produced synthetically (most are plastics) as they are very useful.

Macromolecule: A molecule that consists of a large number of atoms

Polymer: A large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern

Monomer: Small organic molecules that can be covalently bonded to each other in a repeating pattern

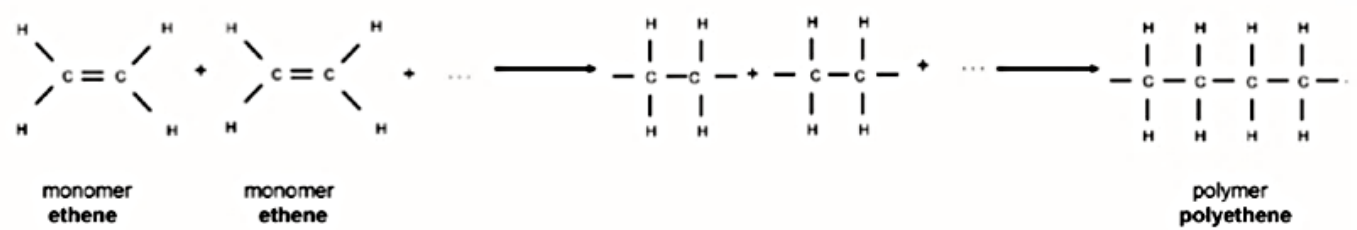
Polymerisation: A chemical reaction in which monomer molecules join to form a polymer

Addition polymerisation: A reaction in which small molecules join to form very large molecules by adding on double bonds

Addition polymer: A polymer formed when monomers (usually containing a double bond) combine through an addition reaction

The only addition polymerisation example you need to learn is the ***formation of polythene (polyethene).***

•The equation for the polymerisation of ethene to produce polythene:

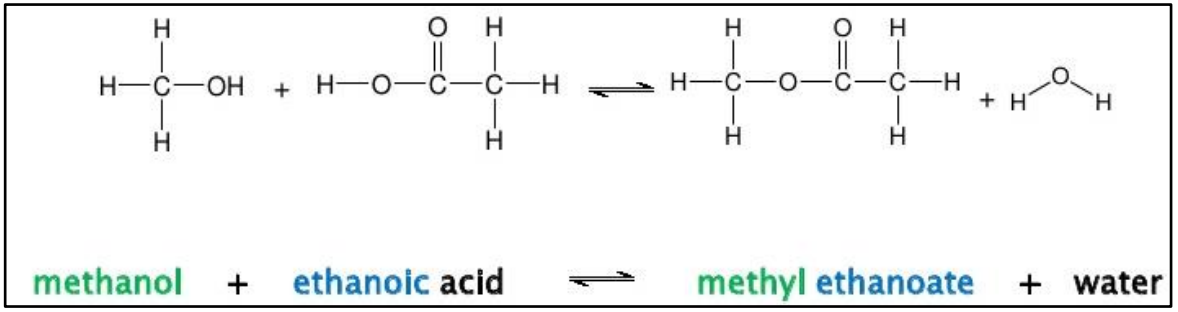


• The length of the polyethene macromolecule depends on the number of **ethene monomers** that bond.

• The structural formula of the polymer polyethene can therefore be abbreviated as follows:

where **n** is the number of monomers that joined.

	The industrial **uses** of polythene: • sandwich bags, cling wrap, car covers, squeeze bottles, liners for tanks and ponds, moisture barriers in construction, freezer bags, water pipes, wire and cable insulation **Condensation polymerisation**: Molecules of two monomers with different functional groups undergo condensation reactions with the loss of small molecules, usually water **Condensation polymer**: A polymer formed by two monomers with different functional groups that are linked together in a condensation reaction in which a small molecule, usually water, is lost ***Example*** *of condensation polymerisation*: • Is the reaction between monomers which are not always the same (monomers have functional groups like an alcohol (-diol), or dicarboxylic acid) to form two products – the polymer and a molecule like H_2O or HCℓ. • The polymers that form is polyesters or nylon. ***Key points to consider when studying this topic:*** • You must be able to state the use of alkanes as fuels and write down an equation for the combustion of an alkane in excess oxygen. This will require you to use molecular formulae. • Make sure you can write down an equation, using structural formulae, for the formation of an ester and to name the alcohol and carboxylic acid used and the ester formed. Write down reaction conditions for esterification. • Identify reactions as elimination, substitution or addition and write down, using structural formulae, equations and name the reaction conditions for the substitution, addition and elimination reactions. • You must be able to distinguish between saturated and unsaturated hydrocarbons using bromine water. •You must be able to describe the following terms: Macromolecule, Polymer, Monomer, Polymerisation, Addition polymer, Condensation polymer • Distinguish between addition polymerisation and condensation polymerization • Identify monomers from given addition polymers. • Write down an equation for the polymerisation of ethene to produce polythene and state the industrial uses of polythene.

	Please remember the following: • Plastics and polymers focus on ONLY BASIC POLYMERISATION as application of organic chemistry. • Saturated compound —*elimination*→ Unsaturated compound *alkane / haloalkane / alcohol* — *alkene* • Unsaturated compound —*addition*→ saturated compound *alkene* — *alkane / haloalkane / alcohol*
ACTIVITIES/ ASSESSMENT	Learners are referred to *Organic Chemistry Reaction activities/assessment* that they can complete/do in their *Physical Sciences textbooks or Study guides.* *Informal assessment activities in Mind the Gap:* • Reactions of organic compounds: Activity 6 (page 38-39) • Polymers and Plastics: Activity 7 (page 47-48)
CONSOLIDATION	In this topic we have introduced the reactions of organic compounds and the reaction conditions for the different types of reactions. • Combustion reactions: **Reaction with oxygen (O_2)** **Exothermic (release energy)** Excess O_2 alkane + $O_2(g) \rightarrow CO_2(g) + H_2O(g)$ + energy • Example of Esterification reaction:  **methanol + ethanoic acid ⇌ methyl ethanoate + water**

- Summary of substitution reactions:

SUBSTITUTION REACTIONS	Reaction conditions	Reaction equations
Halogenation	Endothermic: Sunlight or heat hf or Δ	**alkane** + halogen $\xrightarrow{hf \text{ or } \Delta}$ **haloalkane** + HX
Hydrolysis	Endothermic VERY slow	**haloalkane** + $H_2O \rightarrow$ **alcohol** + HX
	Slow	**haloalkane** + NaOH (diluted) $\rightarrow$ **alcohol** + NaX

- Summary of addition reactions:

ADDITION REACTIONS	Reaction conditions	Reaction equations
Hydrogenation	Catalyst: Pt, Pd or Ni	**alkene** + $H_2(g) \xrightarrow{Pt}$ **alkane**
Halogenation	No catalyst	**alkene** + $X_2 \rightarrow$ **haloalkane**
Hydrohalogenation	No catalyst.	**alkene** + HX $\rightarrow$ **haloalkane**
Hydration	Concentrated H_2SO_4	**alkene** + $H_2O \xrightarrow{H_2SO_4 \text{ (conc)}}$ **alcohol**

	• Summary of elimination reactions: **ELIMINATION REACTIONS** / **Reaction conditions** / **Reaction equations** **Cracking** — Catalyst (Pt), Heat — **alkane** $\xrightarrow{Pt\Delta}$ alkene + alkane (long chains form shorter structures) **Dehydrogenation** — Catalyst (Pt), Heat — **alkane** $\xrightarrow{Pt\Delta}$ alkene + H_2 **Dehydrohalogenation** — Concentrated strong base (NaOH), Heat — **haloalkane** $\xrightarrow{NaOH_{(c)}\Delta}$ alkene + HX **Dehydration** — Concentrated H_2SO_4, Heat — **alcohol** $\xrightarrow{H_2SO_{4(c)}\Delta}$ alkene + H_2O **Consolidation questions** are included at the end of this lesson.
VALUES	Organic chemistry is important because it is the study of life and all of the chemical reactions related to life. Several careers apply an understanding of organic chemistry, such as doctors, veterinarians, dentists, pharmacologists, chemical engineers, and chemists. Organic reactions play a part in the development of common household chemicals, foods, plastics, drugs, and fuels most of the chemicals part of daily life.

CONSOLIDATION ACTIVITY

QUESTION 1

Consider the incomplete equations for reactions **I** to **IV** below. **P, Q, R** and **S** are organic compounds.

I	**Q** + Br_2 ⟶ 2-bromobutane + HBr
II	n**P** ⟶ $-\left[CH_2-CH_2\right]_n-$
III	**R** $\xrightarrow{\text{heat}}$ 2**P** + **Q**
IV	2-bromobutane + KOH (in ethanol) $\xrightarrow{\text{heat}}$ **S** + **T** + H_2O

1.1 Define a cracking reaction. (2)

1.2 Write down the reaction number (**I**, **II**, **III** or **IV**) that represents EACH of the following:

1.2.1 A cracking reaction (1)

1.2.2 An addition reaction (1)

1.2.3 A substitution reaction (1)

1.3 Write down:

1.3.1 ONE reaction condition for reaction **I** (1)

1.3.2 The compound (**P**, **Q**, **R** or **S**) that represents an unsaturated hydrocarbon (1)

1.3.3 The IUPAC name of compound **P** (1)

1.3.4 The molecular formula of compound **R** (2)

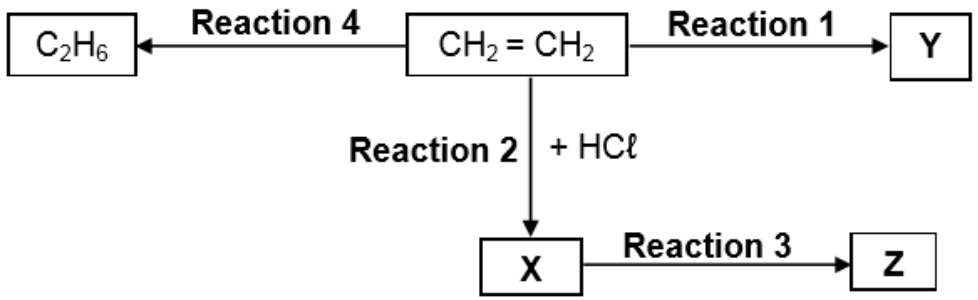
1.3.5 The structural formula of compound **Q** (2)

1.3.6 The structural formula of compound S (2)

[14]

QUESTION 2

The flow diagram below shows different organic reactions using $CH_2 = CH_2$ as the starting reactant. **X**, **Y** and **Z** represent different organic compounds.



2.1 During Reaction **1**, $CH_2 = CH_2$ undergoes polymerisation to form compound **Y**.

For this reaction, write down the:

2.1.1 Type of polymerisation (1)

2.1.2 NAME of compound **Y** (1)

2.2 For Reaction **2**, write down the:

2.2.1 IUPAC name of compound **X** (2)

2.2.2 Type of addition reaction of which this is an example (1)

2.3 During Reaction **3**, compound **X** reacts with excess hot water.

Write down the:

2.3.1 STRUCTURAL FORMULA of compound **Z** (2)

2.3.2 NAME or FORMULA of the INORGANIC product (1)

2.4 Reaction **4** is an addition reaction.

2.4.1 Is C_2H_6 a SATURATED or an UNSATURATED compound? Give a reason for the answer. (2)

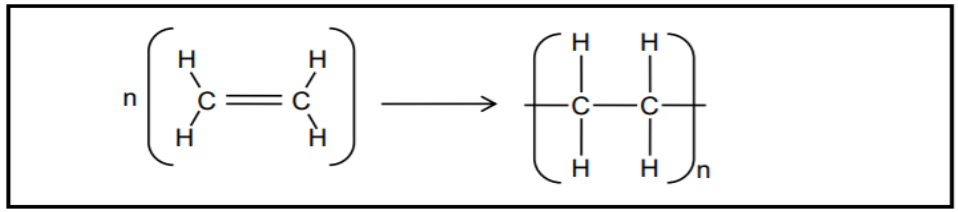
2.4.2 Write down the NAME or FORMULA of the INORGANIC reactant needed for this reaction. (1)

2.4.3 Using molecular formulae, write down a balanced equation for the complete combustion of C_2H_6. (3)

[14]

QUESTION 3

3.1 The balanced equation for a polymerisation reaction is shown below.



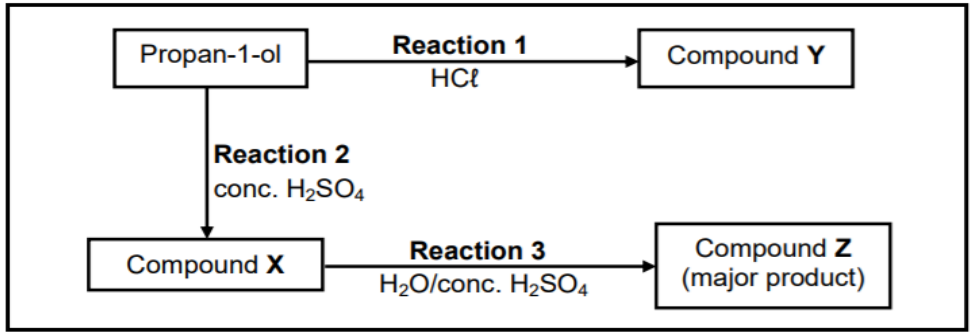
Write down the:

3.1.1 Type of polymerisation reaction represented by the equation (1)

3.1.2 IUPAC name of the monomer (1)

3.1.3 IUPAC name of the polymer (1)

3.2 Propan-1-ol undergoes two different reactions, as shown in the diagram below



Write down the:

3.2.1 Type of reaction represented by reaction **2** (1)

3.2.2 Function of concentrated H_2SO_4 in reaction **2** (1)

3.2.3 IUPAC name of compound **X** (2)

3.2.4 STRUCTURAL FORMULA of compound **Y** (2)

3.2.5 Type of reaction represented by reaction **3** (1)

3.2.6 IUPAC name of compound **Z** (2) **[12]**

CONSOLIDATION ACTIVITY MARKING GUIDELINE

QUESTION 1

1.1 The chemical process in which longer chain hydrocarbon molecules are broken down ✓ to shorter more useful molecules. ✓ (2)

1.2.1 III ✓ (1)

1.2.2 II ✓ (1)

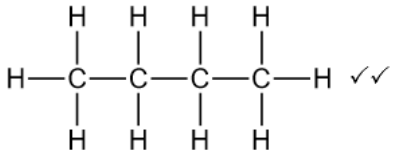
1.2.3 I ✓ (1)

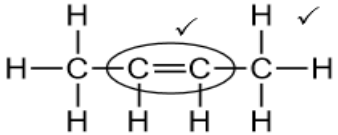
1.3.1 Heat/Light /UV light ✓ (1)

1.3.2 P or S ✓ (1)

1.3.3 Eteen ✓ (1)

1.3.4 C_8H_{18} ✓✓ (2)

1.3.5  ✓✓ (2)

1.3.6  ✓ ✓ (2)

[14]

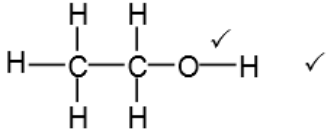
QUESTION 2

2.1.1 Addition ✓ (1)

2.1.2 Polyethene/polythene/polyethelene ✓ (1)

2.2.1 Chloroethane✓✓ (2)

2.2.2 Hydrohalogenation/hydrochlorination ✓ (1)

2.3.1  ✓ ✓ (2)

2.3.2 HCℓ/hydrogen chloride ✓ (1)

2.4.1 Saturated ✓

There are no double/multiple bonds between C atoms./Carbon atoms are bonded to the maximum number of H atoms. ✓✓ (2)

2.4.2 H_2/hydrogen (gas) ✓ (1)

2.4.3 $2C_2H_6 + 7O_2$ ✓→ $4CO_2 + 6H_2O$ ✓ balanced✓ (3)

[14]

QUESTION 3

3.1.1 Addition (polymerisation) ✓ (1)

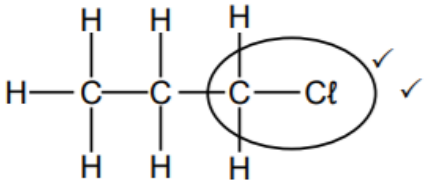
3.1.2 Ethene ✓ (1)

3.1.3 Polyethene/polythene✓ (1)

3.2.1 Dehydration/elimination ✓ (1)

3.2.2 Catalyst/dehydrating agent/causes dehydration/removes water molecules ✓ (1)

3.2.3 Prop-1-ene/propene/1-propene ✓✓ (2)

3.2.4  (2)

3.2.5 Addition/Hydration ✓ (1)

3.2.6 Propan-2-ol/2-propanol✓✓ (2)

[12]