HL IB Chemistry

Your notes

From Models to Materials

Contents

Bonding Models

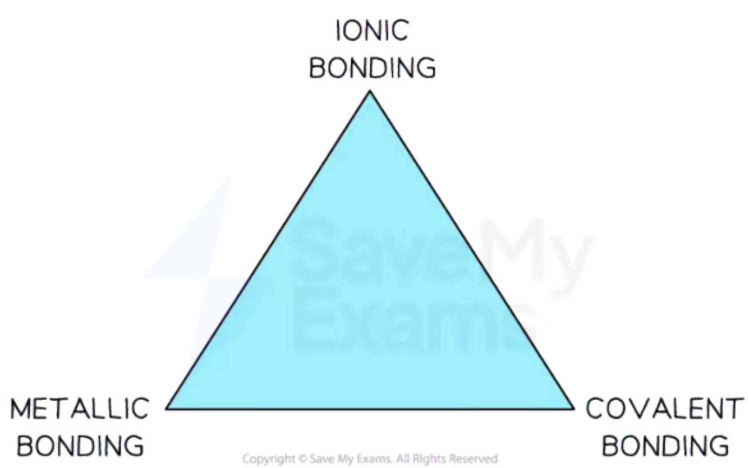
Your notes

Bonding Models

Bonding Models

- Models simplify complex systems and allow us to predict and test theories
- As we have seen, chemical bonding broadly falls into three types: ionic, covalent and metallic
- The bonding types can be used to explain chemical and physical properties of substances
- However, like all models, there are limitations and inaccuracies that arise from oversimplification
- For example, take a substance like aluminium chloride, $AlCl_3$. The compound consists of a metal and non-metal, so the traditional bonding approach would be to predict it has ionic bonding and the associated properties of an ionic compound such as high melting point and boiling point
  - Aluminium chloride actually melts at 192°C, so it does not behave like an ionic compound
- The fact we know polar covalent bonds exist arise provides evidence that bonding type is not something that can be easily compartmentalised
- Bonding is best thought of as a continuum of the three different bonding types like the area of an equilateral triangle

A bonding model



Chemical bonding is a continuum of ionic, covalent and metallic bonding

- The location of an element or compound in the bonding triangle is determined by the electronegativity values of the elements present
- The bonding triangle is anchored by two axes, electronegativity difference on the y-axis and average electronegativity on the x-axis
- The symbol for electronegativity is the Greek letter (chi) χ, pronounced 'ky' as in 'sky'
  - The average electronegativity of two elements, A and B would be: $\Sigma\chi = \dfrac{\chi_A + \chi_B}{2}$

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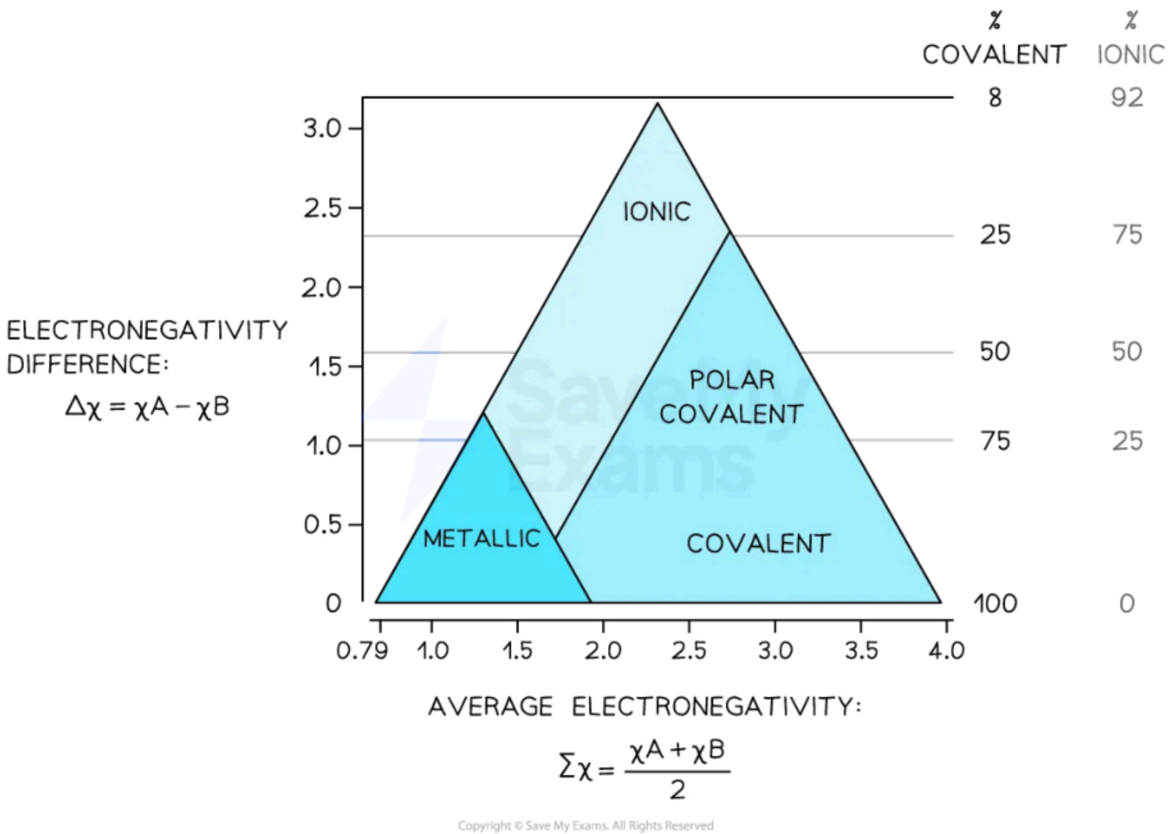
- The difference in electronegativity between two elements A and B would be: $\Delta\chi = \chi_A - \chi_B$

The Bonding Triangle



The bonding triangle is used to determine the percentage of ionic, covalent and metallic character in an element or compound

- Since elements have zero difference in electronegativity they would be found along the x-axis depending on the electronegativity value of the individual element
- Ionic compounds have a large difference in electronegativity so would be located in the top centre part or apex of the triangle
- Covalent compounds with a low difference in electronegativity would be found in the bottom right and polar covalent compounds in the zone between ionic and covalent

Examiner Tip

- You don't need to learn the bonding triangle as it is found in Section 17 of the Data Booklet
- Electronegativity values are found in the Periodic Table in Section 9.

Bonding & Properties

Your notes

Bonding & Properties

Determining the position of a compound in the bonding triangle

- We can use the electronegativity of elements and binary compounds to find their position in the bonding triangle
- For example, take sodium chloride:

Substance	Average electronegativity	Electronegativity difference	Where it is in the triangle
Na	0.9	0.9 - 0.9 = 0.0	Bottom left of the triangle. Na is 100% metallic
Cl_2	3.2	3.2 - 3.2 = 0.0	Bottom right corner. Cl_2 is 100% covalent
NaCl	$\Sigma\chi = \frac{\chi_A + \chi_B}{2} = \frac{3.2 + 0.9}{2} = 2.1$	$\Delta\chi = \chi_A - \chi_B = 3.2 - 0.9 = 2.3$	Centre top of the triangle. It is about 70% ionic on the triangle

Sodium chloride bonding triangle

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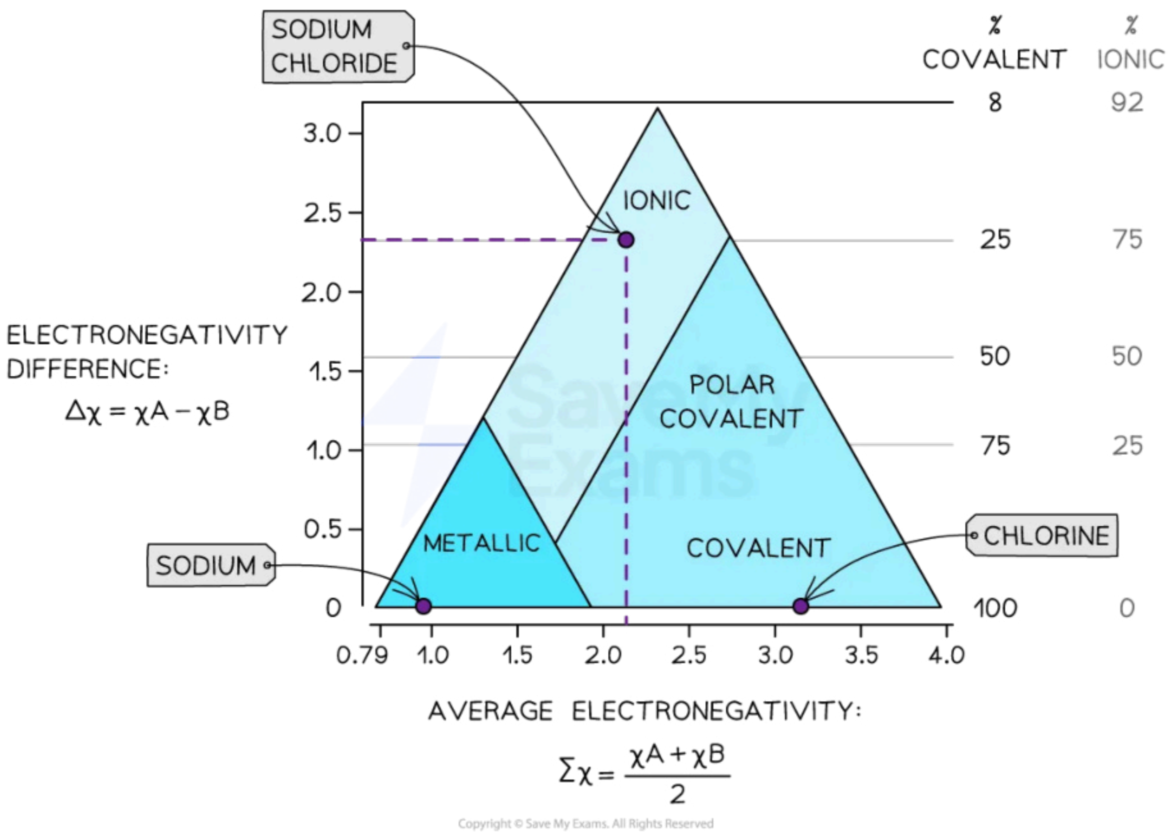

The location of sodium chloride on the bonding triangle using electronegativity values

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Worked example

Use the bonding triangle and electronegativity values from Section 9 of the data booklet to mark the location for the following substances:

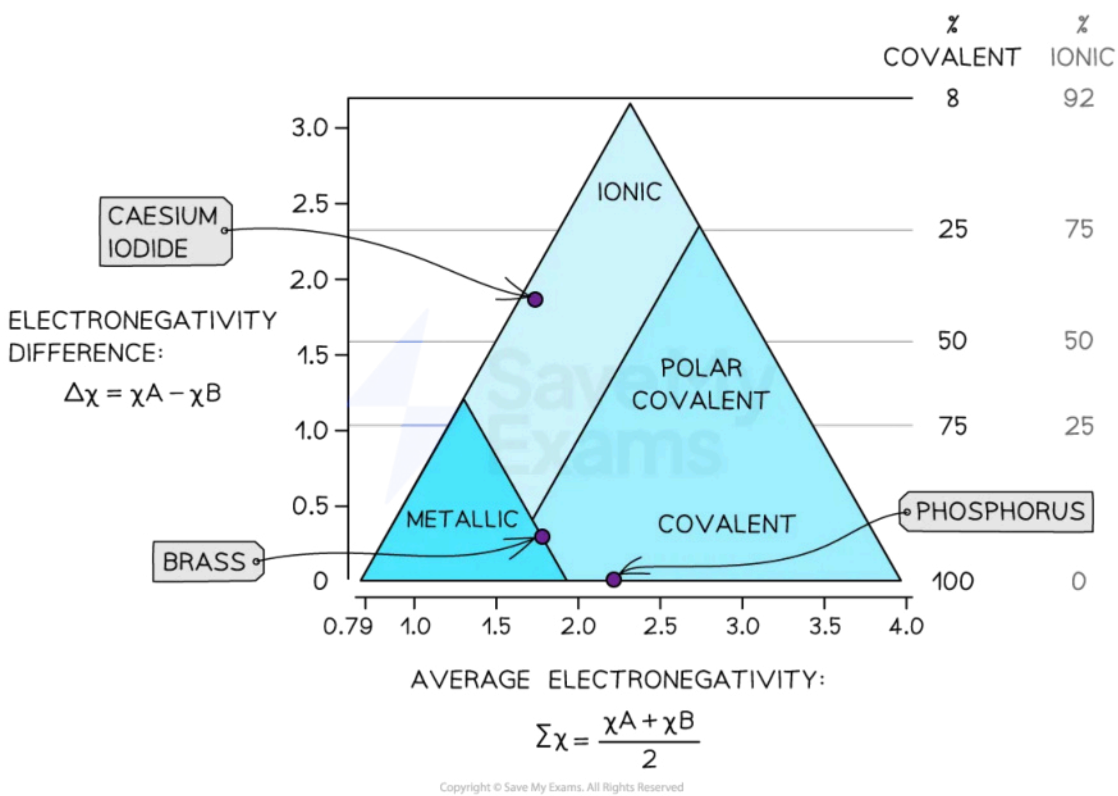
a) phosphorus

b) caesium iodide

c) brass (an alloy of copper and zinc)

Answer

Substance	Average electronegativity	Electronegativity difference
a) phosphorus	2.2	0
b) caesium chloride	$\Sigma\chi = \frac{\chi_A + \chi_B}{2} = \frac{0.8 + 2.7}{2} = 1.8$	$\Delta\chi = \chi_A - \chi_B = 2.7 - 0.8 = 1.9$
c) brass (an alloy of copper and zinc)	$\Sigma\chi = \frac{\chi_A + \chi_B}{2} = \frac{1.9 + 1.6}{2} = 1.8$	$\Delta\chi = \chi_A - \chi_B = 1.9 - 1.6 = 0.3$



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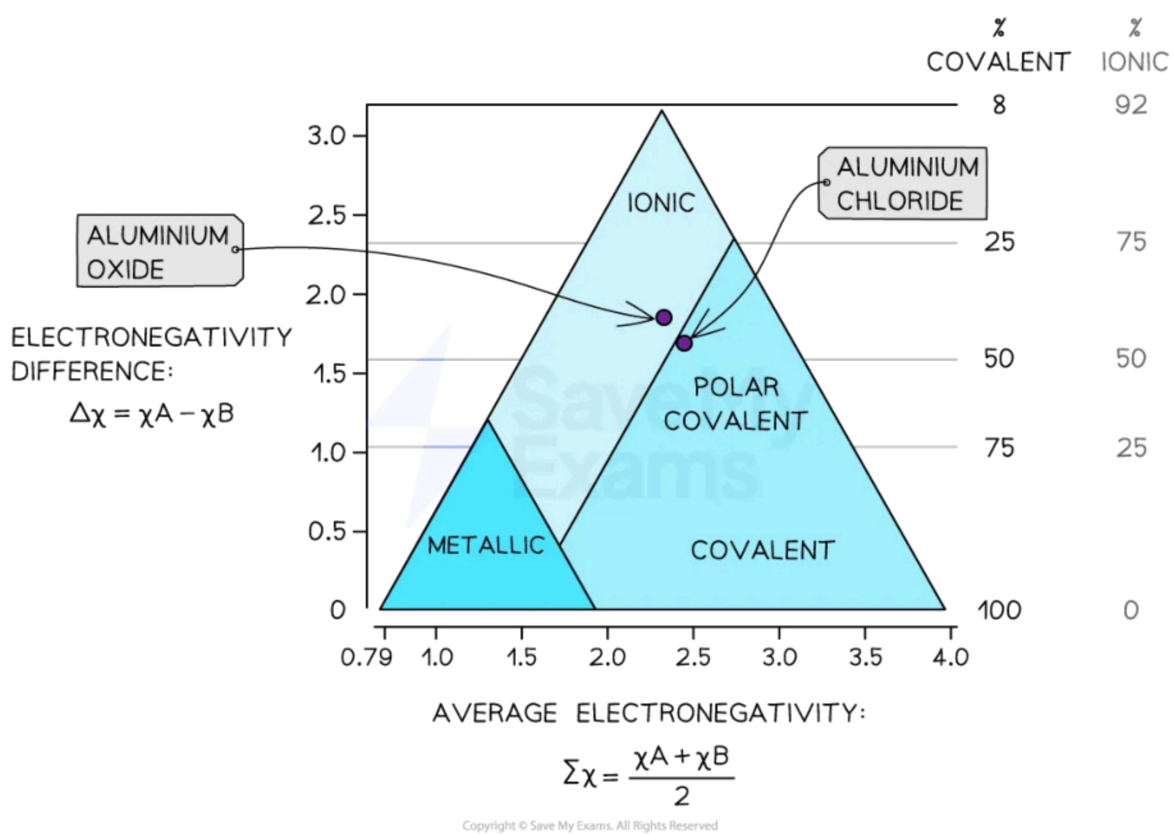
Percentages of Bonding Type

- We can also use the bonding triangle to assess the percentage of ionic or covalent character in a compound
- Take aluminium chloride and aluminium oxide as an example:

Substance	Average electronegativity	Electronegativity difference
aluminium oxide	$\Sigma\chi = \frac{\chi_A + \chi_B}{2} = \frac{1.6 + 3.4}{2} = 2.5$	$\Delta\chi = \chi_A - \chi_B = 3.4 - 1.6 =$
aluminium chloride	$\Sigma\chi = \frac{\chi_A + \chi_B}{2} = \frac{1.6 + 3.2}{2} = 2.4$	$\Delta\chi = \chi_A - \chi_B = 3.2 - 1.6 =$

Percentage of ionic or covalent character diagram



The percentage of bonding type character in aluminium oxide and aluminium chloride can be assessed using the bonding triangle

- From this analysis, we can see why there is a significant difference in properties between aluminium oxide and aluminium chloride
  - The melting point of the oxide is 2072 °C, whereas the chloride is 192°C
- The bonding triangle continuum allows for a more accurate assessment of bonding type and the prediction of associated properties

Examiner Tip

Calculations of percentage ionic character are not required.

Your notes

Properties of Alloys

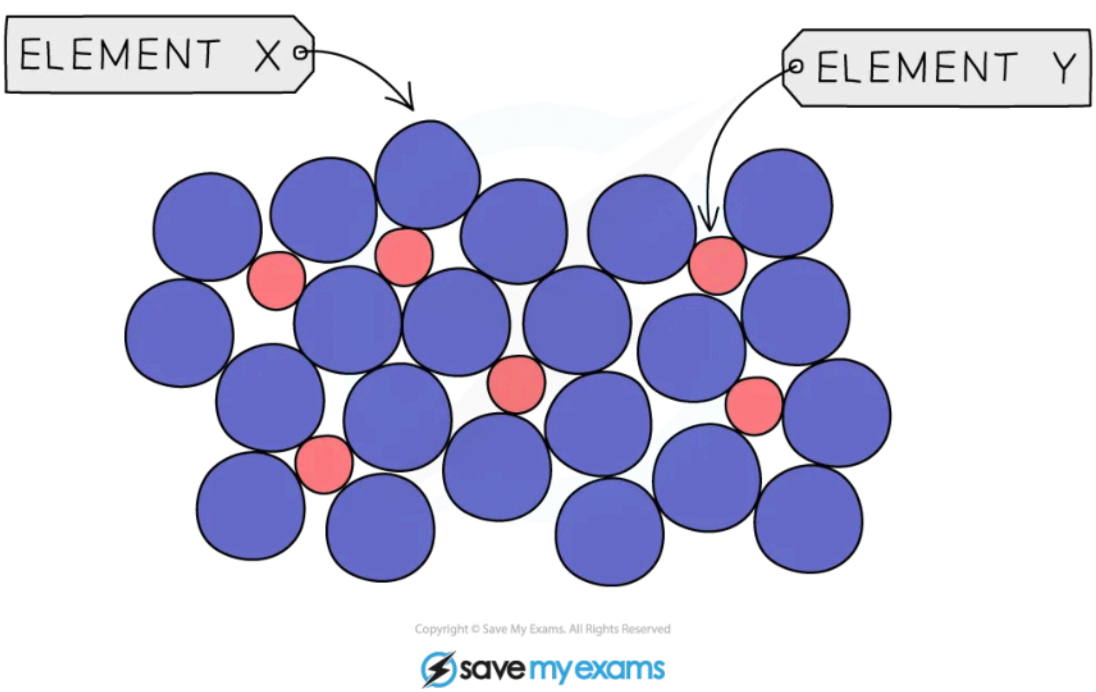
Your notes

Alloys

What is an alloy?

- Alloys are mixtures of metals, where the metals are mixed together physically but are not chemically combined
- They can also be made from metals mixed with nonmetals such as carbon
- Ions of the different metals are spread throughout the **lattice** and are bound together by the **delocalized** electrons
- It is possible to form alloys because of the **non-directional** nature of the metallic bonds

Particle Diagram of an Alloy



In a metallic lattice the regular structure of metal cations (shown by Element Y) is disrupted by the presence of another element (Element X)

Why do alloys have different properties to pure metals?

- Alloys have distinct properties due to the different packing of the cations in the lattice
- Alloys often have properties that can be very **different** to the metals they contain, for example they can have greater **strength, hardness** or **resistance** to **corrosion** or extreme **temperatures**

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- Alloys contain atoms of **different** sizes, which **distorts** the regular arrangements of cations
- This makes it more difficult for the layers to slide over each other, so they are usually much harder than the pure metal
- Below is a table of some common alloys and their uses:

Common Alloys and their Uses Table

Alloy	Elements present	Properties	Uses
Brass	copper and zinc	strong and resistant to corrosion	door handles, hinges, musical instruments
Steel	iron, carbon and other elements like chromium, vanadium and molybdenum	very strong	construction, bridges, cars
Stainless Steel	iron, chromium, nickel, carbon	corrosion resistant	cutlery, surgical instruments, cookware
Solder	lead and tin	low melting point	joining metals in electrical circuits and jewellery
Bronze	copper and tin	hard and strong resistance to corrosion	medals, sculptures, ship fittings

Examiner Tip

You don't need to learn the specific alloys, but you should be able to use examples you know to explain why alloys have the properties they do compared to pure metals

Polymers

Your notes

Polymers

- Polymers are large molecules built by linking 50 or more smaller molecules called **monomers**
- Polymers are known as macromolecules as they are relatively large compared with other molecules
- Each repeat unit is connected to the adjacent units via **covalent bonds**
- Some polymers contain just one type of unit
  - Examples include poly(ethene) and poly(chloroethene), commonly known as PVC
- Others contain two or more different types of monomer units and which are called **copolymers**
  - Examples include nylon and biological proteins
- Different **linkages** also exist, depending on the monomers and the type of polymerisation
  - Examples of linkages are covalent bonds, amide links and ester links

Monomers Forming Polymers Diagram

Your notes

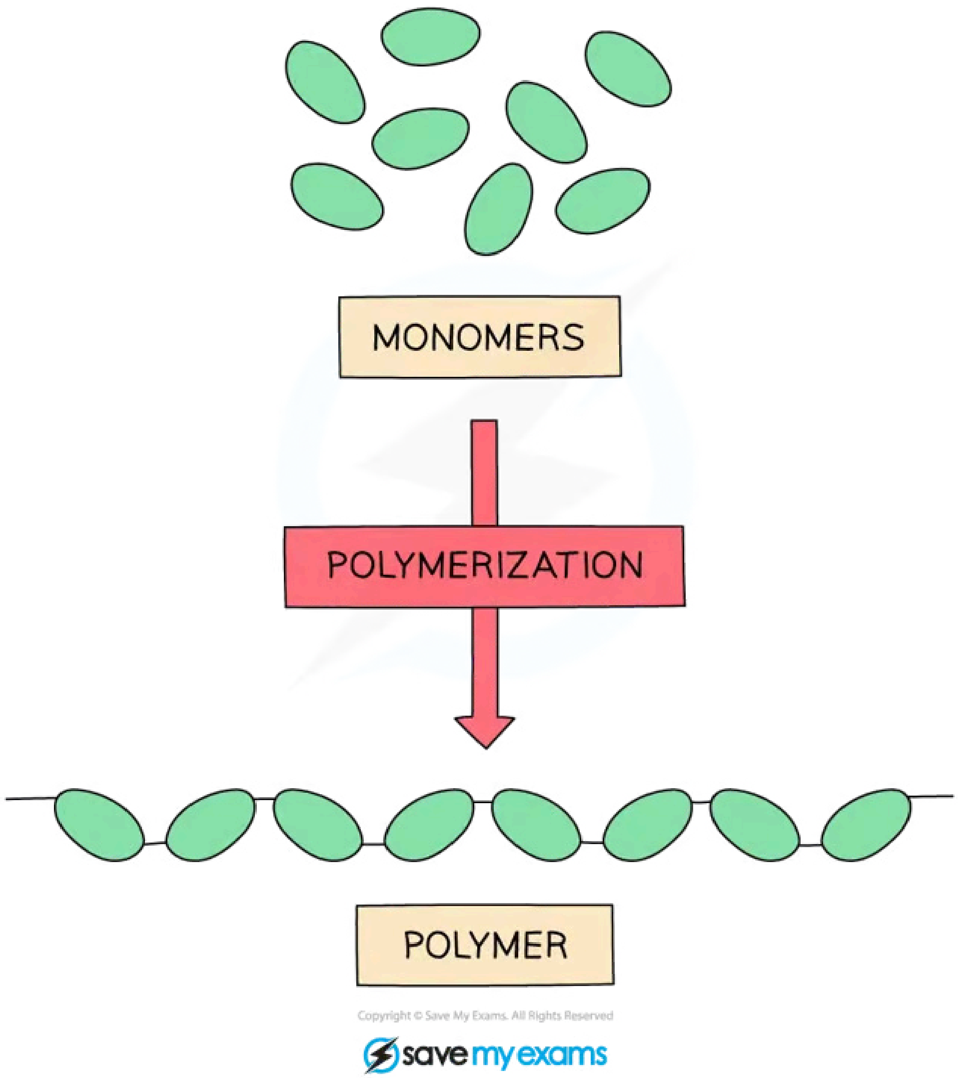

Diagram showing how lots of monomers bond together to form a polymer

- Poly(ethene) is formed by the addition polymerisation of ethene monomers
- Addition polymerisation involves the addition of many monomers to make a long chained polymer
- In this case, many ethene monomers join together due to the carbon carbon double bond breaking
- Polymers are large molecules so their structures re shown as repeating units
  - The polymer poly(ethene) can be represented by the repeating unit below
  - n is the number of monomers in the polymer

Ethene forming poly(ethene) Diagram

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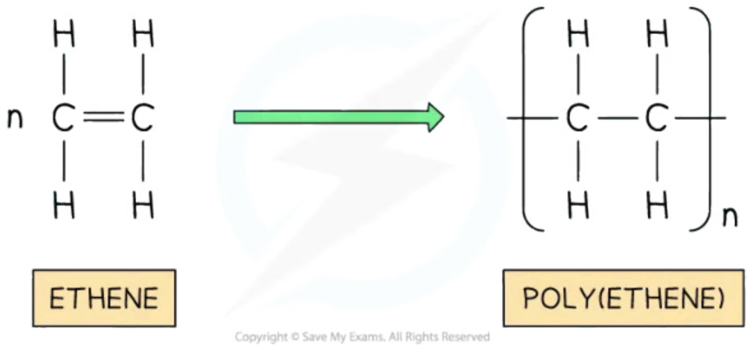

Poly(ethene) is formed by addition polymerisation using ethene monomers

Properties of plastics

- Low weight
  - Polymers are loosely packed so will be less dense and lighter than other materials such as metals
- Unreactive
  - The addition polymers made from alkenes are saturated compounds because they do not contain double bonds and the main carbon chain is non-polar and will therefore are unreactive
- Water resistant
  - Polymers are hydrophobic so they repel water instead of absorbing it
- Strong
  - Polymers so are made up of many strong covalent bonds between the monomers
- These properties make plastics useful for packaging, construction, clothing and transportation

Natural and synthetic polymers

- Proteins, DNA and starch are examples of **natural polymers**
  - Understanding the structure and function of natural polymers has been a major focus of biochemical research for the last 100 years and have contributed to the advancement of vaccines and medicines

DNA is an example of a natural polymer

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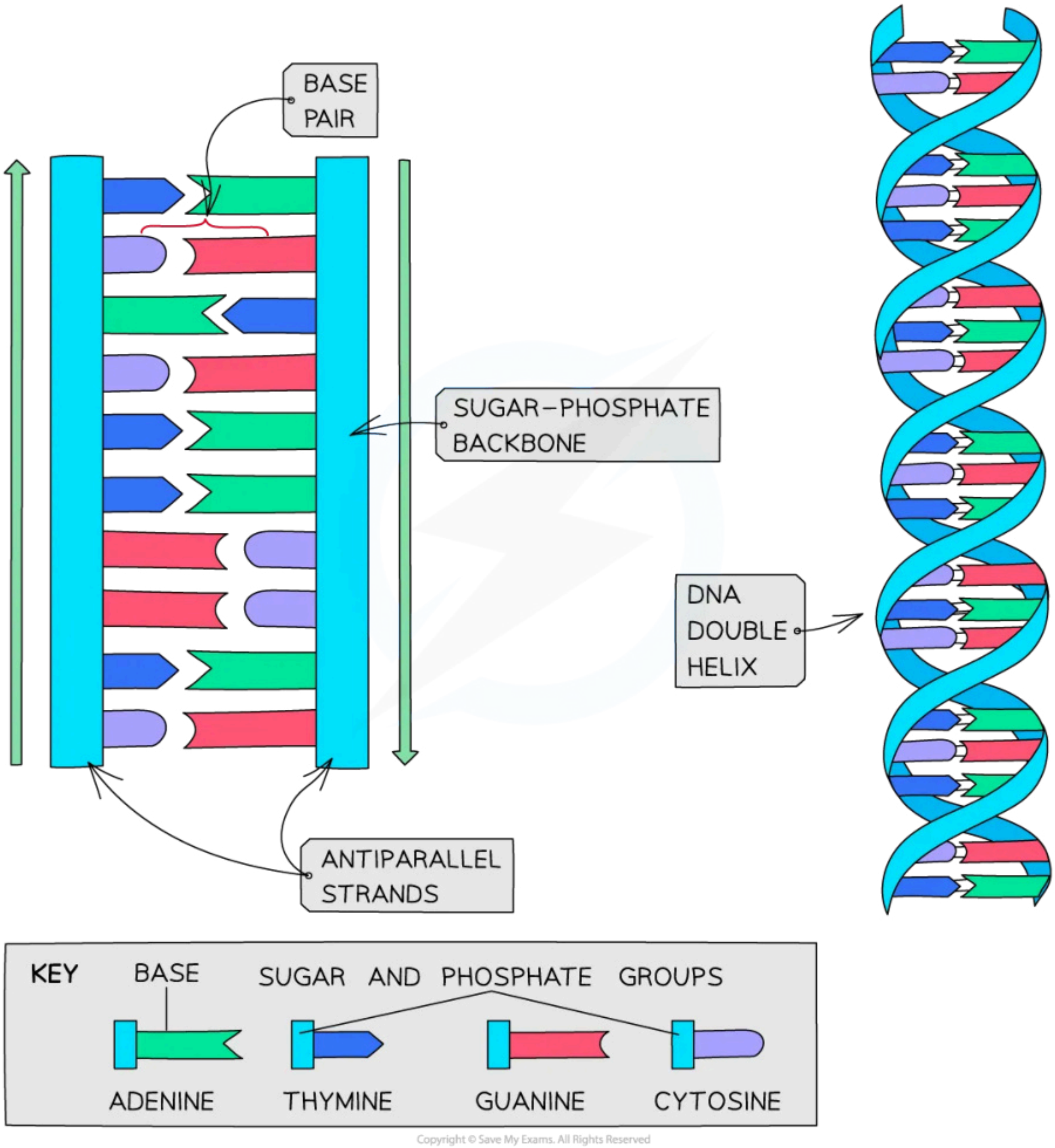
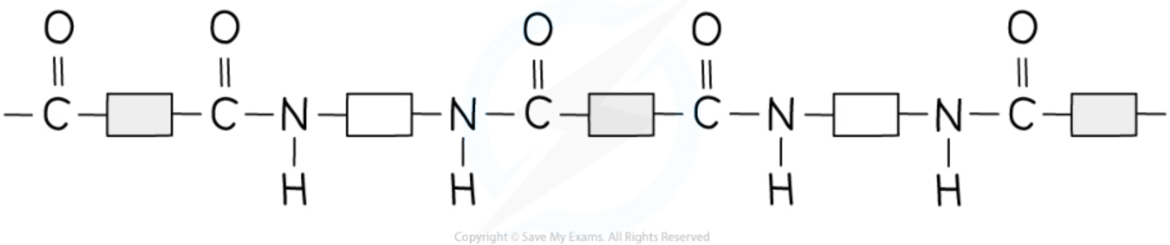


DNA molecules form a three-dimensional structure known as a DNA double helix. It is made from four different monomers known as nucleotides which join together in different combinations to make a long strand

- Plastics are examples of **synthetic polymers** that have widespread uses due to their low weight, low reactivity, water resistance and strength
  - They have become widely distributed across the world
  - Their low reactivity means that they are **non-biodegradable** so will not break down naturally.

- The extensive accumulation of plastics in natural environments remains one of the most pressing environmental concerns

Nylon-6,6 is an example of a synthetic polymer



Nylon-6,6 is formed by condensation polymerisation

Your notes

Your notes

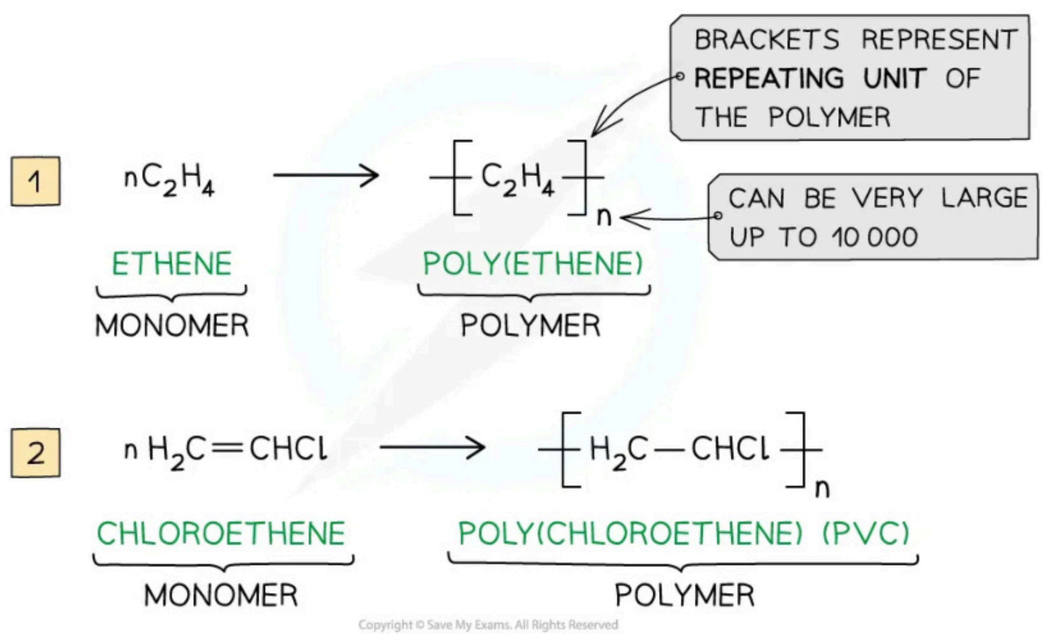
Addition Polymers

Addition Polymers

What is addition polymerisation?

- **Addition polymerisation** is one of the most important addition reactions of alkenes which form the basis of the plastic industry
- Addition polymerisation is the reaction in which many **monomers** containing at least one C=C double bond form long chains of **polymers** as the only product
  - Just like in other addition reactions of alkenes, the π-bond in each C=C bond breaks and then the monomers link together to form new C-C single bonds
- A **polymer** is a long-chain molecule that is made up of many repeating units
- The small, reactive molecules that react together to form the polymer are called **monomers**
- A polymerisation reaction can be represented by a **general formula** or by using **structural / displayed formulae**
  - E.g. poly(ethene) and poly(chloroethene) (also known as **PVC**) are polymers made up of the ethene and chloroethene monomers respectively and are commonly used in making plastics

General Formula Addition Polymerisation



The general formulae of the addition polymerisation of ethene (1) and chloroethene (2)

Displayed / Structural Formula for Addition Polymerisation

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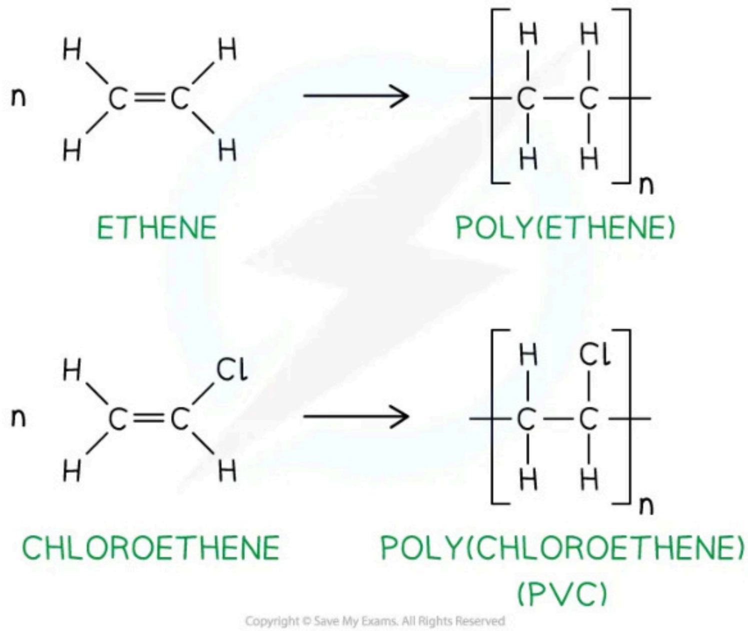

The addition polymerisation of ethene (1) and chloroethene (2)

- Just like any other **addition** reaction of alkenes, addition polymerisation gives only **one** product

Deducing repeat units

- A **repeat unit** is the smallest group of atoms that when connected one after the other make up the polymer chain
  - It is represented by **square brackets** in the displayed and general formula
- In **poly(alkenes)** (such as poly(ethene)) and **substituted poly(alkenes)** (such as PVC) made of **one type of monomer** the repeating unit is the same as the monomer except that the C=C double bond is changed to a C-C single bond

Repeating Units for Addition Polymerisation

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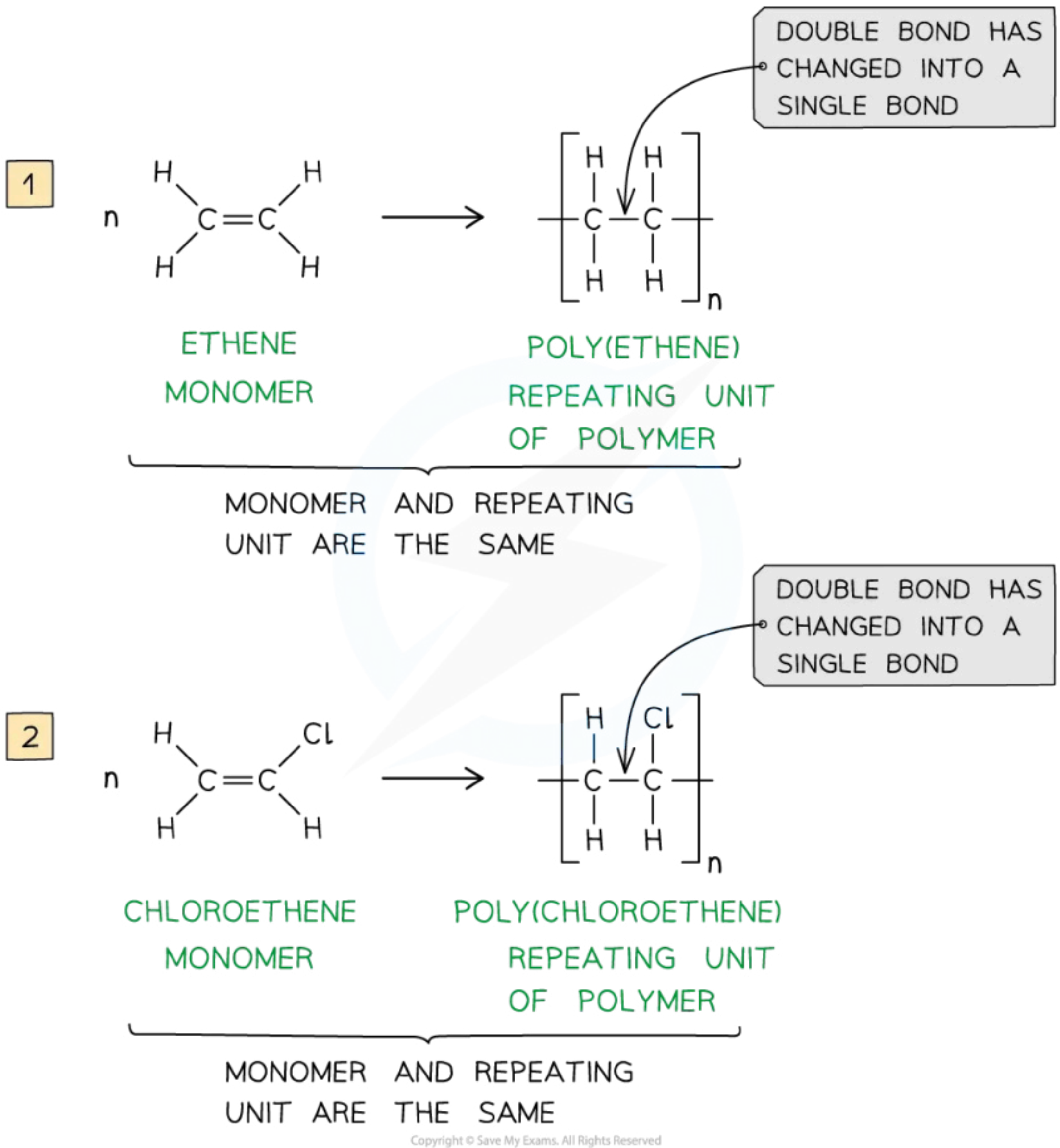
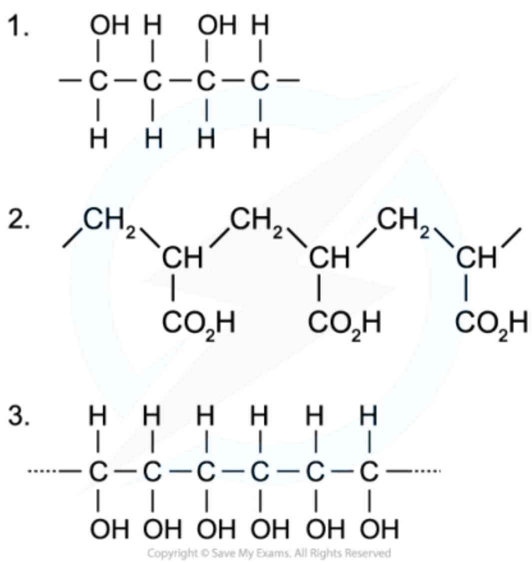


The repeating units of poly(ethene) and poly(chloroethene) are similar to their monomer except that the C=C bond has changed into a C-C bond

Your notes

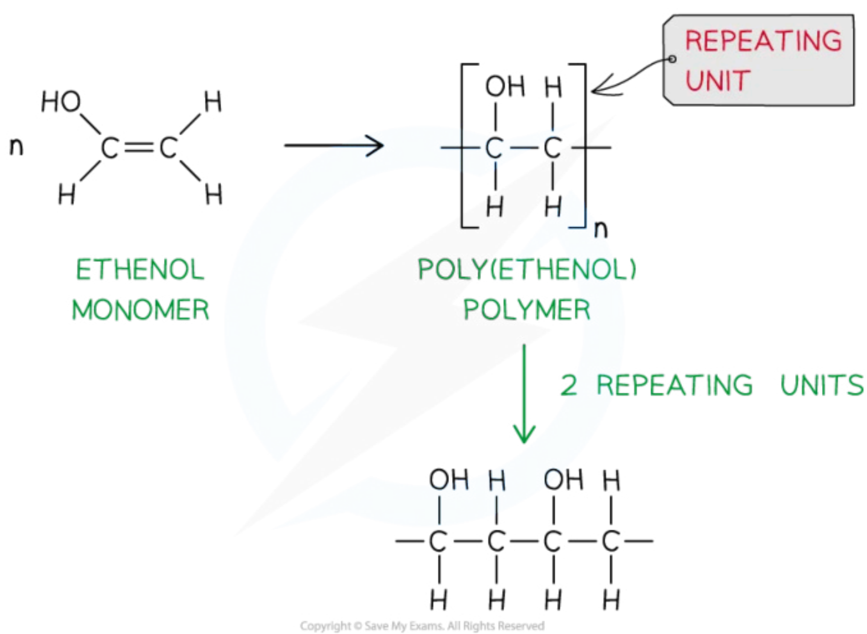
Worked example

Identify the monomers present in the given sections of addition polymer molecules:



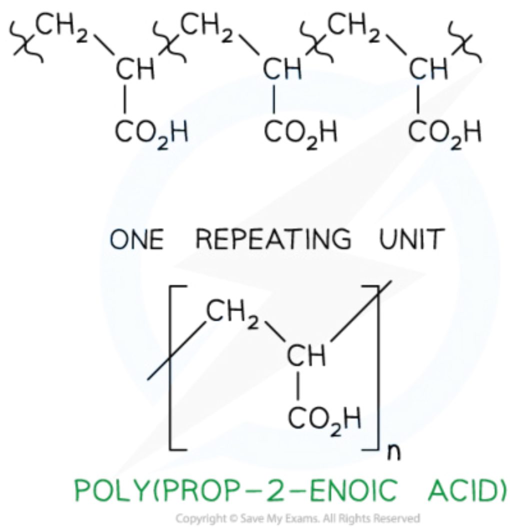
Answer 1:

- When ethenol ($CH(OH)=CH_2$) is polymerised, the C-C double bond opens to produce a repeating unit of $CH(OH)-CH_2$
- This gives the polymer poly(ethenol)

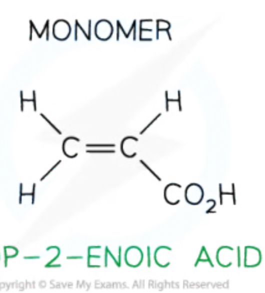


Answer 2:

- To find the monomer, first the repeating unit should be deduced
- Repeating units have only 2 carbons in the polymer main chain



Since the repeating unit is now found, it can be concluded that the monomer is prop-2-enoic acid

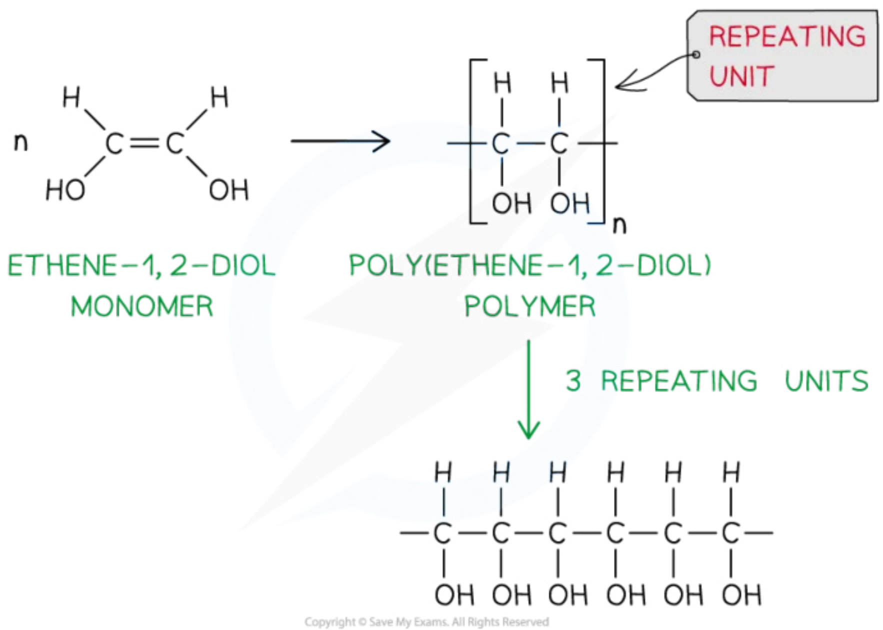


Answer 3:

- Again, the repeating unit only has 2 carbons in the polymer chain which in this case are two carbon atoms that each contain one OH group
- Thus, when ethene-1,2-diol (CH(OH)=CH(OH)) is polymerised, the C=C double bond opens to produce a repeating unit of CH(OH)-CH(OH) which gives the polymer poly(ethene-1,2-diol)

Your notes

Your notes



Examiner Tip

- The section of the polymer chain shown inside the square brackets by the structural or displayed formula is the **repeat unit** and **not** the monomer
- The monomer is the same as the repeat unit except that it has C=C bonds instead of C-C bonds

Your notes

Condensation Polymers (HL)

Condensation Polymers

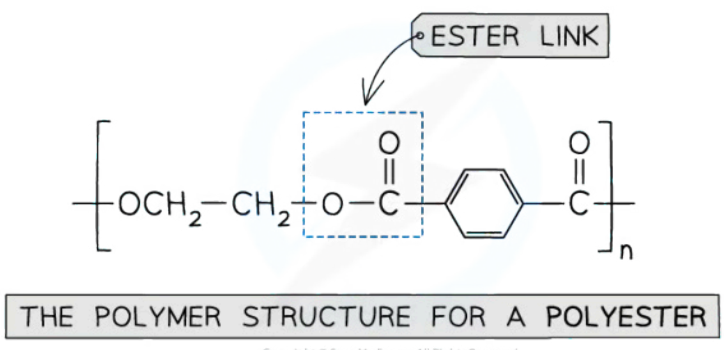
What is condensation polymerisation?

- Condensation polymerisation is another type of reaction whereby a polymer is produced by repeated condensation reactions between monomers
- Natural condensation polymers are all formed by **elimination of water**
  - Although the process of **condensation** polymerisation involves the **elimination of a small molecule**
- **Condensation polymers** can be identified because the monomers are linked by **ester** or **amide links**
- Condensation polymers can be formed by:
  - Dicarboxylic acids and diols
  - Hydroxycarboxylic acids
  - Dicarboxylic acids and diamines
  - Amino acids

What is polyester?

- Polyester is a polymer, most commonly formed by the condensation polymerisation of **dicarboxylic acid monomers** and **diol monomers**
- A polyester is produced by linking these monomers with **ester bonds / links**

Ester Link in a Polyester



This polymer structure shows an ester functional group linking monomers together

Formation of polyesters using diols and dicarboxylic acids

- A diol and a dicarboxylic acid are required to form a polyester
  - A diol contains two alcohol –OH groups
  - A dicarboxylic acid contains two carboxylic acid –COOH groups

Diol and dicarboxylic acid monomer structures

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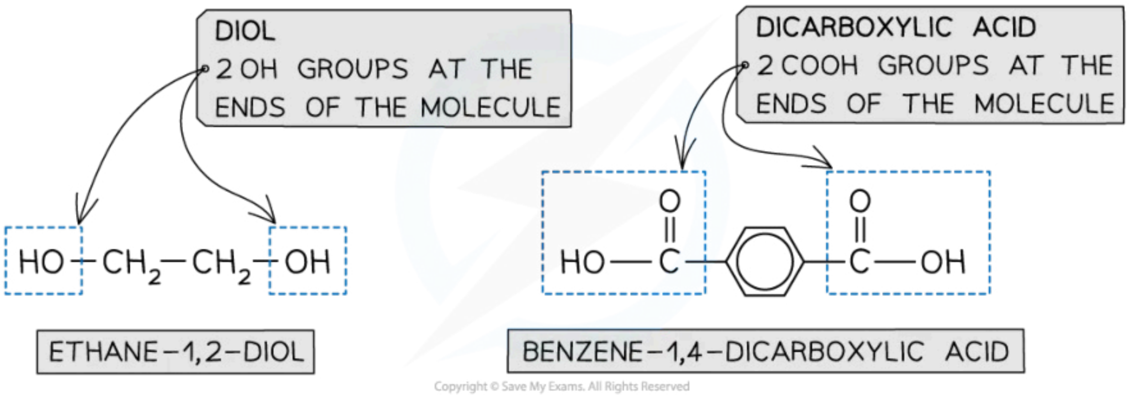
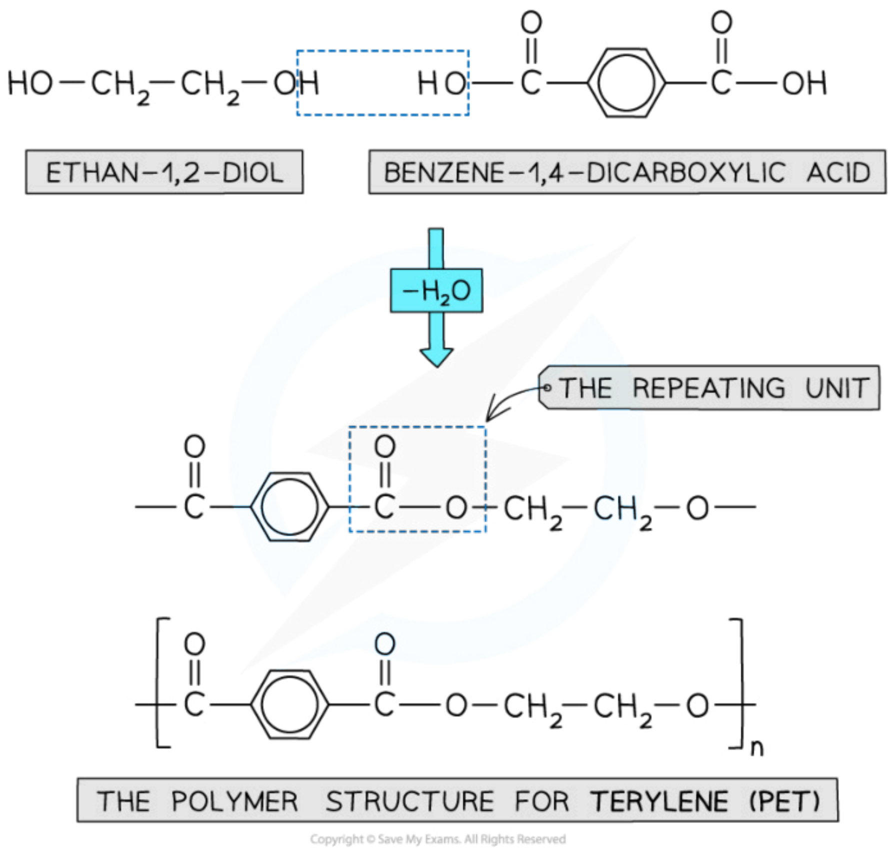


The position of the functional groups on both of these monomer molecules allows condensation polymerisation to take place effectively

- When the polyester is formed, one of the diol –OH groups and a hydrogen atom from one of the carboxylic acid –COOH groups are eliminated as a water molecule (H_2O)
- The resulting polymer is a polyester
  - For example, the polyester **poly(ethylene terephthalate)** or PET, which is sometimes known by its brand names of Terylene or Dacron

Formation of Poly(ethylene terephthalate)



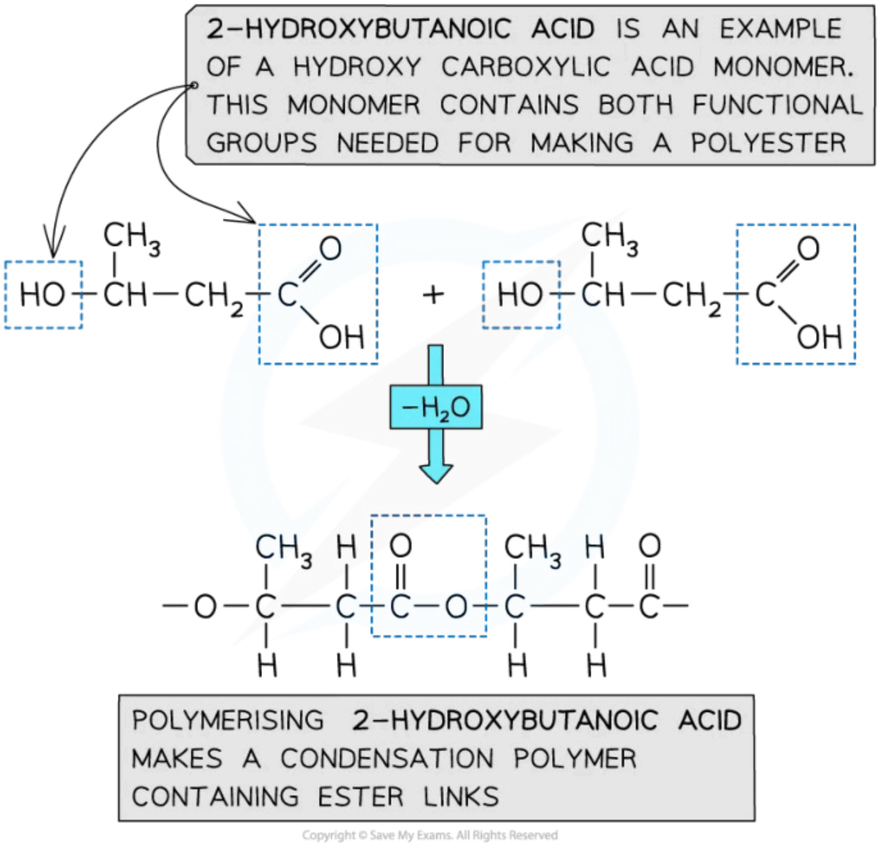
The elimination of a water molecule in this condensation polymerisation forms the polyester called poly(ethylene terephthalate) (PET)

Formation of polyesters using hydroxycarboxylic acids

- So far, the examples of making polyesters have focused on using 2 separate monomers for the polymerisation
- There is another route to making polyesters
- A single monomer containing both of the key functional groups can also be used
  - These monomers are called **hydroxycarboxylic acids**
  - They contain an alcohol -OH group at one end of the molecule and a carboxylic acid -COOH group at the other end of the molecule

Formation of polyesters from hydroxycarboxylic acids

Your notes

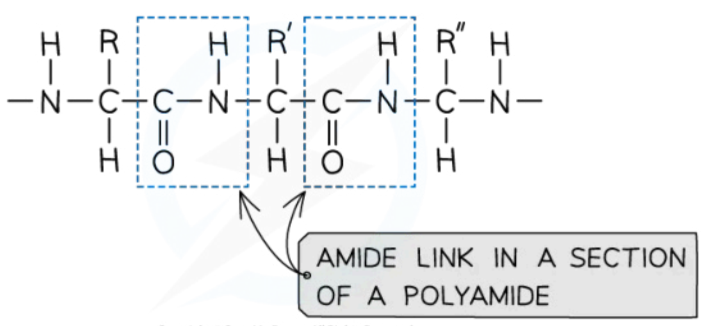


Both functional groups that are needed to form the ester link of the polyester come from the same monomer

What are polyamides?

- Polyamides are polymers where the repeating units are bonded together by amide links
- The formula of an amide group is –CONH

Amide links in Polyamides



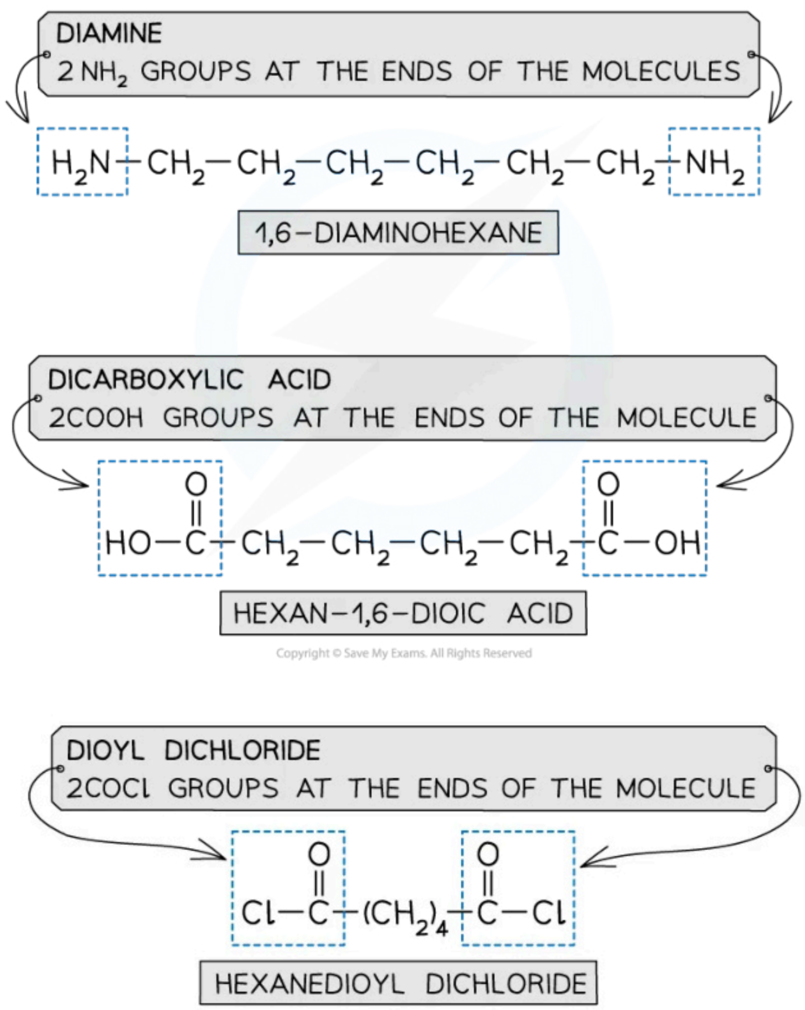
An amide link – also known as a peptide link – is the key functional group in a polyamide

Your notes

Polyamide monomers

- A diamine and a dicarboxylic acid are required to form a polyamide
  - A diamine contains 2 $-NH_2$ groups
  - A dicarboxylic acid contains 2 –COOH groups
- Dioyl dichlorides can also used to react with the diamine instead of the acid
  - A dioyl chloride contains 2 –COCl groups
  - This is a more reactive monomer but more expensive than dicarboxylic acid

Polyamide monomers

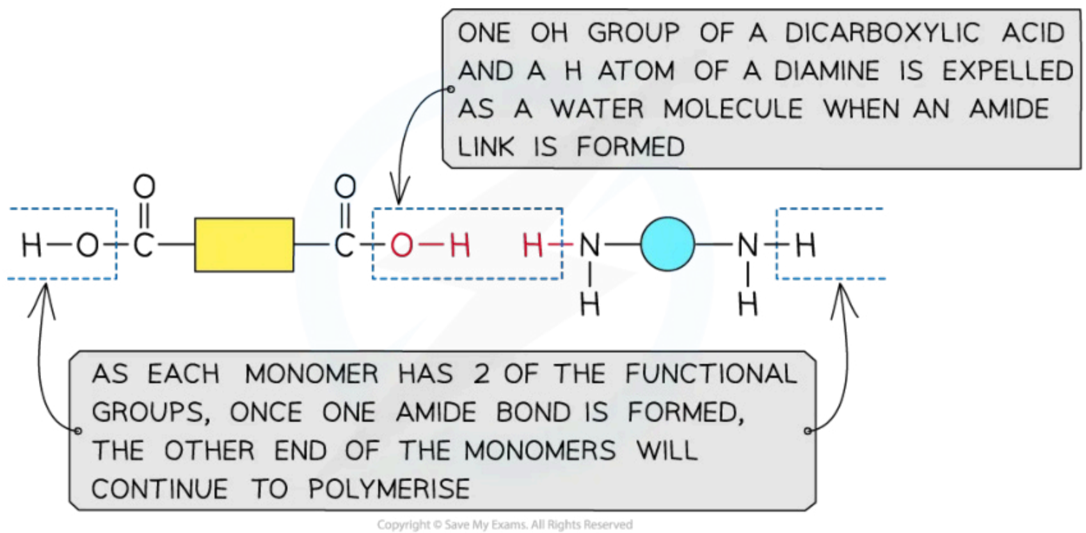


The monomers for making polyamides

Formation of polyamides

Your notes

Formation of Polyamides from Monomers



This shows the elimination of a small molecule as the amide link forms

Biodegradable polymers

- Both polyesters and polyamides can be broken down using **hydrolysis** reactions
- This is a major advantage over the addition polymers produced using alkene monomers (polyalkenes)
- When polyesters and polyamides are taken to landfill sites, they can be broken down easily and their products used for other applications
- Hydrolysis occurs during
  - Digestion
  - Decomposition
- Both condensation and hydrolysis reactions are controlled by **enzymes**

Diagram to show hydrolysis of condensation polymers

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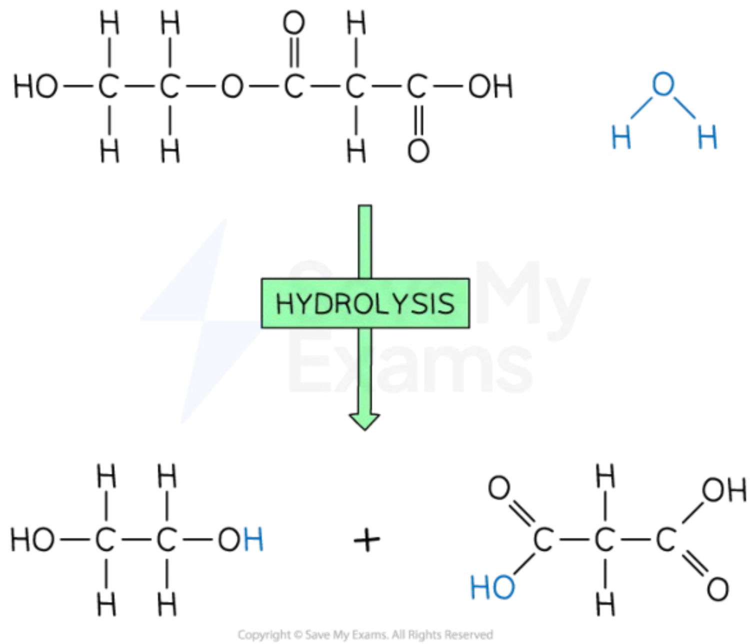

Water is added which causes the polymer to break down into the original monomers