DP IB Chemistry: SL

Your notes

From Models to Materials

Contents

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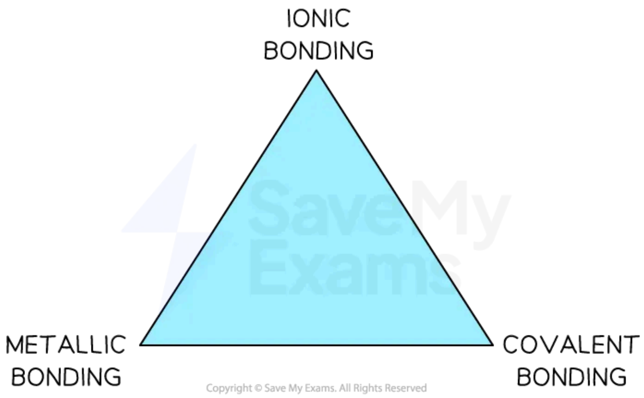
Bonding models

- Bonding models simplify complex systems and allow us to predict the properties of substances
- Chemical bonding broadly falls into three types:
  - Ionic
  - Covalent
  - Metallic
- The bonding types help explain the chemical and physical properties of substances
- However, real bonding situations are more complex than these three bonding types suggest
- For example: Aluminium chloride, $AlCl_3$
  - $AlCl_3$ contains a metal (Al) and non-metal (Cl)
  - Therefore, it would be expected to be:
    - **Ionic bonding**
    - High melting point and boiling point
  - However, $AlCl_3$ melts at 192 °C
    - This is **lower** than expected for an ionic compound
  - This is due to **covalent character**
    - The bonding is **polar covalent**, not purely ionic

Bonding as a continuum

- Bonding is better visualised using a **bonding triangle**, which places compounds on a spectrum:

Simple bonding triangle diagram



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

- The triangle uses:
  - **Electronegativity difference ($\Delta\chi$)** on the **y-axis**
  - **Average electronegativity ($\bar{\chi}$)** on the **x-axis**
- The **Greek letter** for electronegativity is (chi) χ, pronounced 'ky' as in 'sky'

Key relationships:

- Difference in electronegativity:

$$\Delta\chi = \chi_A - \chi_B$$

- Average electronegativity:

$$\bar{\chi} = \frac{\chi_A + \chi_B}{2}$$

How to use the bonding triangle

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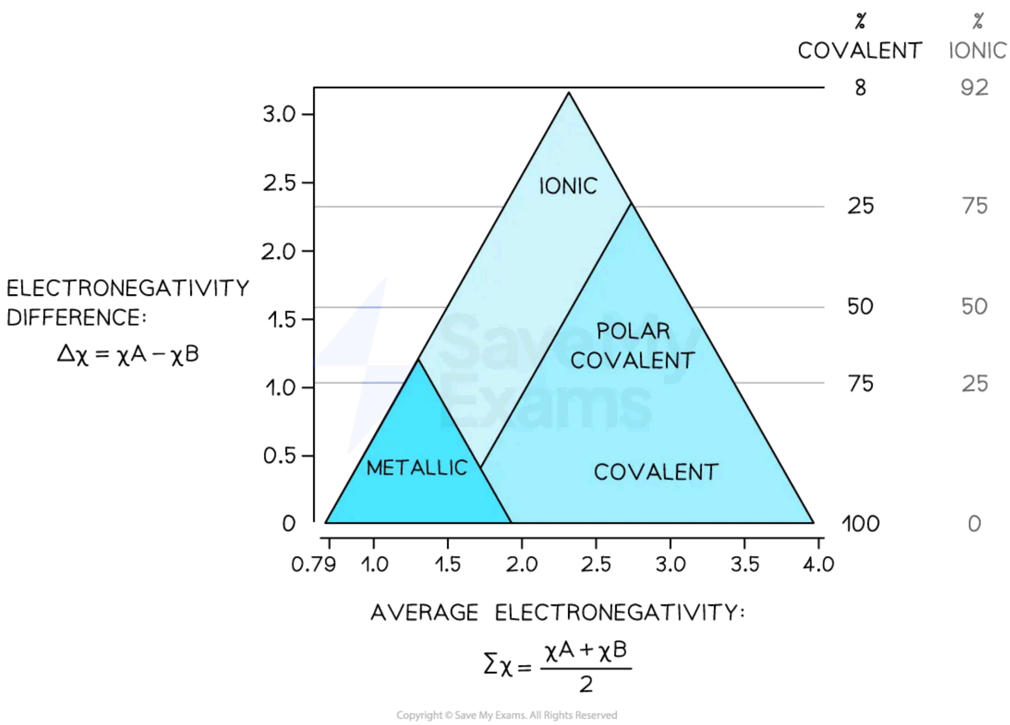

Bonding character is based on electronegativity trends, not just the position in the Periodic Table

- **Elements** have zero $\Delta\chi$ and appear along the **x-axis** depending on their electronegativity
  - **Metals** have zero $\Delta\chi$ and appear along the **x-axis**, but near the metallic corner
- **Ionic compounds** have **large $\Delta\chi$** and are placed near the **apex** of the triangle
- **Covalent compounds** with low $\Delta\chi$ are near the **bottom right**
- **Polar covalent** compounds lie in between ionic and covalent

Examiner Tips and Tricks

IB Data Booklet Links:

- The bonding triangle appears in Section 17 of the IB Chemistry Data Booklet
- Electronegativity values are in Section 9 of the IB Chemistry Data Booklet

You don't need to memorise the bonding triangle. Instead, focus on interpreting it when needed

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Bonding & properties

Understanding the triangular bonding diagram

The triangular bonding diagram is a visual model used to classify chemical bonds by comparing electronegativity values. It shows bonding as a continuum between three idealised types:

- **Ionic bonding** at the top (apex)
- **Covalent bonding** at the bottom right
- **Metallic bonding** at the bottom left

The position of a substance on the diagram is based on two values:

- **x-axis (horizontal)**: average electronegativity of the elements involved
- **y-axis (vertical)**: difference in electronegativity between the two elements

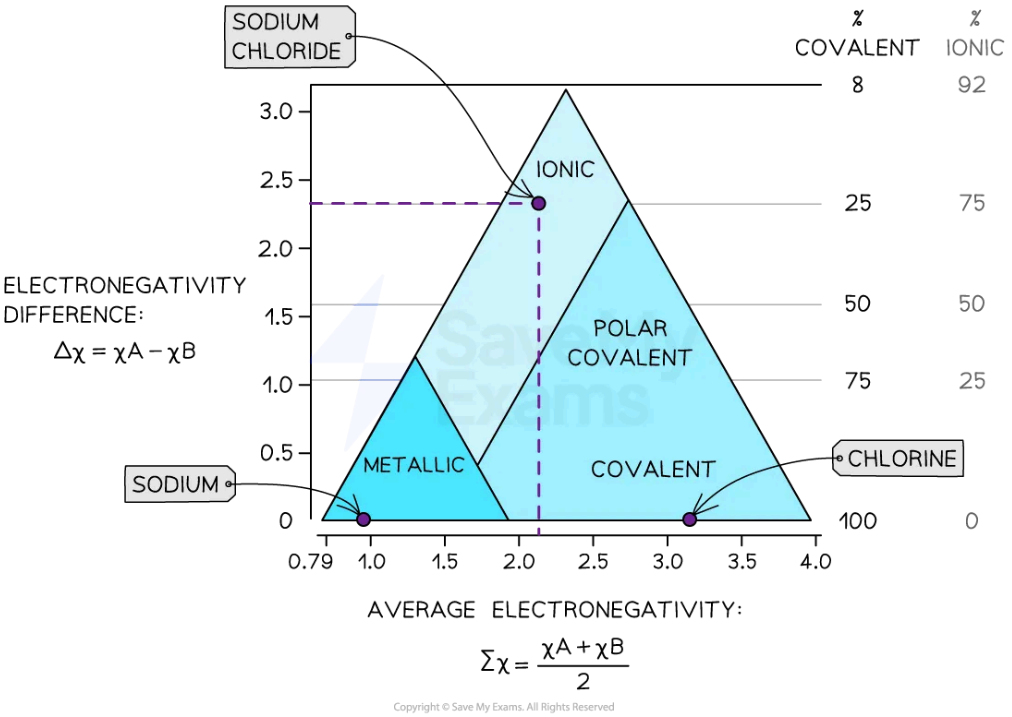
Each compound is plotted using these values in the format *(x, y)*. This determines how much covalent, ionic, or metallic character the bonding has.

Determining the position of a compound

- The electronegativity of elements and binary compounds can be used to find their position in the triangular bonding diagram
- For example, sodium chloride:
    - Sodium (Na)
        - Has an electronegativity value of 0.9
        - As a pure element, the difference in electronegativity is 0
        - This places sodium in the bottom left of the triangle, 100% metallic
    - Chlorine (Cl_2)
        - Has an electronegativity value of 3.2
        - As a diatomic molecule, the difference in electronegativity is 0
        - This places chlorine in the bottom right of the triangle, 100% covalent
    - Sodium chloride (NaCl)
        - Has an average electronegativity value of $\Sigma\chi = \frac{3.2 + 0.9}{2} = 2.05$
        - Has a difference in electronegativity of $\Delta\chi = 3.2 - 0.9 = 2.3$

- This places sodium chloride near the triangle's apex, with around 75% ionic character
- This explains NaCl's high melting point and ability to conduct electricity when molten.

Sodium chloride triangular bonding diagram



The location of sodium chloride, and its component elements, on the bonding triangle using electronegativity values

Worked Example

Use the bonding triangle (Section 17 of the Data Booklet) and electronegativity values (Section 9 of the Data Booklet) to mark the location for the following substances:

a) phosphorus

b) caesium iodide

c) brass (a copper-zinc alloy)

Answers

a) phosphorus

- Has an electronegativity value of 2.2
- Since it's a pure element, the difference in electronegativity is 0
- This places phosphorus at (0, 2.2), at the bottom middle of the triangle as 100% covalent

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b) caesium iodide

- Caesium has an electronegativity value of 1.0
- Iodine has an electronegativity value of 2.7
- The average electronegativity of caesium iodide is:

$$\Sigma\chi = \frac{(1.0 + 2.7)}{2} = 1.85$$

- The difference in electronegativity is:

$$\Delta\chi = 2.7 - 1.0 = 1.7$$

- This places caesium iodide at (1.85, 1.7) in the triangle, as an ionic compound

c) brass (a copper-zinc alloy)

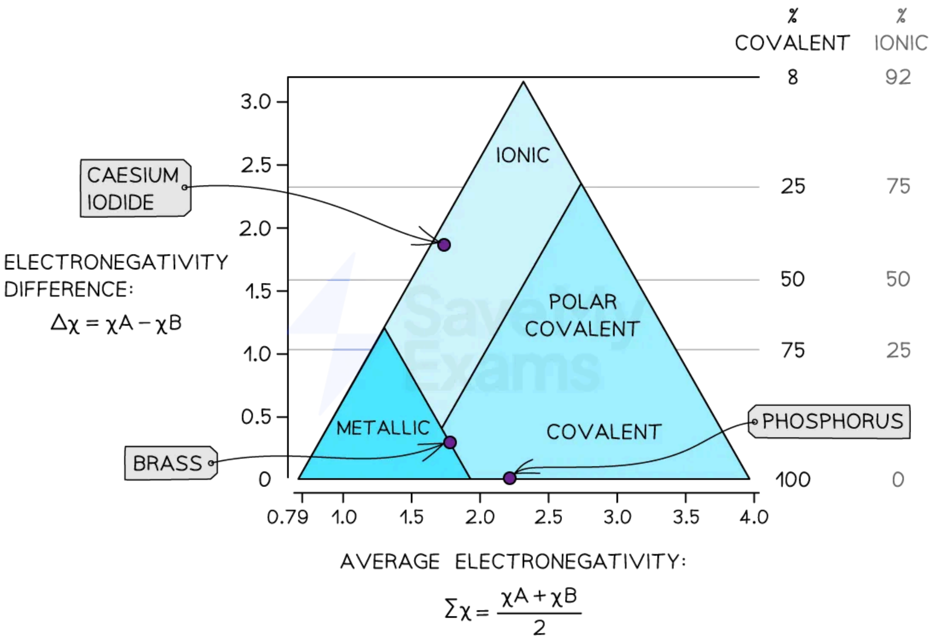
- Copper has an electronegativity of 1.9
- Zinc has an electronegativity of 1.6
- The average electronegativity of brass is:

$$\Sigma\chi = \frac{(1.9 + 1.6)}{2} = 1.75$$

- The difference in electronegativity is:

$$\Delta\chi = 1.9 - 1.6 = 0.3$$

- This places brass at (1.75, 0.3) in the triangle, on the border of metallic and covalent



Percentages of bonding type

- The triangular bonding diagram can help estimate the percentage of ionic or covalent character in a compound
- For example, comparing aluminium chloride ($AlCl_3$) and aluminium oxide (Al_2O_3):
  - Aluminium (Al) has an electronegativity value of 1.6

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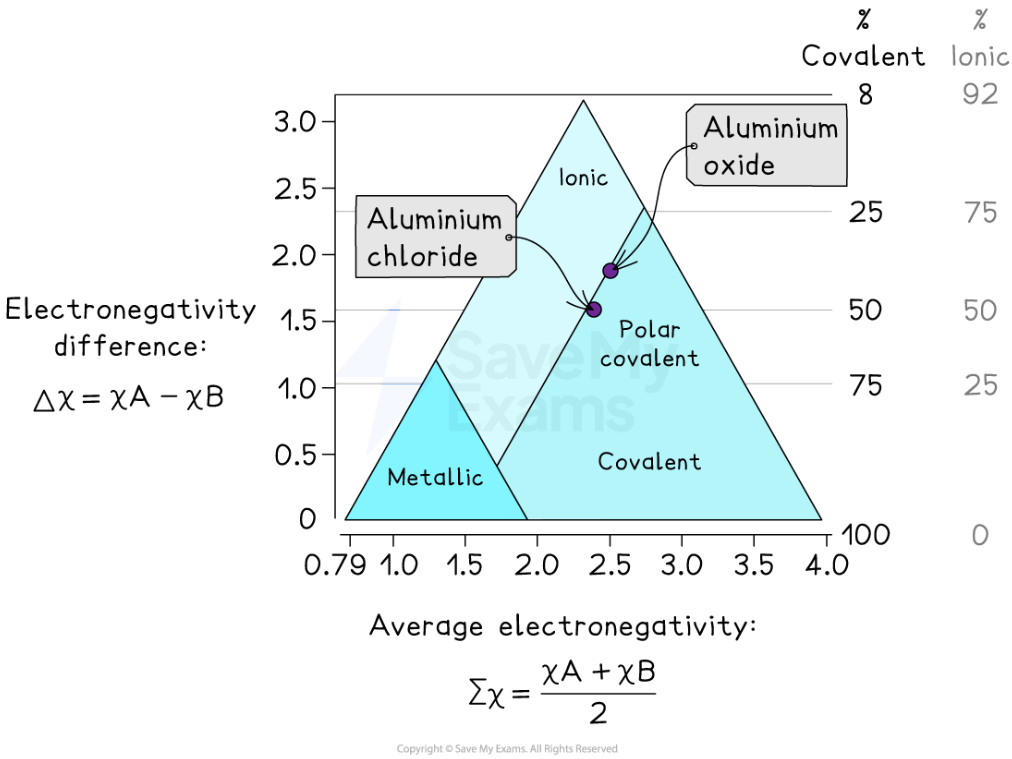
- Chlorine (Cl) has an electronegativity value of 3.2
- Oxygen (O) has an electronegativity value of 3.4
- Aluminium chloride ($AlCl_3$)
  - Has an average electronegativity of $\Sigma\chi = \frac{(1.6 + 3.2)}{2}$ = 2.4
  - Has a difference in electronegativity of $\Delta\chi$ = 3.2 - 1.6 = 1.6
  - This places aluminium chloride at (2.4, 1.6)
    - By finding this point on the diagram and reading horizontally across to the right-hand axis, this corresponds to 50% ionic character
- Aluminium oxide (Al_2O_3)
  - Has an average electronegativity of $\Sigma\chi = \frac{(1.6 + 3.4)}{2}$ = 2.5
  - Has a difference in electronegativity of $\Delta\chi$ = 3.4 - 1.6 = 1.8
  - This places aluminium oxide at (2.5, 1.8)
    - By finding this point on the diagram and reading horizontally across to the right-hand axis, this corresponds to 60% ionic character
- Both $AlCl_3$ and A_2O_3 fall near the 'Polar Covalent' region, indicating that:
  - They have significant ionic character
  - Their bonding also has covalent properties

Percentage of ionic or covalent character diagram



- This helps explain the differences in their properties:
  - Al_2O_3 has a much higher melting point (2072 °C) due to stronger ionic bonding
  - $AlCl_3$ melts at just 192 °C due to weaker covalent interactions

Examiner Tips and Tricks

You do not need to calculate exact percentage ionic character in exams.

Use the bonding triangle (Section 17, Data Booklet) to compare materials qualitatively based on electronegativity data (Section 9, Data Booklet).

- The triangular bonding diagram allows for:
  - Accurately assessing real bonding behaviour
  - Predicting properties like melting point, solubility and electrical conductivity

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Properties of Alloys

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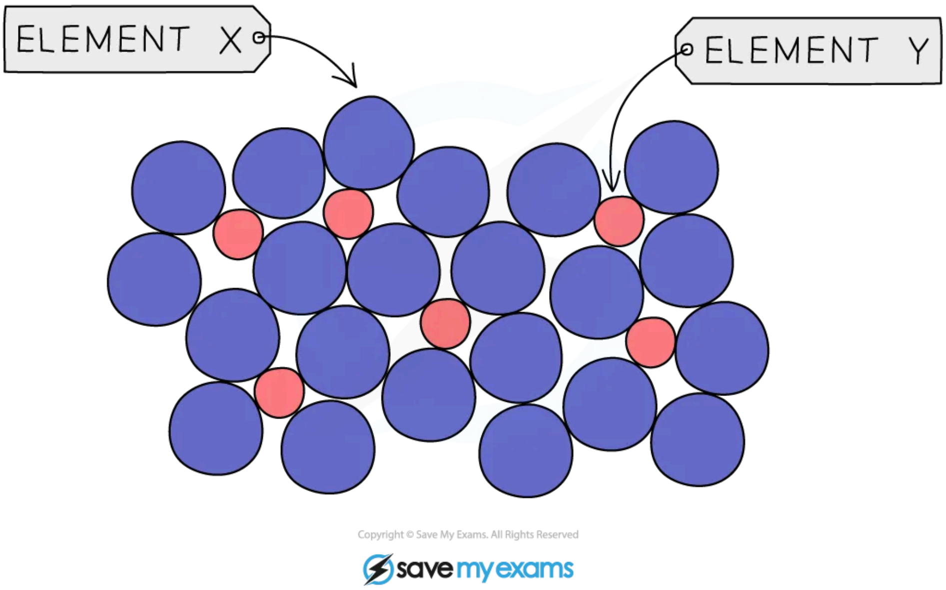
Alloys

What is an alloy?

- An alloy is a mixture of metals, or a metal mixed with a non-metal such as carbon
- The elements are **physically combined** but not chemically bonded
- Atoms of different elements are spread throughout the metallic lattice
- These atoms are held together by **delocalized electrons**, as in pure metals
- Metallic bonds are **non-directional**, allowing atoms of different sizes to occupy the lattice

Particle diagram of an alloy



A regular metal lattice (e.g. element X) is disrupted by a second element (e.g. element Y), making the structure harder and less malleable.

Why do alloys have different properties to pure metals?

- In a pure metal, metal cations are arranged in regular layers
  - This allows them to slide past one another easily, causing the metal to be malleable
- In alloys, atoms of different sizes disrupt this regular pattern:
  - The distorted lattice makes it harder for the layers to slide

- This gives alloys **increased hardness** and **strength** compared to pure metals
- Alloys may also be more **corrosion resistant** or **resistant to extreme temperatures**

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Examples of common alloys

Brass

- **Component elements:** copper and zinc
- **Properties:** Strong and corrosion resistant
- **Uses:** Door handles, hinges, musical instruments

Steel

- **Component elements:** Iron with carbon
  - Often includes other elements such as chromium, vanadium and molybdenum
- **Properties:** Very strong
- **Uses:** Construction, bridges, cars

Stainless steel

- **Component elements:** Iron, chromium, nickel, and carbon
- **Properties:** Corrosion resistant
- **Uses:** Cutlery, surgical instruments, cookware

Solder

- **Component elements:** Lead and tin
- **Properties:** Low melting point
- **Uses:** Joining metals in electrical circuits and jewellery

Bronze

- **Component elements:** Copper and tin
- **Properties:** Hard and corrosion resistant
- **Uses:** Medals, sculptures, ship fittings

Examiner Tips and Tricks

Alloys are a key application of the metallic bonding model, and understanding their structure helps explain their wide range of useful properties

You don't need to memorise specific alloy names, compositions or uses. But you should be able to:

- Compare the properties of an alloy with the pure metal(s) it is made from
- Explain why alloys are generally harder, using ideas about atomic size and lattice disruption
- Use examples provided in the question to support your explanation

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Polymers

What are polymers?

- Polymers are large molecules made by chemically linking many small molecules called **monomers**
- A polymer must contain at least 50 repeating units
- Each unit is joined to the next by **strong covalent bonds**
- Polymers are also known as **macromolecules** due to their large size compared with simple molecules

Monomers forming polymers diagram

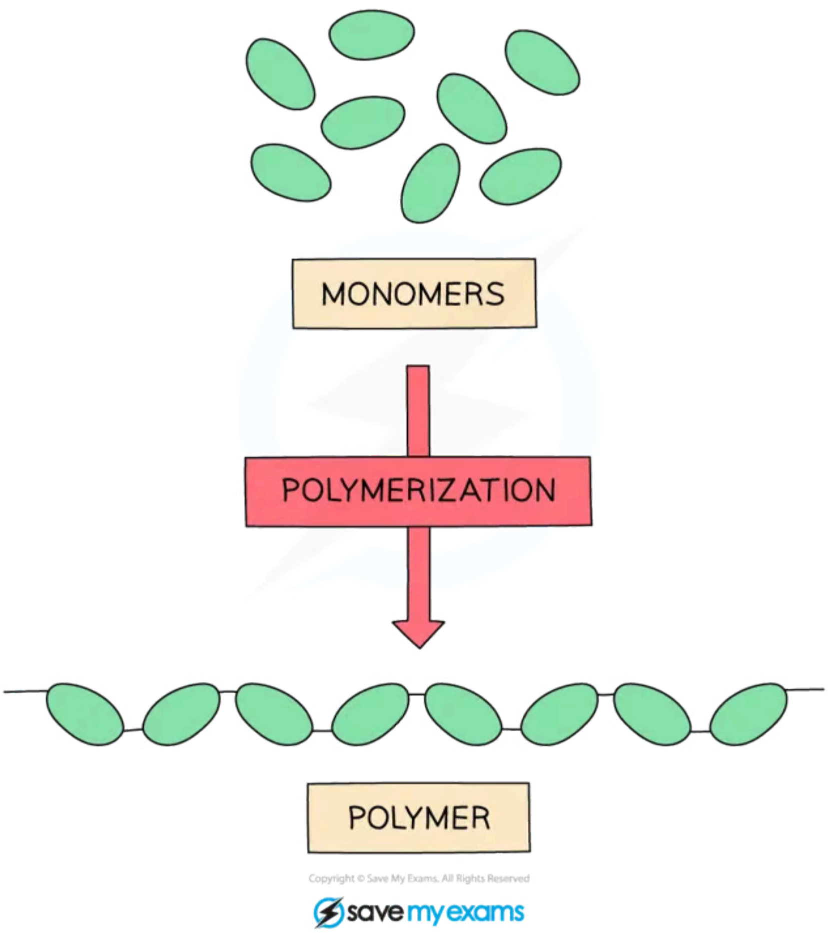


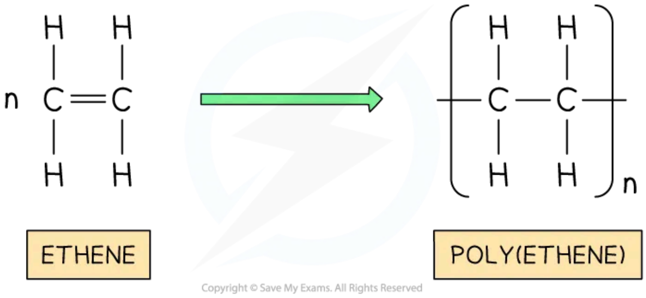
Diagram showing how lots of monomers bond together to form a polymer

- Some polymers contain just one type of monomer 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

Addition polymerisation

- In **addition polymerisation**, many monomers join together without forming any by-products
- The monomers usually contain **carbon–carbon double bonds (C=C)**, which break to form single bonds that link the units
- The polymer **poly(ethene)** is formed from ethene monomers:



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

- Poly(ethene) is made when many ethene molecules join together via addition polymerisation
  - The C=C double bonds open up and link into a chain
- The structure of polymers is usually shown using:
  - A **repeating unit** in square brackets
  - An "n" outside, indicating a large number of monomer units

Properties of polymers

- Plastics are made from long-chain molecules called polymers. Their structure gives them useful properties:
  - **Low density** – Polymer chains are loosely packed, so plastics are lightweight compared to metals or ceramics
  - **Unreactive** – Most plastics don't react easily because the polymer chains are chemically stable
  - **Water-resistant** – Plastics repel water and don't absorb moisture, making them ideal for containers and packaging
  - **Strong** – Polymers are held together by strong covalent bonds, making many plastics tough and durable
- These properties make polymers useful in everyday materials such as **packaging, clothing, construction products, and transportation components**.

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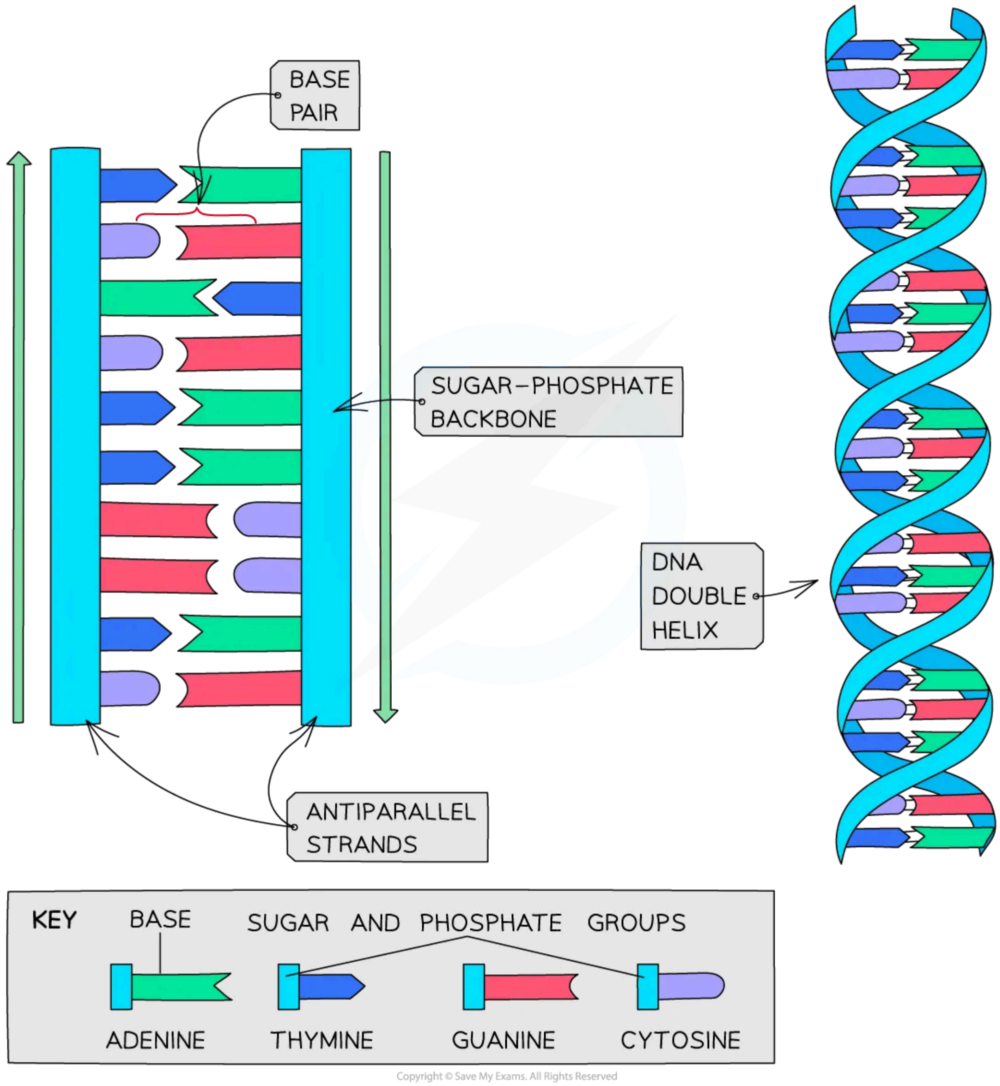
Natural and synthetic polymers

- **Natural polymers** include **proteins**, **starch** and **DNA**
  - These are formed by living organisms from monomers like amino acids or nucleotides
  - DNA forms a **double helix** with millions of linked nucleotides

DNA is a natural polymer



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

- **Synthetic polymers** include **plastics** like **poly(ethene)** and **nylon**
  - These are man-made and have widespread uses due to their durability, low reactivity, and water resistance

Environmental impact of synthetic polymers

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- Synthetic polymers are generally **non-biodegradable** because of their chemical stability
- They do not break down naturally, leading to long-lasting pollution
- The accumulation of plastics in the environment is a major global concern

Examiner Tips and Tricks

You don't need to memorise full polymer structures, but you should be able to:

- Describe how **addition polymerisation** works using alkenes
- Recognise a **repeating unit** in a polymer chain
- Deduce the **monomer** from a polymer structure (and vice versa)
- Use examples like **poly(ethene)** or **PVC** to explain the properties and uses of plastics
- Explain how **polymer properties** (e.g. strength, low reactivity, water resistance) relate to their structure

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Addition polymers

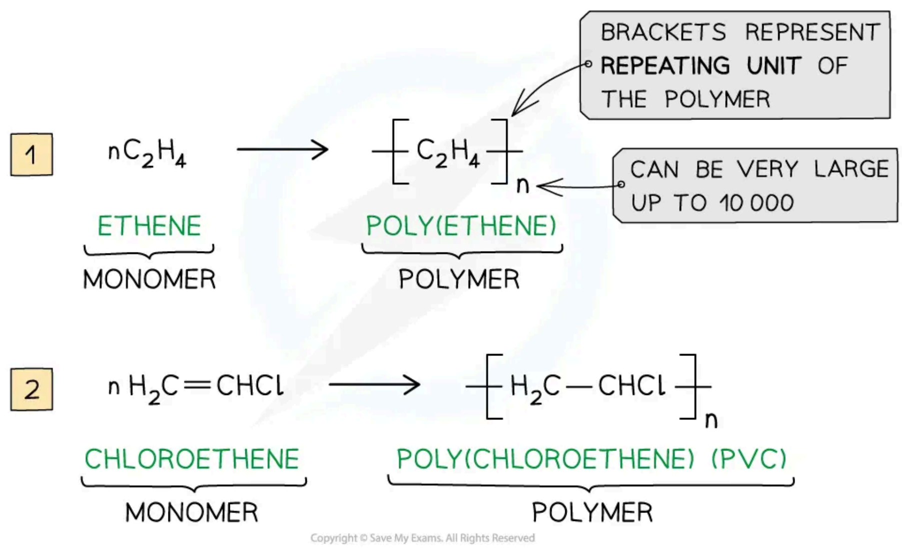
What is addition polymerisation?

- **Addition polymerisation** is an important reaction of alkenes and forms the basis of the plastic industry
- Addition polymerisation involves monomers containing at least one C=C double bond
- These monomers join together to form a long-chain polymer
- The only product is the polymer
  - Just like in other alkene addition reactions, the π-bond in each C=C bond breaks and allows monomers to link by forming 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**
- Examples include:
  - Poly(ethene) - formed from ethene monomers
  - Poly(chloroethene) or PVC - formed from chloroethene monomers

Representing addition polymerisation

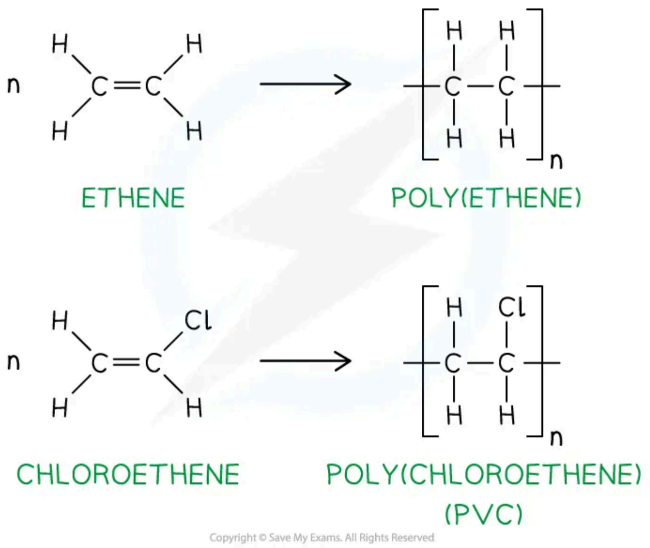
Addition polymerisation reactions can be shown using:

- **General formulae**



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

- **Structural / displayed formulae**



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

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

What is a repeat unit?

- A **repeat unit** is the smallest group of atoms that repeats to form the polymer chain
  - Repeat units are shown inside square brackets [ ]
- In **poly(alkenes)** such as poly(ethene), the repeat unit is the same as the monomer except the C=C becomes a C–C bond

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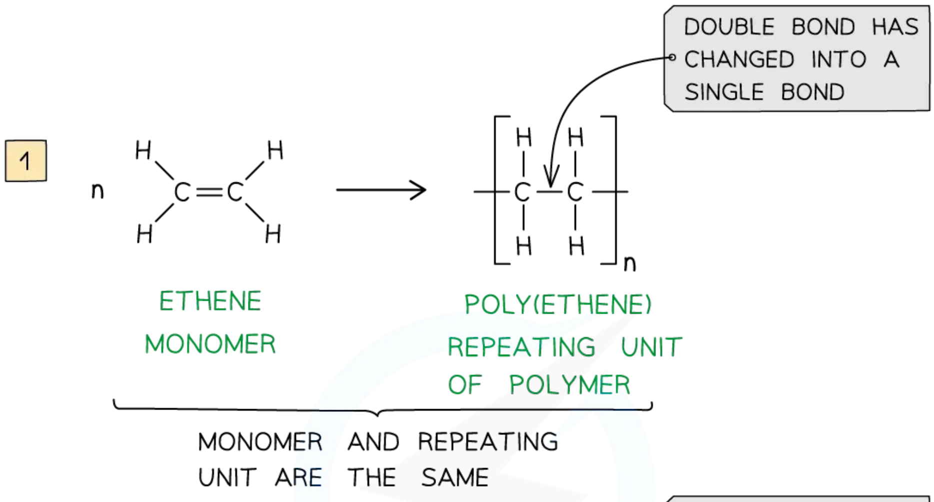

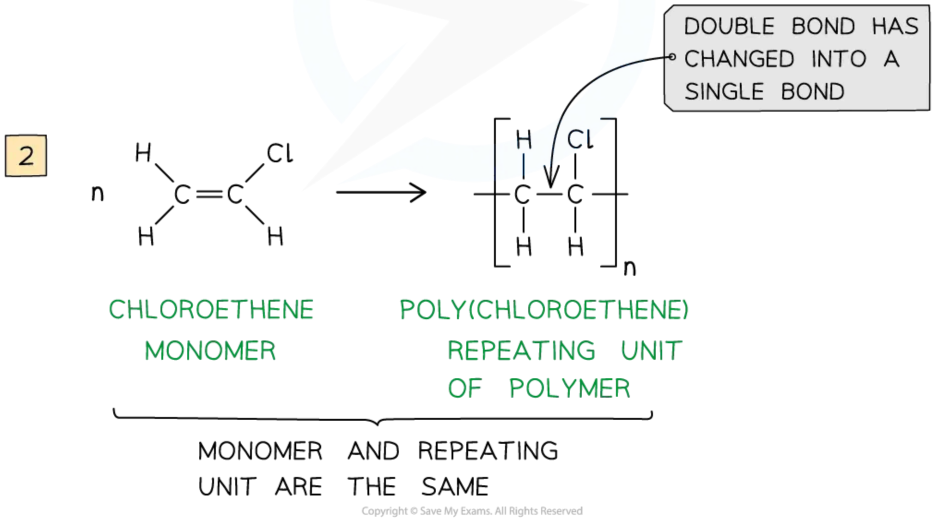

The repeating units of poly(ethene) and poly(chloroethene) are similar to their monomer except that the C=C bond has changed into a C-C bond

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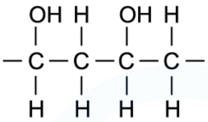
Worked Example

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

1.



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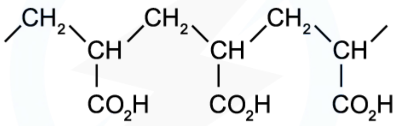
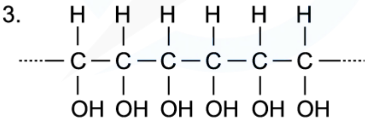
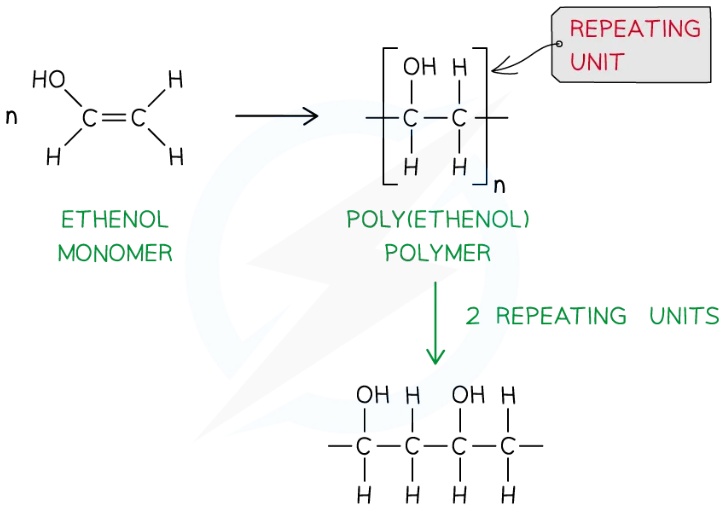


3.



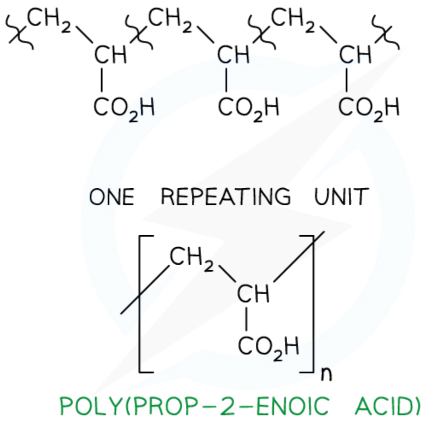
Answer 1:

- The monomer is **ethenol** (CH(OH)=CH_2)
- The C=C double bond breaks, forming a repeating unit of CH(OH)-CH_2
- This gives the polymer poly(ethenol)

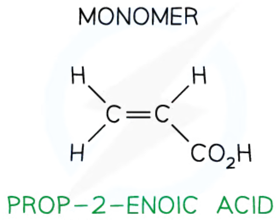


Answer 2:

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

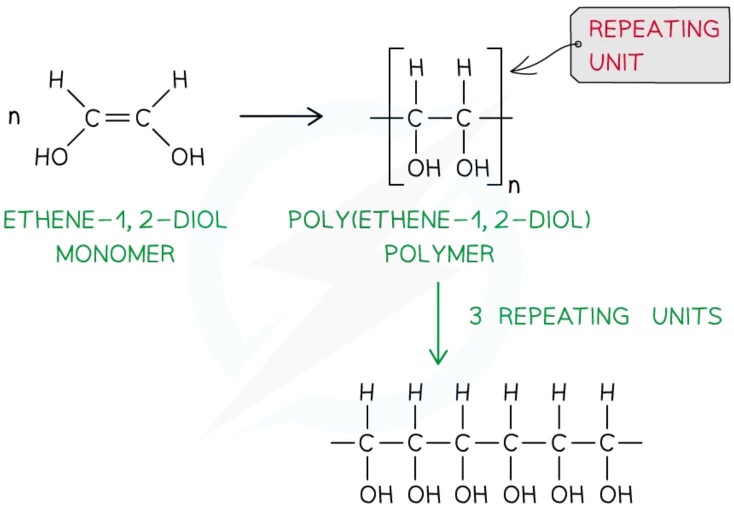


- The monomer is prop-2-enoic acid



Answer 3:

- The repeat unit has two -OH groups on adjacent carbon atoms
- The monomer is **ethene-1,2-diol** (CH(OH)=CH(OH))
- This forms the polymer **poly(ethene-1,2-diol)**



Examiner Tips and Tricks

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- The structure inside square brackets is the **repeat unit** – not the monomer
- The **monomer** is the same as the repeat unit, but with **C=C** bonds instead of **C–C** bonds

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