Bonding, Structure and the Properties of Matter

AQA Chemistry topic 2
2.1 - Chemical bonds, ionic, covalent and metallic
Different forms of elements and compounds

Elements and compounds can form many different structures, including:

1) Ionic, like sodium chloride:

   ![Ionic structure image]

2) Giant covalent structures, like graphite:

   ![Giant covalent structure image]

3) Metallic, like iron:

   ![Metallic structure image]

4) Simple covalent molecules, like methane:

   ![Simple covalent molecule image]
Hi. My name’s Johnny Chlorine. I’m in Group 7, so I have 7 electrons in my outer shell.

I’d quite like to have a full outer shell. To do this I need to GAIN an electron. Who can help me?
Here comes a friend, Sophie Sodium.

Hey Johnny. I'm in Group 1 so I have one electron in my outer shell. I don't like only having one electron there so I'm quite happy to get rid of it. Do you want it?

Now we've both got full outer shells and we've both gained a charge which attracts us together. We've formed an IONIC bond.
Covalent Bonding introduced

Here comes another one of my friends, Harry Hydrogen.

Hey Johnny. I’ve only got one electron but it’s really close to my nucleus so I don’t want to lose it. Fancy sharing?

Now we’re both really stable. We’ve formed a covalent bond.
Ions

An ion is formed when an atom gains or loses electrons and becomes charged:

- The electron is negatively charged.
- The proton is positively charged.

If we “take away” the electron, we’re left with just a positive charge.

This is called an ion (in this case, a positive hydrogen ion).
Ionic bonding

This is where a metal bonds with a non-metal (usually). Instead of sharing the electrons one of the atoms “______” one or more electrons to the other. For example, consider sodium and chlorine:

Sodium has 1 electron on its outer shell and chlorine has 7, so if sodium gives its electron to chlorine they both have a ___ outer shell and are ______.

A ______ charged sodium ion (cation)

Group 1 ______ will always form ions with a charge of +1 when they react with group 7 elements. The group 7 element will always form a negative ion with charge -1.

Words - full, transfers, positively, negatively, metals, anion, stable
Some examples of ionic bonds

Magnesium chloride: $\text{MgCl}_2$

$\text{Mg}^{2+} \text{Cl}^{-}$

Calcium oxide: $\text{CaO}$

$\text{Ca}^{2+} \text{O}^{2-}$
Balancing ions

Some common ions:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Na⁺</td>
</tr>
<tr>
<td>Potassium</td>
<td>K⁺</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg²⁺</td>
</tr>
<tr>
<td>Ammonium</td>
<td>NH₄⁺</td>
</tr>
<tr>
<td>Chloride</td>
<td>Cl⁻</td>
</tr>
<tr>
<td>Bromide</td>
<td>Br⁻</td>
</tr>
<tr>
<td>Oxide</td>
<td>O²⁻</td>
</tr>
<tr>
<td>Sulphate</td>
<td>SO₄²⁻</td>
</tr>
</tbody>
</table>

**Determine the formula of these compounds:**

1) Sodium chloride
2) Magnesium oxide
3) Magnesium chloride
4) Ammonium chloride
5) Sodium sulphate
6) Sodium oxide

**Answers:**

1) NaCl
2) MgO
3) MgCl₂
4) NH₄Cl
5) Na₂SO₄
6) NaO
Giant Ionic Structures

When many positive and negative ions are joined they form a “giant ionic lattice” where each ion is held to the other by strong electrostatic forces of attraction (ionic bonds).

If these ions are strongly held together what affect would this have on the substance’s:

1) Melting point?
2) Boiling point?
3) State (solid, liquid or gas) at room temperature?
Covalent Bonding recap

Here comes another one of my friends, Harry Hydrogen

Hey Johnny. I’ve only got one electron but it’s really close to my nucleus so I don’t want to lose it. Fancy sharing?

Now we’re both really stable. We’ve formed a covalent bond.
Covalent bonding

Consider an atom of hydrogen:

Notice that hydrogen has just ___ electron in its outer shell. A full (inner) shell would have ___ electrons, so two hydrogen atoms get together and “_____” their electrons:

Now they both have a _____ outer shell and are more ______. The formula for this molecule is H₂.

When two or more atoms bond by sharing electrons we call it ____________ BONDING. This type of bonding normally occurs between _______ atoms. It causes the atoms in a molecule to be held together very strongly but there are _____ forces between individual molecules. This is why covalently-bonded molecules have low melting and boiling points (i.e. they are usually _____ or _______).

Words - gas, covalent, non-metal, 1, 2, liquid, share, full, weak, stable
Water, $\text{H}_2\text{O}$:

[Diagram of a water molecule with two hydrogen atoms (H) and one oxygen atom (O) with bonds represented by crosses.]
Oxygen, $O_2$:
Dot and cross diagrams

Water, $\text{H}_2\text{O}$:

Step 1: Draw the atoms with their outer shell:

- $\text{H}$
- $\text{H}$
- $\text{O}$

Step 2: Put the atoms together and check they all have a full outer shell:

- $\text{H}$
- $\text{O}$
- $\text{H}$

Oxygen, $\text{O}_2$:

- $\text{O}$
- $\text{O}$

- $\text{O}$
- $\text{O}$
Dot and cross diagrams

Nitrogen, $N_2$:

Ammonia $NH_3$:

Methane $CH_4$:

Carbon dioxide, $CO_2$:
Other ways of drawing covalent bonds

Consider ammonia (NH$_3$):

Bonds formed between non-metals are usually covalent. Common examples are NH$_3$, CO$_2$, CH$_4$, H$_2$O etc.
Giant Covalent structures

Here are some examples of giant covalent structures:

1. Diamond – a giant covalent structure containing only carbon atoms.

2. Graphite – carbon atoms arranged in a layered structure.

3. Silicon dioxide (sand) – a giant covalent structure of silicon and oxygen atoms.
A polymer is a large molecule made from lots of smaller molecules (monomers). For example, consider polythene:

\[
\text{Ethene} + \text{Ethene} \rightarrow \text{Poly(e)thene}
\]

**General formula for addition polymerisation:**

\[
n \left( \begin{array}{c} C \equiv C \\ H \quad \text{CH}_3 \\ H \end{array} \right) \rightarrow \left( \begin{array}{c} -C -C - \\ -C -C - \\ -C -C - \end{array} \right)_n
\]
Metallic Bonding

Metals are defined as elements that readily lose electrons to form positive ions. The atoms exist in giant structures where the electrons in the highest shells are delocalised and surround positive ions. There are a number of ways of drawing this:

Delocalised electrons
2.2 - How bonding and structure are related to the properties of a substance
Particle theory is all about explaining the properties of solids, liquids and gases by looking at what the particles do.

In a solid the particles _______ around a _____ position. There is a _______ force of attraction between each particle and they are very _____ together.

Words - strong, close, vibrate, fixed
LIQUIDS

In a liquid the particles are _____ together but can move in any direction. They won’t keep a _____ shape like _____ do.

GASES

In a gas the particles are very far apart and move _____ in all directions. They often ______ with each other and because they are far apart they can be easily ________.

Notice that the individual particles have very different properties compared to when they are in bulk.

Words - fixed, collide, quickly, close, squashed, solids
Particle theory questions

Using particle theory explain how the following work:

1) A 2l drinks bottle filled with air can be squashed

2) A 2l drinks bottle filled with water is difficult to squash

3) Liquids and gases can be poured whereas solids can’t

Each question is worth 3 marks!!!
What are these processes called? Choose from freezing, evaporating, melting, condensing.
This flat line shows where energy is being used to break bonds - this has to be done during melting.

This flat line shows where energy is being used to push the particles further apart for evaporation.
Limitations of this model (higher)

The particle model does have a few limitations...

1) The particles can be represented as spheres

2) All spheres are assumed to be solid

3) There are no forces between the spheres

Q. How does this explain a change of state?
Here is some data about the halogens in group 7. What state would each one be in at room temperature?

<table>
<thead>
<tr>
<th>Element</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flourine</td>
<td>-220</td>
<td>-188</td>
</tr>
<tr>
<td>Chlorine</td>
<td>-101</td>
<td>-34</td>
</tr>
<tr>
<td>Bromine</td>
<td>-7</td>
<td>59</td>
</tr>
<tr>
<td>Iodine</td>
<td>114</td>
<td>184</td>
</tr>
</tbody>
</table>
Consider this reaction:

Sodium + water $\rightarrow$ sodium hydroxide + hydrogen

\[ 2\text{Na}(s) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{NaOH}(aq) + \text{H}_2(g) \]

$s = \text{solid}$  
$l = \text{liquid}$  
$aq = \text{aqueous solution}$  
$g = \text{gas}$
Giant Ionic Structures

When many positive and negative ions are joined they form a “giant ionic lattice” where each ion is held to the other by strong electrostatic forces of attraction. This is an “ionic bond”:

If these ions are strongly held together what affect would this have on the substance’s:

1) Melting point?
2) Boiling point?
3) State (solid, liquid or gas) at room temperature?
Dissolving Ionic Structures

When an ionic structure like sodium chloride is dissolved it enables the water to conduct electricity as charge is carried by the ions:
Properties of simple molecules

Recall our model of a simple covalent compound like hydrogen, $H_2$:

Hydrogen has a very low melting point and a very low boiling point. Why?

1) The intermolecular forces are very weak so each one of these $H_2$ molecules doesn't really care about the others - it's very easy to pull them apart.

2) When a substance is heated it is the intermolecular forces that are overcome, NOT the covalent bond in each molecule, which is much stronger!

Also, the molecules do not carry a charge so covalent compounds usually do not conduct electricity.
Recall this data about group 7. Can you explain why the melting and boiling points get bigger as you go down the group?

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</table>

The intermolecular forces get bigger as the molecules get bigger. This is why melting point and boiling points go up.
Polymers

Polymers are large chains of small molecules joined together:

Ethene + Ethene → Poly(e)thene

General formula for polymerisation:

\[ \text{C} = \text{C} \quad \text{C} = \text{C} \quad n \quad \text{C} - \text{C} \quad n \]

These substances are solid at room temperature. What does this tell you about the bonds in these molecules?
Some examples

$$n\begin{array}{c}
\text{H} \\
\text{C} = \text{C} \\
\text{H}
\end{array} \rightarrow \begin{array}{c}
\text{H} \\
\text{C} - \text{C} \\
\text{H}
\end{array}$$

$$n\begin{array}{c}
\text{H} \\
\text{C} = \text{C} \\
\text{Cl}
\end{array} \rightarrow \begin{array}{c}
\text{H} \\
\text{C} - \text{C} \\
\text{Cl}
\end{array}$$

$$n\begin{array}{c}
\text{H} \\
\text{C} = \text{C} \\
\text{Br}
\end{array} \rightarrow \begin{array}{c}
\text{H} \\
\text{C} - \text{C} \\
\text{Br}
\end{array}$$
Metals are defined as elements that readily lose electrons to form positive ions. The electrons in the highest shells are delocalised and able to move around, causing the ions to be held together by strong electrostatic forces, causing metals to have high melting points.
Metals and Alloys

Metals are also easy to bend. This is because the layers slide over each other:

A pure metal:

An alloy is a mixture of metals that causes the metal to behave differently:
Alloys

Steel is an “alloy” – i.e. a mixture of metals. Here are other alloys:

- Gold mixed with copper
- Aluminium mixed with magnesium and copper
- Aluminium mixed with chromium
Understanding thermal and electrical conductivity

As we’ve said before, metals have delocalised electrons that enable them to conduct electricity and heat very well:

The delocalised electrons can move around the metal ions. This is how metals conduct heat and electricity.
2.3 - Structures and Bonding of Carbon
Giant Covalent structures ("lattices")

1. Diamond - a giant covalent structure with a very ____ melting point due to ______ bonds between carbon atoms.

2. Graphite - carbon atoms arranged in a layered structure, with free _______ in between each layer enabling carbon to conduct _________ (like metals). Graphite has a high melting point.

3. Silicon dioxide (sand) - a giant covalent structure of silicon and oxygen atoms with strong ______ causing a high _______ point and it’s a good insulator as it has no free electrons.

Words - melting, high, electrons, bonds, strong, electricity
<table>
<thead>
<tr>
<th>Element/compound</th>
<th>Property</th>
<th>Uses</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon - diamond</td>
<td>Very hard</td>
<td>Drill tips</td>
<td>Extremely strong covalent structure</td>
</tr>
<tr>
<td>Silicon dioxide</td>
<td>High melting point (1610°C)</td>
<td>Furnace linings</td>
<td>Very difficult to melt</td>
</tr>
<tr>
<td>Silica glass</td>
<td>Doesn’t conduct electricity</td>
<td>Electrical insulators</td>
<td>No free electrons to carry charge</td>
</tr>
</tbody>
</table>
Graphene is a single layer of carbon atoms and is only one atom thick.

Q. What are the possible uses for graphene?
Carbon can also be used to make structures called “fullerenes” (carbon atoms forming an empty shape). Fullerenes are compounds used for applications such as drug delivery, lubricants, catalysts and nanotubes and they have structures based on carbon atoms forming hexagonal rings:

A “carbon nanotube” – high tensile strength, high electrical conductivity and high thermal conductivity

“Buckminster fullerene” – the first fullerene to be discovered in 1960.
2.4 - Bulk and surface properties of matter including nanoparticles (Chemistry only)
Some Definitions

Coarse particles ($PM_{10}$) - these are particles around $1 \times 10^{-5}$ m and $2.5 \times 10^{-6}$ m in diameter. Coarse particles are often referred to as “dust”.

Fine particles ($PM_{2.5}$) - these are particles around 100nm and 2500nm ($1 \times 10^{-7}$ to $2.5 \times 10^{-6}$ m) in diameter.

Nanoparticles - these are particles around 1-100nm in size ($1 \times 10^{-9}$ to $1 \times 10^{-7}$ m) in diameter. They are only a few hundred atoms big.
Nanotechnology

Task: To find out what nanotechnology is and what it is used for

1) What is nanotechnology?

2) Define the terms nanoparticle and nanocomposite

3) Give 6 examples of its uses

4) Describe some of the future developments of this technology

5) Describe some of the ethical concerns over this technology
Nanotechnology is a new branch of science that refers to structures built from a few hundred atoms and are 1-100nm big. They show different properties to the same materials in bulk, partly because they also have a large surface area to volume ratio and their properties could lead to new developments in computers, building materials etc.

Q. Where does the large surface area come from?

1) What is the total surface area of a cube of sides 1cm?
   - 6cm²

2) What is the surface area to volume ratio for this cube?
   - 6:1

3) What is the total surface area of a cube of sides 10cm?
   - 600cm²

4) What is the surface area to volume ratio for this cube?
   - 0.6:1

5) Which one has the largest surface area to volume ratio - the large one or the smaller one?
   - The smaller one!
Two examples of nanotechnology

The “Nano Carbon Pro” tennis racket uses nanoparticles to increase its strength.

Silver nanoparticles can be used to give fibres antibacterial properties – look at what they do to e-coli bacteria:

- Normal e-coli
- E-coli affected by silver nanoparticles
Nano particles are used in some sun creams. The smaller particles give better skin coverage and more effective protection against skin cancer. Why do you think some people are against it?