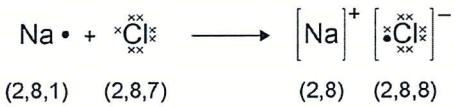
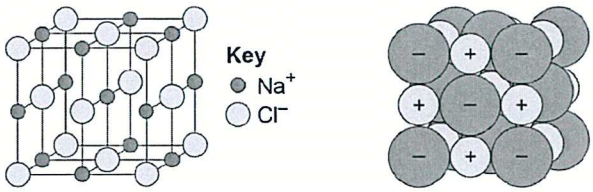
GCSE Combined Science Chemistry

Topic 2 – Bonding, Structure and the Properties of Matter

Name: _____

C2 Bonding, Structure & Properties of Matter

Can you...?	☺	😐	☹
2.1.1 Chemical bonds			
State the three types of strong chemical bonds.			
For each bond, state what it is, where it occurs and the particles involved.			
2.1.2 Ionic bonding			
Describe the formation of an ionic bond in terms of electron transfer.			
Represent the electron transfer during the formation of an ionic compound using dot and cross diagrams. For example.  (2,8,1) (2,8,7) (2,8) (2,8,8)			
Work out the charge on the ions of elements in group 1, 2, 6 and 7.			
Draw dot and cross diagrams for ionic compounds formed by elements in groups 1 and 2 with elements in group 6 and 7.			
2.1.3 Ionic compounds			
Describe the structure of a giant ionic lattice, with references to the forces holding it together.			
Recognise ionic structures represented in the following forms, for example sodium chloride.  			
Describe the limitations of using dot and cross diagrams to represent a giant ionic structure.			
Describe the limitations of using ball and stick diagrams to represent a giant ionic structure.			
Describe the limitations of using 2D diagrams to represent a giant ionic structure.			
Describe the limitations of using 3D diagrams to represent a giant ionic structure.			
Work out the empirical formula of an ionic compound from given information.			
2.1.4 Covalent bonding			
Describe a covalent bond in terms of electron sharing.			
Recall that some covalent substances consist of small molecules, some have very large			

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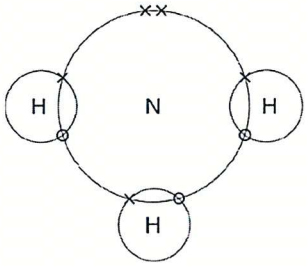
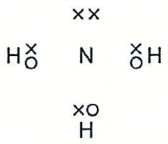
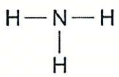
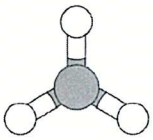
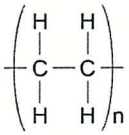
Can you…?	☺	😐	☹
molecules, such as polymers, and some have giant covalent structures such as diamond and silicon dioxide.			
Recognise common substances that consist of small molecules from their chemical formula.			
Recognise the covalent bonds in molecules and giants structures in the following forms. **For ammonia (NH_3)**  and/or  and/or  and/or  Polymers can be represent in the form:  poly(ethene) where n is a large number.			
Draw dot and cross diagrams for the molecules of hydrogen, chlorine, oxygen, nitrogen, hydrogen chloride, water, ammonia and methane.			
Represent the covalent bonds in small molecules, in the repeating units of polymers and in part of giant covalent structures, using a line to represent a single bond.			
Describe the limitations of using dot and cross diagrams to represent molecules or giant structures.			
Describe the limitations of using ball and stick diagrams to represent molecules or giant structures.			
Describe the limitations of using 2D diagrams to represent molecules or giant structures.			
Describe the limitations of using 3D diagrams to represent molecules or giant structures.			
Work out the molecular formula of a substance from a given model or diagram in these forms, showing the atoms and bonds in the molecule.			

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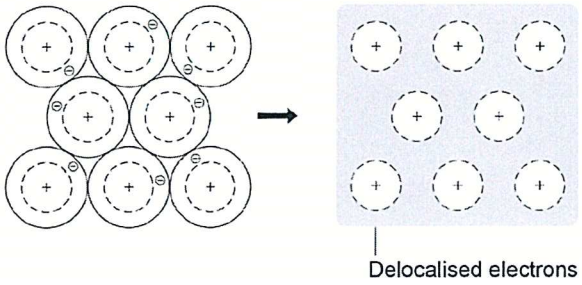
Can you...?	☺	😐	☹
2.1.5 Metallic bonding			
Describe the structure of a metallic lattice, with reference to positive ions and electrons.			
Describe metallic bonding with reference to electrons.			
Recognise metallic substances in the following forms.  			
2.2.1 The three states of matter			
Describe the particle model.			
Describe the three states of matter using the particle model.			
Explain changes in state using the particle model.			
Explain what determines the melting and boiling point of different substances, with reference to forces, particles, bonding and structure.			
Predict the states of substances at different temperatures given appropriate data.			
Explain the different temperatures at which changes of state occur in terms of energy transfers and the types of bonding present.			
Recognise that atoms themselves do not have the bulk properties of materials.			
Explain the limitations of the particle theory in relation to changes of state.			
2.2.2 State symbols			
State the four state symbols and what they mean.			
Use state symbols in chemical equations.			
2.2.3 Properties of ionic compounds			
Describe the structure of a giant ionic lattice with reference to ions and electrostatic forces.			
Recall that ionic compounds have high melting and boiling points.			
Recall that ionic compounds don't conduct electricity when solid, but do when melted or dissolved.			

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Can you...?	☺	😐	☹
Explain the properties of ionic compounds in terms of their structure and bonding.			
2.2.4 Properties of small molecules			
Recall that substances which consist of small molecules are usually gases or liquids and have relatively low melting points and boiling points.			
Describe what happens when these substances melt or boil, with reference to the intermolecular forces present.			
Describe how these forces change as the size of the molecules increase, and the effect this has on the melting and boiling points of substances.			
Recall that these substances don't conduct electricity.			
Explain the properties of small molecules in terms of their structure and bonding.			
Use ideas about the strength of intermolecular forces and covalent bonds to explain the bulk properties of molecular substances.			
2.2.5 Polymers			
Recall that polymers have very large molecules, and that the atoms in the polymer molecules are linked to other atoms by strong covalent bonds			
State the relative strength of the intermolecular forces between polymer molecules, and the effect this has on their state at room temperature.			
Recognise polymers from diagrams showing their structure and bonding.			
2.2.6 Giant covalent structures			
Recall that substances that consist of giant covalent structures are solids with very high melting points.			
Recall that all of the atoms in these structures are linked to other atoms by strong covalent bonds.			
Explain the properties of giant covalent structures in terms of their structure and bonding.			
Describe what happens when these substances melt or boil, with reference to the covalent bonds present.			
Recall that diamond and graphite (which are forms of carbon) and silicon dioxide (silica) are examples of giant covalent structures.			
Recognise giant covalent structures from diagrams showing their bonding and structure.			
2.2.7 Properties of metals and alloys			
Recall that metals have giant structures of atoms with strong metallic bonds.			

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Can you...?	☺	😐	☹
Recall that these strong metallic bonds mean that most metals have high melting and boiling points.			
Describe the arrangements of atoms in pure metals.			
Explain the properties of metals in terms of their structure and bonding.			
State what an alloy is and describe how the atoms are arranged.			
Explain the properties of alloys (when compared to pure metals) in terms of their structure and bonding.			
2.2.8 Metals as conductors			
Recall that metals are good conductors of electricity.			
Recall that metals are good conductors of thermal energy.			
Explain these properties of metals in terms of their structure and bonding.			
2.3.1 Diamond			
Describe the structure of diamond.			
Recall that diamond is very hard and has a very high melting point.			
Recall that diamond doesn't conduct electricity.			
Explain these properties in terms of its structure and bonding.			
2.3.2 Graphite			
Describe the structure of graphite.			
Recall that graphite is soft and slippery.			
Recall that graphite has a high melting point.			
Recall that graphite conducts electricity.			
Explain these properties in terms of its structure and bonding.			
2.3.3 Graphene and fullerenes			
Describe the structure of graphene.			
Recall that its properties make it useful in electronics and composites.			
Explain the properties of graphene in terms of its structure and bonding.			
Describe the structure of fullerenes.			

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Can you…?	☺	😐	☹
Recall that the first fullerene to be discovered was Buckminsterfullerene (C_{60}) which has a spherical shape.			
Recall that carbon nanotubes are cylindrical fullerenes with very high length to diameter ratios.			
Recall that their properties make them useful for nanotechnology, electronics and materials.			
Recognise graphene and fullerenes from diagrams and descriptions of their bonding and structure			
Give examples of the uses of fullerenes, including carbon nanotubes.			

Topic 2 - Bonding, structure, and the properties of matter

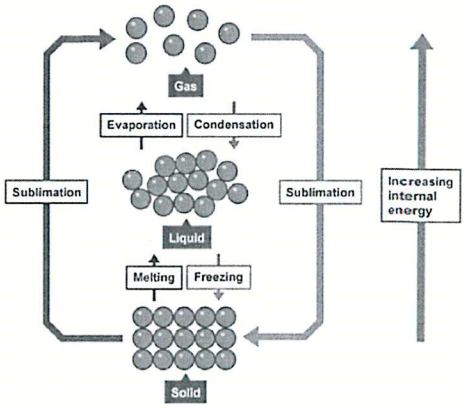
Chemists use theories of structure and bonding to explain the physical and chemical properties of materials. Analysis of structures shows that atoms can be arranged in a variety of ways, some of which are molecular while others are giant structures.

Theories of bonding explain how atoms are held together in these structures. Scientists use this knowledge of structure and bonding to engineer new materials with desirable properties. The properties of these materials may offer new applications in a range of different technologies.

The three states of matter

The three states of matter are solid, liquid and gas.

Melting and freezing take place at the melting point, boiling and condensing take place at the boiling point. The three states of matter can be represented by a simple model. In this model, particles are represented by small solid spheres. Particle theory can help to explain melting, boiling, freezing and condensing.



The amount of energy needed to change state from solid to liquid and from liquid to gas depends on the strength of the forces between the particles of the substance. The nature of the particles involved depends on the type of bonding and the structure of the substance. The stronger the forces between the particles the higher the melting point and boiling point of the substance.

Higher tier only

Limitations of the simple model above include that in the model there are no forces, that all particles are represented as spheres and that the spheres are solid.

State symbols

In chemical equations, the three states of matter are shown as (s), (l) and (g), with (aq) for aqueous solutions.

Chemical bonds

Atoms react and form chemical bonds with other atoms to achieve a full outer shell (noble gas configuration) so that they can become stable (unreactive).

There are three types of strong chemical bonds: ionic, covalent and metallic.

- For ionic bonding the particles are oppositely charged ions and occurs in compounds formed from metals combined with non-metals.
- For covalent bonding the particles are atoms which share pairs of electrons and occurs in most non-metallic elements and in compounds of non-metals.
- For metallic bonding the particles are atoms which share delocalised electrons and occurs in metallic elements and alloys.

The three states of matter

1. Copper oxide is a solid. It reacts with dilute sulfuric acid to form a solution of copper sulfate.

Which symbol equation correctly shows the state symbols for this reaction?

Tick **one** box. [1 mark]

Remember
(aq) stands for 'aqueous', which means a solution of a soluble substance in water.

- ☐ $CuO\ (s) + H_2SO_4\ (l) \rightarrow CuSO_4\ (aq) + H_2O\ (l)$
- ☐ $CuO\ (s) + H_2SO_4\ (aq) \rightarrow CuSO_4\ (s) + H_2O\ (l)$
- ☐ $CuO\ (s) + H_2SO_4\ (aq) \rightarrow CuSO_4\ (aq) + H_2O\ (l)$
- ☐ $CuO\ (s) + H_2SO_4\ (l) \rightarrow CuSO_4\ (aq) + H_2O\ (aq)$

2. In **Figure 1** each change of state is shown by a letter.

Write the correct letter (A, B, C or D) in the box next to each change of state.

Boiling ☐ Condensing ☐

Freezing ☐ Melting ☐ [4 marks]

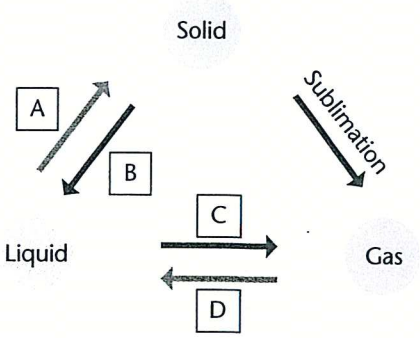


Figure 1

3. A student wanted to find out the melting point of the compound salol.

This is the method they used:

1. Put two spatulas of salol into a boiling tube and add a thermometer.
2. Put the boiling tube in a hot water bath.

Practical **a** Describe how they would measure the melting point of salol.

_____

_____

_____ [2 marks]

b They could not measure the melting point of magnesium oxide in school.

Suggest why

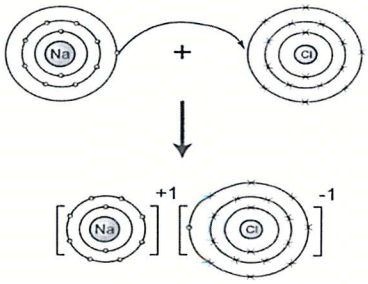
_____

_____ [2 marks]

Ionic bonding

When a metal atom reacts with a non-metal atom electrons in the outer shell of the metal atom are transferred to the outer shell of the non-metal atom.

- Metal atoms lose electrons to become positively charged ions.
- Non-metal atoms gain electrons to become negatively charged ions.
- The electrostatic forces of attraction between the oppositely charged ions form the ionic bond.



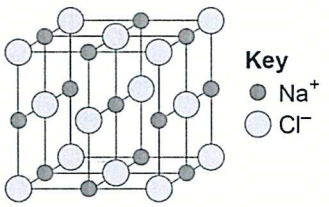
The electron transfer during the formation of an ionic compound can be represented by a dot and cross diagram, e.g. for sodium chloride.

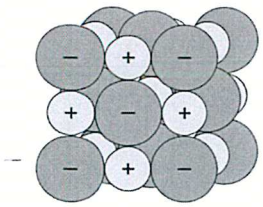
The charge on the ions produced by the atoms relate to the group number of the Periodic Table:

Group 1 = +1	Group 5 = -3
Group 2 = +2	Group 6 = -2
Group 3 = +3	Group 7 = -1

Ionic compounds

Ionic compounds have regular structures (giant ionic lattices) in which there are strong electrostatic forces of attraction in all directions between oppositely charged ions (each negative ion is surrounded by positive ions and each positive ion is surrounded by negative ions).





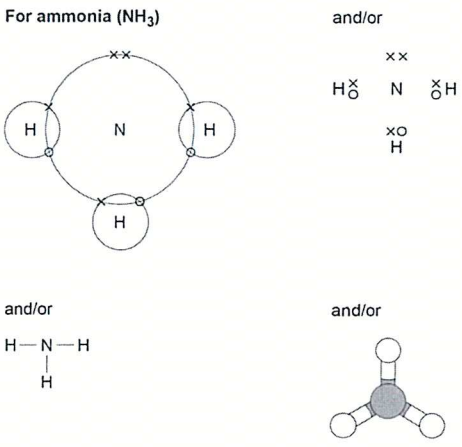
Ionic compounds are held together by strong electrostatic forces of attraction between oppositely charged ions. There are the same number of positive ions and negative ions so ionic compounds have no overall charge.

Properties of ionic compounds

- Ionic compounds have high melting points and high boiling points because of the large amounts of energy needed to break the many strong bonds.
- Ionic compounds with larger ions have higher melting and boiling points.
- They cannot conduct electricity when solid as the ions cannot move around however when melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and so charge can flow.

Covalent bonding

When atoms of non-metals share pairs of electrons, they form covalent bonds.



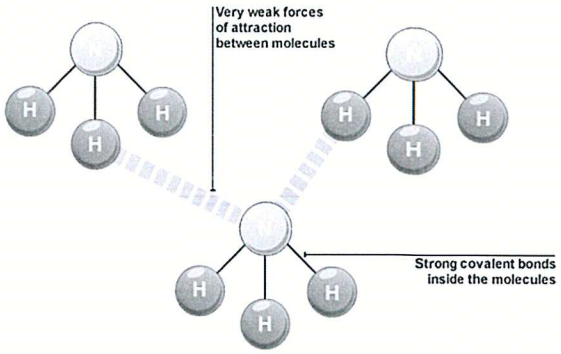
- Each atom shares one of its own electrons to form a sharing pair – this is the covalent bond.
- When two pairs of electrons are shared (so each atoms shares two of its own electrons) a double covalent bond is formed.
- If three pairs are shared then it is called a triple covalent bond.
- Atoms share electrons until they have a full outer shell (this is 8 electrons with the exception of hydrogen which needs 2 electrons for a full outer shell)

Covalent bonds between atoms are strong. Covalently bonded substances may consist of small molecules, large molecules and giant structures.

Simple molecules

An element or compound that is made of only a few atoms covalently bonded together is called a simple molecule.

Within a simple covalent substance each molecule tends to be quite separate from its neighbouring molecules.



The force of attraction between the individual molecules in a covalent substance is relatively small – there are weak intermolecular forces between the molecules. In simple molecular substances this force is relatively small so overcoming these forces does not take much energy.

Properties of simple molecules

- Simple molecular substances have low melting points and boiling points as not much energy is required to overcome the weak intermolecular forces (It is these intermolecular forces that are overcome, not the covalent bonds, when the substance melts or boils.)
- The intermolecular forces increase with the size of the molecules, so larger molecules have higher melting and boiling points
- These substances do not conduct electricity because the molecules do not have an overall electric charge.

Polymers

Polymers are very large covalent molecules. They are made up of many smaller molecules bonded together. The atoms in the polymer molecules are linked to other atoms by strong covalent bonds and they have relatively strong intermolecular forces.

Ionic bonding and ionic compounds

1. Which of the following compounds are ionic?

Tick **two** boxes.

- ☐ sodium chloride (NaCl)
- ☐ carbon dioxide (CO_2)
- ☐ lithium oxide (Li_2O)
- ☐ hydrogen chloride (HCl)

[2 marks]

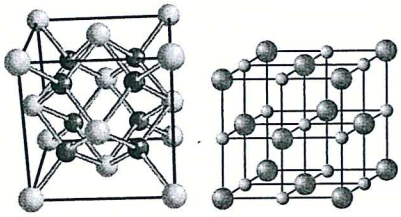
2. Calcium oxide (CaO) is an ionic compound.

a What ions does it contain?

Tick **one** box

☐ Ca^+ and O^- ☐ Ca^+ and O^{2-} ☐ Ca^{2+} and O^- ☐ Ca^{2+} and O^{2-} [1 mark]

b **Figure 2** shows two ball and stick diagrams (A and B).



A B

Figure 2

i Which diagram represents calcium oxide? [1 mark]

_____

Remember

You can count the number of each types of ion to give you an estimate of the ratio.

It won't be an exact number because this is just one part of a much bigger structure. The ions on the sides and corners are bonded to other ions that are not included in the image.

Worked Example

ii Explain your choice. [1 mark]

The formula of calcium oxide is CaO (this is given above)

Marks gained: [1 mark]

In B there are 14 of the large spheres 13 of the smaller ones.

This is approximately a ratio of 1:1, so it must contain 1 calcium ion to every 1 oxide ion.

3. State the formula for the ionic compound potassium sulfide.

_____ [2 marks]

Analyse the question

Use the periodic table to find what groups potassium and sulfur are in.

Use this to work out the charge on their ions.

The charge on the compound needs to be neutral.

Dot and cross diagrams for ionic compounds

1. The substance magnesium fluoride is made up of Mg^{2+} and F^- ions.

a What type of bonding occurs in magnesium fluoride?

Tick **one** box.

☐ Covalent ☐ Hydrogen ☐ Ionic ☐ Metallic [1 mark]

b What is the formula of magnesium fluoride?

Tick **one** box.

☐ MgF ☐ Mg^2F ☐ Mg_2F ☐ MgF_2 [1 mark]

2. **Figure 3** shows an atom of sodium and an atom of oxygen.

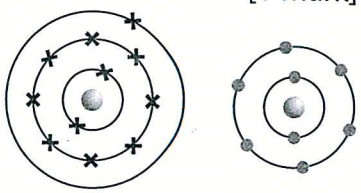


Figure 3

Describe what happens when sodium reacts with oxygen to form the compound sodium oxide.

Analyse the question

This question is worth 5 marks so try and include as much detail as you can. Describe what will happen to the electrons and what ions will be formed.

[5 marks]

Properties of ionic compounds

1. Which statement is **true** about ionic compounds?

Tick **two** boxes.

☐ They have low boiling points.

☐ They have high boiling points.

☐ They are all gases at room temperature.

☐ They are all solids at room temperature.

Remember

The ions in ionic compounds are bonded very strongly to each other by ionic bonds.

A lot of energy is required to break them.

[2 marks]

2. **Figure 4** shows a 2D diagram of the structure of an ionic compound.

Only some of the charges on the ions are shown.

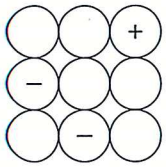


Figure 4

a Draw in the rest of the charges to complete the diagram. [1 mark]

b What do we call this type of structure?

Tick **one** box.

- ☐ Giant covalent structure
- ☐ Giant ionic lattice
- ☐ A polymer
- ☐ Giant molecular structure

[1 mark]

3. Sodium chloride is an ionic compound.

Literacy It has a high melting point.

It will not conduct electricity when solid but will when melted.

Use what you know about the structure of sodium chloride to explain these properties.

[6 marks]

Covalent bonding in small molecules

1. Which substances are made up of small molecules?

Tick **two** boxes.

- ☐ Gold
- ☐ Carbon dioxide
- ☐ Water
- ☐ Aluminium oxide

[2 marks]

2. Use the words in the box to complete the sentence about covalent bonding.

electrons	full	protons	share	strong	transfer	weak

A covalent bond is formed when atoms _____ pairs of _____.

The covalent bonds between atoms are _____. [3 marks]

3. **Figure 5** is a diagram of one molecule of a covalent substance.

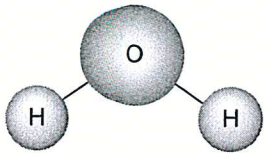


Figure 5

Worked Example

a State the chemical formula of the substance. [1 mark]

H_2O *Marks gained:* [1 mark]

Remember

When you write a formula of a compound the symbol of the metal or hydrogen is placed first.

Small subscript numbers $_{\text{like this}}$ are placed after the symbols to show how many of each atom are present.

You might need to add brackets – for example there are two nitrate (NO_3) ions in $Mg(NO_3)_2$

Without the brackets it would be $MgNO_{32}$ which means there are 32 oxygen atoms!

b Name the substance. _____ [1 mark]

4. Methane has the formula CH_4.

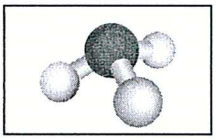
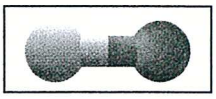
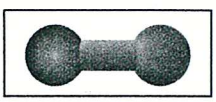
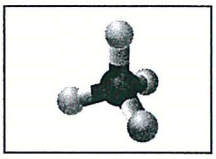
Complete the diagram below by drawing **lines** to show the bonds in methane. [1 mark]

H
H C H
H

Dot and cross diagrams for covalent compounds

1. Some substances are made up of small covalent molecules.

Draw **one** line from each covalent molecule to the diagram which shows its structure.

Covalent molecule	Structure
Ammonia (NH_3)	
Methane (CH_4)	
Chlorine (Cl_2)	
Hydrogen chloride (HCl)	

[4 marks]

2. **Figure 6** shows how the outer electrons are arranged in an atom of hydrogen and an atom of chlorine.

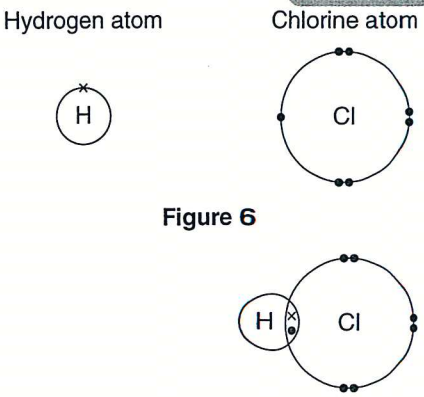


Figure 6

Worked Example

a Draw a diagram to show how the atoms are arranged in a molecule of hydrogen chloride. [3 marks]

Marks gained: [3 marks]

b A dot and cross diagram is not a true representation of the structure of a small molecule.

Give one reason why.

_____ [1 mark]

3. **Figure 7** shows how the outer electrons are arranged in an atom of nitrogen.

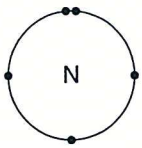


Figure 7

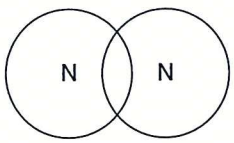


Figure 8

Remember
In some molecules, more than one pair of electrons are shared.

Complete **Figure 8** to show how the electrons are arranged in a molecule of nitrogen (N_2). [2 marks]

Properties of small molecules

1. Which are properties of small molecules?

Tick **two** boxes.

- ☐ Normally gases or liquids at room temperature
- ☐ Normally solids at room temperature
- ☐ Relatively high melting and boiling points
- ☐ Do not conduct electricity when dissolved in water

Common misconception
It is important to remember that the intermolecular bonds between small molecules are weak.

But, the covalent bonds between the atoms in the molecules are very strong.

2. The alkanes are a family of molecules.

Methane (CH_4) and ethane (C_2H_6) are both alkanes.

Alkanes contain atoms of which two elements?

1 _____ 2 _____ [2 marks]

3. What type of bonding exists between the atoms in alkane molecules?

Tick **one** box.

☐ Covalent ☐ Ionic ☐ Intermolecular ☐ Metallic [1 mark]

4. A liquid alkane is heated until it becomes a gas.

Which sentence explains what happens?

Tick **one** box.

☐ The bonds between the atoms in the molecules break.

☐ The forces between the molecules (intermolecular forces) break.

☐ The molecules become atoms.

☐ The molecules become ions. [1 mark]

Polymers

1. Which material is made from polymers?

Tick **one** box.

☐ Sodium chloride ☐ Diamond ☐ Plastic ☐ Steel [1 mark]

2. **Figure 9** shows two polymer chains.

Draw **one** intermolecular force. [1 mark]

Figure 9

Remember

Intermolecular means between molecules.

Intramolecular means between the atoms in molecules.

3. Poly(ethene) is a polymer made from the gas ethene.

Poly(ethene) is a solid at room temperature. Ethene is a gas.

Explain why.

Use the strength of their intermolecular forces in your answer.

_____

_____

_____ [3 marks]