Bonding in compounds

Simple molecular covalent bonding

When non-metals react with other non-metals there is a sharing of outermost electrons so that they gain a structure similar to a noble gas. The atoms in the molecules are held together by shared electrons (bonding pairs). These are strong intramolecular covalent bonds. However, there is little attraction between the individual molecules and they tend to be quite separated. The intermolecular forces between the covalent molecules are very weak. In models, the electrons are drawn in fixed positions. In reality, they are constantly moving, but on average are found most of the time between the two nuclei of the atoms they are bonding together.

- **Melting & boiling point –** The covalent intramolecular bonds within simple molecules are strong. However, the electrostatic attractions between different simple molecules are weak. This means that a relatively small amount of energy is required to separate one molecule from another. Therefore, elements and compounds with a simple covalent structure have a relatively low melting and boiling point.

- **State -** Intermolecular forces increase with size of the molecules, so larger molecules have higher melting points and boiling points. E.g. polymers are made from very long chains of molecules, so the intermolecular forces are higher compared with simple molecules. These stronger intermolecular forces mean polymers are solids at room temperature.

- **Shape –** atoms are bonded by strong covalent bonds forming separate individual molecules held closely together (due to the sharing of electrons/overlapping of outer shells). This makes simple molecules small in size. The shape of the molecule is dependent on electronic repulsion between bonding pairs and lone pairs.

  Because similar charges repel: groups of electrons arrange themselves as far apart as possible. It does not matter if they are in groups of bonding pairs or lone pairs. Lone pairs of electrons repel more strongly than bonding pairs. Therefore the shape a simple molecule forms is dependent on **electron pair repulsion theory:**

Molecule Type	Formula	No. groups of electrons	Lone pairs	Bonding pairs	Shape	Bond angles
Linear molecule	BeCl2	2	0	2	Linear	180^0
Planar molecule	BF_2	3	0	3	Trigonal planar	120^0
Bent (planar)	H_2O	4	2	2	Bent	104.5^0
Pyramidal (tri)	NH_3	4	1	3	Trigonal pyramidal	107^0
Pyramidal (tetra)	CH_4	4	0	4	Tetrahedral	109.5^0
Bipyramid	PCl_5	5	0	5	Bipyramidal	90^0 & 120^0
Octahedral	SF_6	6	0	6	Octahedral	90^0

- **Electrical conductivity -** Compounds made of simple molecules cannot conduct electricity, even when they are molten or dissolved in water. This is because the molecules have no overall charge and so are unable to carry electrical charge.
  However, some simple molecules are able to conduct electricity if they react with the water to dissociate into ions in aqueous solutions. Acids are a good example of this (HCL + $H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$ i.e. hydrogen behaves as a metal although forms a covalent compound).

- **Strength –** Simple covalent molecules have very strong intramolecular covalent bonds between the atoms forming individual molecules. However, the electrostatic forces of attractions between individual molecules is low and so there are weak intermolecular forces. These require little energy to overcome and so molecules can easily be separated from one another, this governs the overall properties of simple molecules. They usually formulate in many small easy to separate molecules (e.g. oxygen molecules).

What substances form this?	Some Non-metal elements/compounds
Examples	Carbon dioxide, Chlorine, Water
What type of particles formulate?	Small molecules
How are particles bonded?	Weak intermolecular (electrostatic forces) attraction, strong intramolecular covalent bonds
Typical melting & boiling point:	Low
Electrical conductivity	Does not conduct (except some that dissociate - e.g. HCL in solution)
Strength	Soft
Solubility (water)	Usually insoluble unless molecules contain groups that can hydrogen bond with water (polarised).
Solubility (non-polar solvent e.g. hexane)	Usually soluble

Giant covalent bonding

Some atoms bond covalently in large networks opposed to small molecules. These are called giant covalent lattices. The atoms within the lattice are bonded strongly with covalent bonds. They are sometimes referred to as macromolecules (containing a large number, typically thousands, of atoms).

Examples include: silicon dioxide found in quartz, diamond, graphite.

The intramolecular forces of covalent bonds exist throughout the whole structure and require lots of energy to break.

Melting point – This results in very high melting and boiling points. As a result, giant covalent structures are solid at room temperature.

Strength – Very hard since they are formed of many atoms bonded strongly with covalent intramolecular forces that exist through a lattice. A lot of energy is needed to break the strong bonds. This description is particularly prevalent to 3-d structures.

Shape – Huge numbers of atoms are bonded covalently in a giant lattice network. This forms a rigid structure which is hard and requires a lot of energy to split.

Electrical conductivity – Most do not conduct electricity since the outermost electrons of each atom in the structure are all involved in a bonding pair to form covalent bonds. Therefore there are no valence electrons which are delocalised so there are no electrons capable of carrying charge. Moreover, all the atoms are bonded tightly in the lattice, there are no free ions to move charge

Solubility – They are not soluble in water since the atoms hard held by strong covalent intramolecular bonds within the lattice so the water is unable to dissociate the atoms/split the lattice. **It is hard to dissolve such a large molecule.**

What substances form this?	Some elements in Group 4/some of their compounds
Examples	Diamond, Silica, Graphite
What type of particles formulate?	Atoms
How are particles bonded?	Strong covalent bonds (attraction of atom's nuclei to shared electrons)
Typical melting & boiling point:	Very high
Electrical conductivity	Do not conduct (except graphite)
Strength	Very hard (if 3-D)
Solubility (water)	Insoluble
Solubility (non-polar solvent e.g. hexane)	Insoluble

Giant Covalent lattice examples:

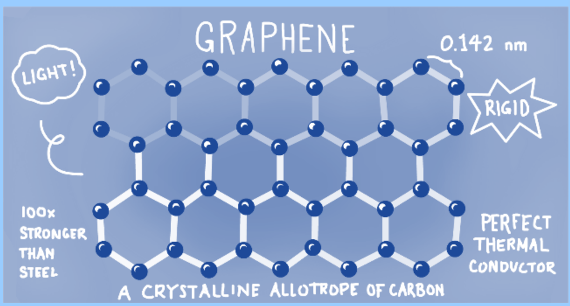
Graphite:

Graphite is an exception to the conductivity rule. Each carbon atom within the giant lattice has **4 outermost electrons** but only **3** of which are involved in **bonding pairs** to form covalent bonds with **3 other neighbouring carbon atoms**. This results in every carbon atom in the structure having **1 free valence electron -** not associated to any particular atom. This free electron is **delocalised** and able to move throughout the structure so carry electrical charge.

Since only 3 of the 4 outermost electrons in every carbon atom is involved in a bonding pair: there is **no covalent bond between a 4th carbon atom**. Only **planar molecules** form in a regular hexagonal arrangement in the giant lattice with no covalent bonds between atoms in other **layers**. This means that **layers are able to slide** over each other. There are only very weak forces of attraction (intermolecular forces) between the graphene layers in graphite. This require little energy to overcome.

This gives graphite lubricating properties and also makes it a soft material.

The small amount of frictional force between paper is enough to overcome the weak intermolecular forces between the layers of graphene in graphite so that layers can slide of the giant structure onto the paper.



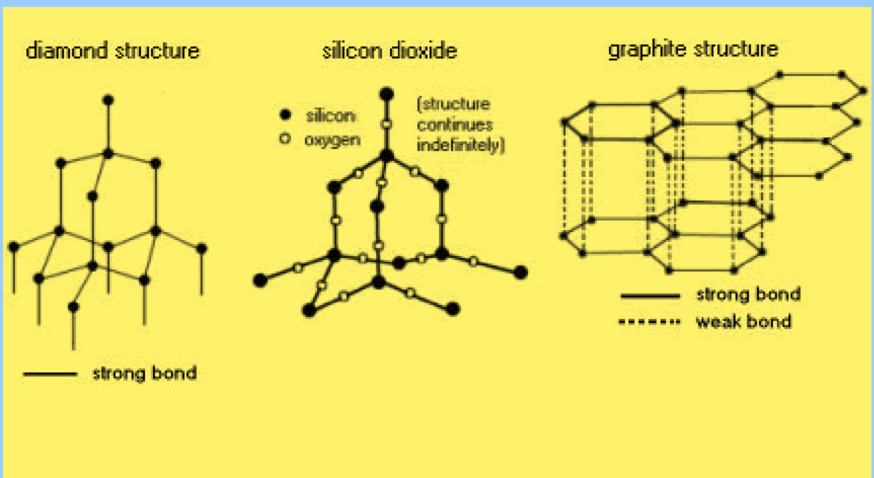
Diamond:

Diamond is an exceptionally hard material. Every carbon atom within its structure forms 4 strong covalent bonds with surrounding carbon atoms. All 4 of the outermost electrons of every carbon atom are involved in bonding pairs. The giant covalent lattice is particularly strong and requires a great deal of energy to break the bonds. No free electrons means no electrical conductivity. It has a hardness of 10 on Moh's scale.

Silica (Quartz, SiO_2):

This is very similar to the structure of diamond. However, it is formed of silicon atoms bonded with two oxygen atoms. It has special properties making it useful in the manufacture of semiconductors.

SiO_2 has a number of distinct crystalline forms (polymorphs) in addition to amorphous forms.



Macromolecular substances

#Macromolecule = a molecule containing a very large number, usually thousands, of atoms (such as a protein, nucleic acid, or synthetic polymer).

The term macromolecule can refer to both giant covalent structures forming in 3-D lattice networks and long-chained molecules like polymers.

However, in the exam it commonly just means long-chained molecules that continue to repeat.

The structure of simple macromolecules, such as homopolymers, may be described in terms of the individual monomer subunits (repeating units).

Polymers

These are formed from covalently bonded molecules that link together in repeating units, also bonded covalently. I.e. they are very long chains of atoms bonded covalently.

The polymer chains are held together by strong intramolecular covalent bonds. However, the intermolecular forces between chains tend to be weak due to the lack of electrostatic forces. Although some polymers can form cross-links (covalent bonds) between chains, creating a stronger rigid structure (sulfide bridges). Thermosetting polymers are good examples of this, opposed to thermosoftening polymers.

The properties of polymers can vary widely.

e.g. LD poly(ethene) is a polymer formed of many branched chains. This means there are fewer opportunities for intermolecular forces to exist between the chains. Less energy is needed to overcome the weak intermolecular forces and separate the polymer chains.

HD poly(ethene) has a structure of compact polymer chains arranged neatly and closely. This allows for more intermolecular forces between the chains. Therefore more energy is required to overcome these forces (while they are relatively weak). This results in a more heat resistant and rigid structure.

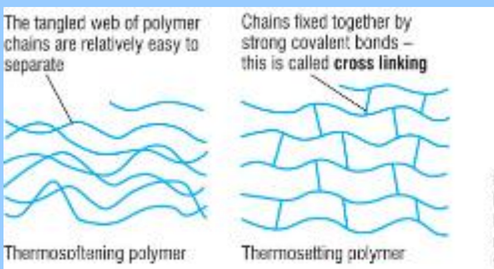


Figure 4 Extensive cross linking by covalent bonds between polymer chains makes a thermosetting plastic that is heat-resistant and rigid

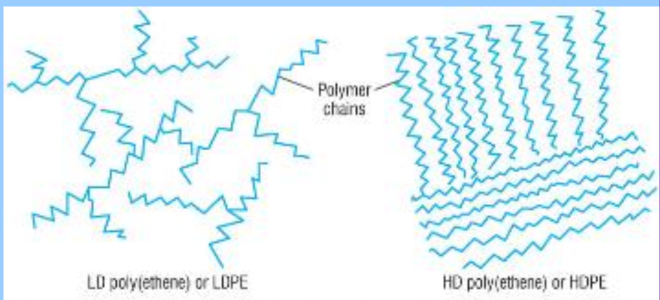


Figure 3 The branched chains of LD poly(ethene) cannot pack as tightly together as the straighter chains in HD poly(ethene), giving them different properties

What substances form this?	Polymers, proteins, nucleic acids, pyroxene
Examples	Poly(ethene), nylon, DNA, ferromagnesian silicates (pyroxene)
What type of particles formulate?	Long-chain molecules
How are particles bonded?	Weak intermolecular bonds between molecules, strong covalent intramolecular bonds
Typical melting & boiling point:	Moderate – often decompose on heating
Electrical conductivity	Don't normally conduct
Strength	Variable – many soft but often flexible
Solubility (water)	Usually insoluble
Solubility (non-polar solvent e.g. hexane)	Sometimes soluble