

4.2 BONDING AND STRUCTURE

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Learning outcomes

Candidates should be able to:

1. describe, in simple terms, the lattice structure of a crystalline solid which is:
 - (a) giant ionic, including sodium chloride and magnesium oxide
 - (b) simple molecular, including iodine, buckminsterfullerene C_{60} and ice
 - (c) giant molecular, including silicon(IV) oxide, graphite and diamond
 - (d) giant metallic, including copper
2. describe, interpret and predict the effect of different types of structure and bonding on the physical properties of substances, including melting point, boiling point, electrical conductivity and solubility
3. deduce the type of structure and bonding present in a substance from given information

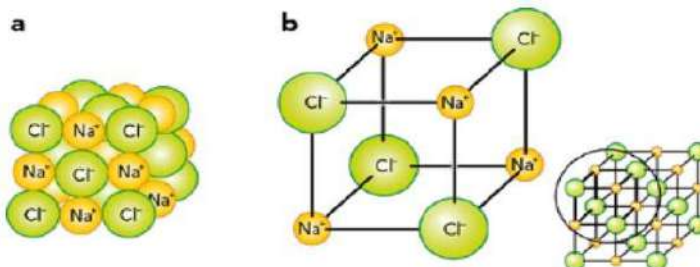
Introduction

Many ionic, metallic and covalent compounds are crystalline. The regular structure of crystals is due to the regular packing of the particles within the crystal. We call this regularly repeating arrangement of ions, atoms or molecules a **crystal lattice**.

Ionic lattices

Ionic lattices have three-dimensional arrangements of alternating positive and negative ions. Compounds with ionic lattices are sometimes called giant ionic structures.

The ionic lattices for sodium chloride are cubic. In sodium chloride, each sodium ion is surrounded by six oppositely charged chloride ions. The chloride ions are much larger than the sodium ions. The sodium ions fit into the spaces between the chloride ions so that they are as close as possible to them.



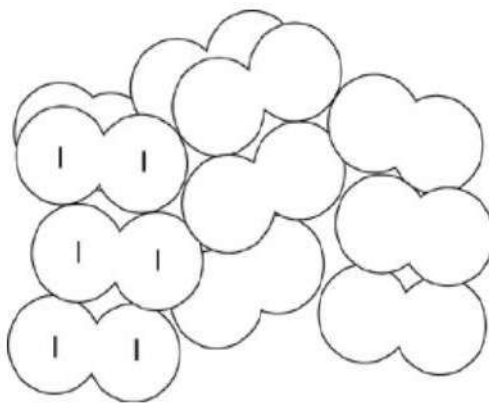
Magnesium oxide has the same lattice structure as sodium chloride. Magnesium ions replace sodium ions and the oxide ions replace the chloride ions.

The properties of ionic compounds reflect their structure as well as their bonding

- They are hard.
- They are brittle.
- They have high melting points and high boiling points.
- Many ionic compounds are soluble in water because they can form ion–dipole bonds.
- They only conduct electricity when molten or in solution.

Simple molecular lattices

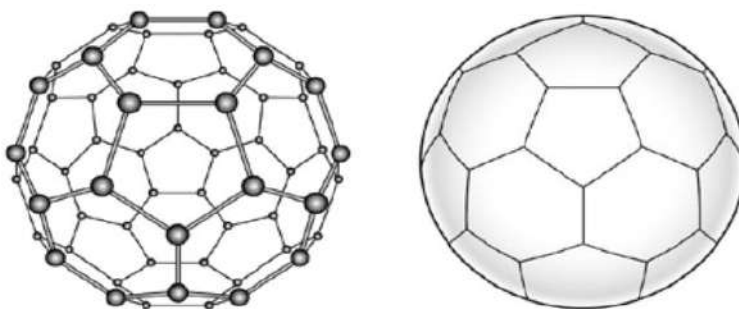
Substances with a simple molecular structure, such as **iodine**, can also form crystals. This reflects the regular packing of the molecules in a lattice structure.



The distance between the nuclei of neighbouring iodine molecules is greater than the distance between the nuclei within the iodine molecule. This is because the forces between the molecules are weak intermolecular forces, whereas the forces between the atoms within the molecule are strong covalent bonds. Very little energy is needed to overcome the weak intermolecular forces between the molecules. The lattice is easily broken down when iodine crystals are heated, so iodine has a low melting point. Iodine is a volatile substance too.

Ice also forms a crystalline lattice.

Buckminsterfullerene (C_{60}) is a simple molecular structure. The C_{60} molecule has the shape of a football. The carbon atoms are arranged at the corners of 20 hexagons and 12 pentagons.



Giant structure: have network of either covalent bonds (molecular giant structures), metallic bonds (metallic giant structures) or ionic bonds (ionic giant structures). The network of strong bonds is hard to break and so the melting and boiling points of these structures are generally very high.

Giant molecular structures

Some covalently bonded structures have a three-dimensional network of covalent bonds throughout the whole structure. We call these structures **giant molecular structures** or **giant covalent structures**.

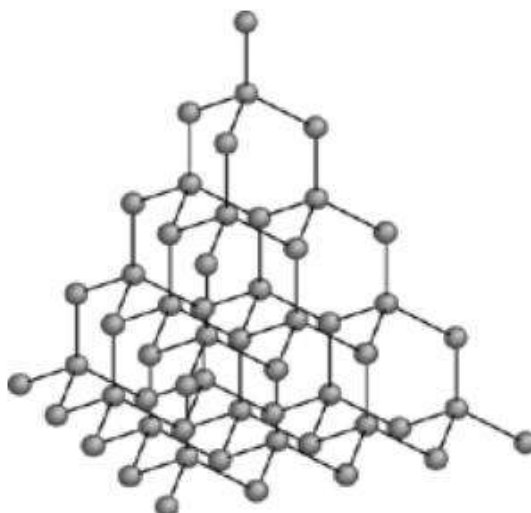
Diamond

In diamond, each carbon atom forms four covalent bonds with other carbon atoms.

The carbon atoms are positioned around each other in a tetrahedral arrangement. The network of carbon atoms extends almost unbroken throughout the whole structure. The regular arrangement of the atoms gives diamond a crystalline structure.

Properties of diamond

- High melting and boiling points
- Hardness
- Does not conduct electricity



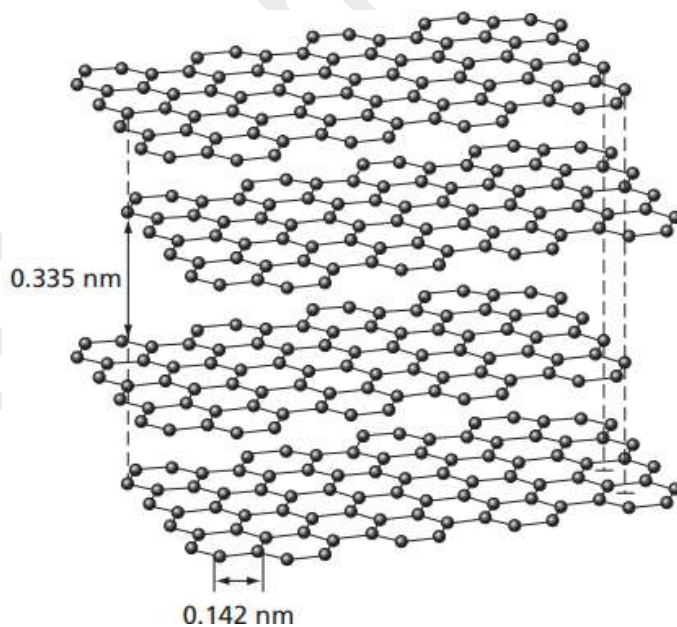
Graphite

In graphite, the carbon atoms are arranged in planar layers. Within the layers, the carbon atoms are arranged in hexagons. Each carbon atom is joined to three other carbon atoms by strong covalent bonds. The fourth electron of each carbon atom occupies a p orbital. These p orbitals on every carbon atom in each planar layer overlap sideways. A cloud of delocalised electrons is formed above and below the plane of the carbon rings. These electron clouds join up to form extended delocalised rings of electrons.

The layers of carbon atoms are kept next to each other by weak instantaneous dipole-induced dipole forces.

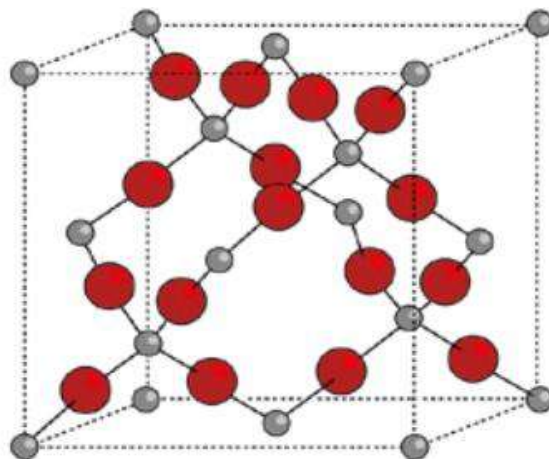
Properties of graphite

- High melting and boiling points
- Softness
- Good conductor of electricity



Silicon(IV) oxide

There are several forms of silicon(IV) oxide. The silicon(IV) oxide found in the mineral quartz has a structure similar to diamond.



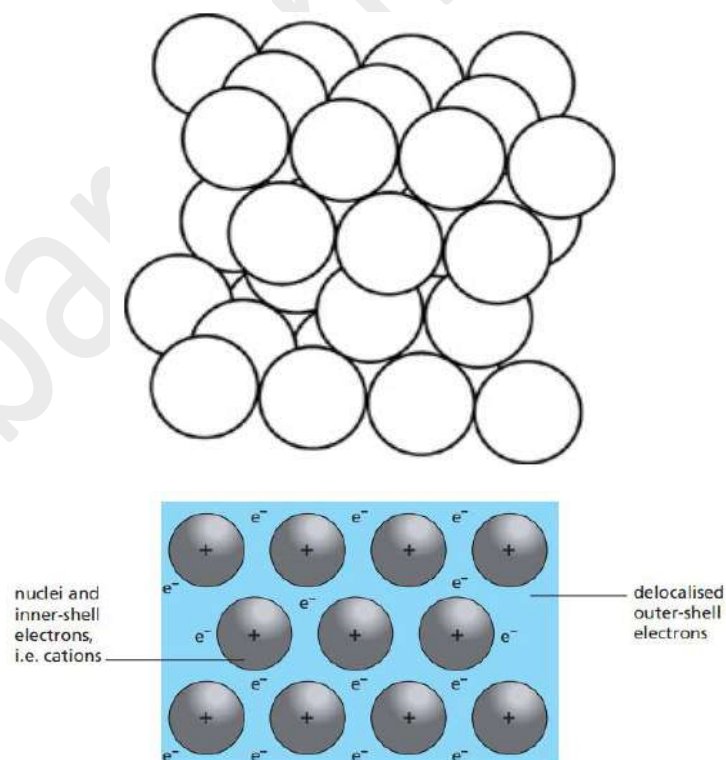
Each silicon atom is bonded to four oxygen atoms but each oxygen atom is bonded to only two silicon atoms. So the formula for silicon(IV) oxide is SiO_2 . Silicon dioxide has properties similar to that of diamond. It forms hard, colourless crystals with high melting and boiling points and it does not conduct electricity. Sand is largely silicon(IV) oxide.

Most giant molecular structures do not conduct electricity. One exception is graphite.
Most do not conduct heat but diamond is a good conductor of heat.

Allotropes are different crystalline forms of the same elements. The term only applies to solids. E.g, diamond, graphite and buckminsterfullerene are allotropes of carbon.

Metallic lattices

The ions are often packed in hexagonal layers or in a cubic arrangement. The following figure shows part of a lattice of copper ions arranged in layers.



When a force is applied, the layers can slide over each other. But in a metallic bond, the attractive forces between the metal ions and the delocalised electrons act in all directions. So, when the layers slide, new metallic bonds are easily re-formed between ions in new lattice positions and the delocalised electrons. The delocalised electrons continue to hold the ions in the lattice together. The metal now has a different shape. This explains why metals are malleable and ductile.

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