Atoms, elements and compounds

3.1 Atomic structure and the periodic table

All elements are made up of atoms. An atom is the smallest part of an element than can retain the properties of that element. The atom consists of a minute heavy nucleus of protons and neutrons and a surrounding region of space containing fast moving electrons.

Particles	Charge	Mass
Proton (p)	+	1 u
Neutron (n)	0	1 u
Electron (e^-)	-	1/1836 (negligible)

Because the atom is electrically neutral, the protons in any atom equal the number of electrons.

Atomic (proton) # and Mass (nuclear) #:

Atomic number is the number of protons in the nucleus of an atom.

Mass number is the number of protons + neutrons in the nucleus of an atom.

$$^{\text{Mass number}}_{\text{Atomic number}}X \quad \text{Element symbol}$$

Isotopes:

Isotopes are atoms of the same element having the same proton number but different mass number. In other words, it is an atom having the same number of protons but different number of electrons.

E.g. Hydrogen's isotopes:

	$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$
	Hydrogen	Deuterium	Tritium
e=	1	1	1
n=	0	1	2
p=	1	1	1

The isotopes of an element have different physical properties but because they all have the same electron configuration, their chemical reactions are the same.

Radioactive isotopes:

Radioactive isotopes have unstable nuclei. Unstable nuclei are particularly those of heavy elements, such as uranium and radium. Some light elements also have a little number of naturally occurring radioactive isotopes. Most artificial isotopes are radioactive.

Radioactive isotopes eject alpha and beta particles from their nuclei, so that they can become more stable. They are often accompanied by a release of energy in the form of gamma rays.

Uses of radioactive isotopes:

Medical uses:

1. Treatment of cancer by subjecting cancerous tumour to controlled amounts of gamma rays from a cobalt-60 source.

2. Sterilizing medical equipment using gamma rays.

Industrial uses:

1. Controlling the thickness of paper, rubber, metal and plastic accurately.

2. The energy produced by radioactive fission of uranium-235, is used within a nuclear power station to produce electricity.

Electron configuration:

1. Electrons move rapidly around the nucleus in energy levels or shells.

2. These shells from the nucleus outward are:

	K	L	M	N	O	P	Q
No. of shell (n)	1	2	3	4	5	6	7

3. The number of electrons that can b held by a certain shell = $2n^2$

K Shell	$2 \times 1^2 =$	2e
L Shell	$2 \times 2^2 =$	8e
M Shell	$2 \times 3^2 =$	18e
N Shell	$2 \times 4^2 =$	32e

4. The outermost shell cannot hold more than 8 electrons, except the first shell, which can hold up to 2 electrons only.

5. When 8 electrons are in the third shell, there is a degree of stability and the next 2 electrons added go into the fourth shell. Then the extra electrons enter the third energy level until it contains a maximum of 18 electrons.

6. The electron configuration is written to show the number of electrons present in each shell.

7. The electrons in the outermost shell (valence electrons) are the only involved in the chemical reactions and therefore determine how reactive the atom is and also its valency.

Group	I (one)	II (two)	III (three)	IV(four)	V (five)	VI (six)	VII (seven)	0 (eight)
Valency	1	2	3	4	3	2	1	0

8. When an atom reacts, it tries to have a full outer shell:

- Noble or inert gases all have full outer shell, which makes it difficult for them to gain or lose electrons. They are therefore unreactive.

- Other elements are reactive because they do not have full outer shells:

- Atoms of metals with a nearly empty outer shell, lose electrons and so become positive ions.
  E.g. Na (2.8.1) $-e^-$ = Na^+ (2.8)
- Atoms of non-metals with a nearly full shell, gain electrons and so become negative ions.
  E.g. Cl (2.8.7) + e^- = Cl^- (2.8.8)

3.2 Bonding – the structure of matter

Elements, compound and mixtures

Pure substances are either elements or compounds.

An element is a substance, which cannot be broken chemically into a simpler substance.

There are over 105 elements, most of them are metals.

Elements can be classified as metals, non-metals, or metalloids. There are only 22 non-metals.

Some elements such as silicon (Si) have both metallic and non-metallic properties and are known as metalloids.

A comparison between metals and non-metals

Metals	Non-metals
- All are solids except mercury - Have high melting points except alkali metals Shiny - Malleable and ductile (can be beaten into sheets and drawn into wires) - Good conductors of heat and electricity	- Solids, gases and one liquid (bromine) - Have low melting points except carbon and silicon - Dull - Brittle - Bad conductors of heat and electricity except graphite

Compounds are pure substances, which consists of two or more elements chemically combined.

The properties of the compound are completely different from those of its elements.

Mixtures are impure substances containing two or more compounds (elements and/or compounds) mixed together, not chemically combined. Its components can be easily separated by physical methods such as filtration, distillation and crystallization.

Mixtures are either clear and in one phase or cloudy and in more than one phase (suspensions)

The substances making up a solution are often solute and solvent.

The **solute** is the part of the solution that is dissolved, while the solvent is the part that does the dissolving.

A saturated solution is a solution, which has as much solute dissolved in it as is possible at that temperature.

Solubility is the maximum mass of solute that will dissolve in 100g of the solvent at a stated temperature. For most solutes, solubility increases with temperature. It follows that when a saturated solution is cooled the solution can hold less solute at the lower temperature. Some solute comes out of the solution; it crystallizes.

Alloys:

An alloy is a mixture of a metal with other elements especially metals.

It is made by weighing out correctly the different constituents and melting them together.

Steel is the most important alloy. It is an alloy of iron and about 1% carbon.

Brass is an alloy of 80% copper and 20% zinc. It is harder than copper, does not corrode and is easily worked. It is often used for ornaments and picture frames.

Some examples are:

Alloy	Typical composition		Particular properties
Brass	copper	70%	Harder than pure copper; gold coloured
	zinc	30%	
Bronze	copper	90%	Harder than pure copper
	tin	10%	
Mild Steel	iron	99.7%	Stronger and harder than pure iron
	carbon	00.3%	
Stainless Steel	iron	70%	Harder than pure iron; does not rust
	chromium	20%	
	nickel	10%	
Solder	tin	50%	lower melting point than either tin or lead
	lead	50%	

3.2 (a) Ions and ionic bonds

Ionic bonding involves complete transfer of elements from a metallic atom to a non-metallic atom.

An ion is a charged particle formed by the loss or gain of electrons. A cation is a positive ion and an anion is a negative ion.

Ionic bond is the electrostatic forces of attraction between two oppositely charged ions

Electrovalency is the number of electrons lost or gained by an atom.

Properties of ionic compounds:

1. Have high melting and boiling points because the bonds between positive and negative ions are strong and therefore a large amount of energy is needed to break them.

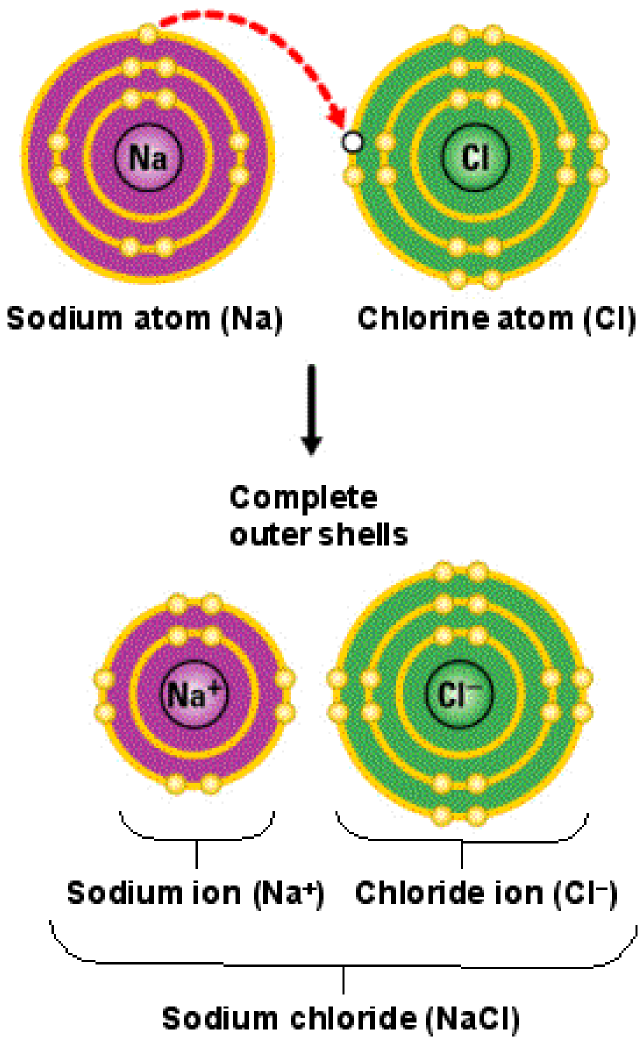
2. Usually soluble in water (a polar solvent) but insoluble in organic (non-polar) solvents such as ethanol and petrol. (If they do not dissolve in water it is often because they have very high lattice energy).

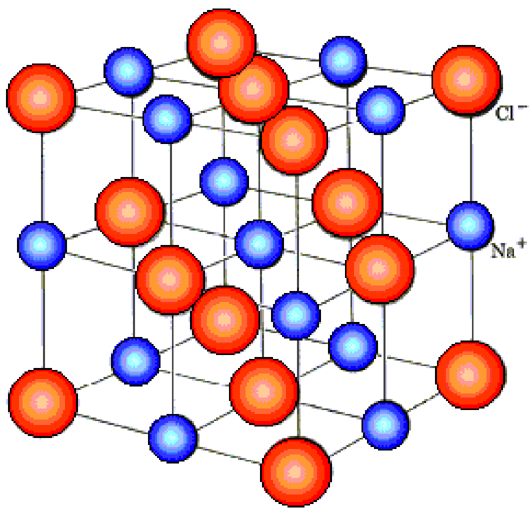
3. Conduct electricity when molten or dissolved in water because ions ar free to move towards the electrodes.

Examples of ionic compounds:

1. Sodium Chloride (NaCl):

- A sodium atom has an electronic configuration of 2.8.1
- A chlorine atom has an electronic configuration of 2.8.7
- Sodium atom loses one electron to form Na^+ ion, and chlorine gains one electron to form Cl^- Ion.
- The oppositely charged ions are held together by strong electrostatic attraction called ionic bond. Sodium chloride formed is an ionic compound.
- Ionic compounds tend to form crystals. A crystal of an ionic compound is a regular arrangement of a great number of alternating negative and positive ions.





2. Magnesium oxide (MgO):

- One atom of magnesium, Mg (2.8.2), gives 2 electrons to one atom of oxygen, O (2.6)
- The ions Mg^{2+} and O^{2-} are formed. The electrostatic attraction between them is an ionic bond.

3.2 (b) Molecules and covalent compounds

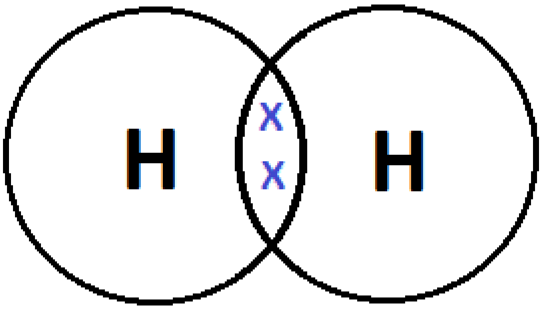
Covalent bonding involves sharing of electrons between non-metallic atoms. By sharing all the bonded atoms gain a full outer shell of electrons and the particle they form is a covalent compound.

Single covalent bonds:

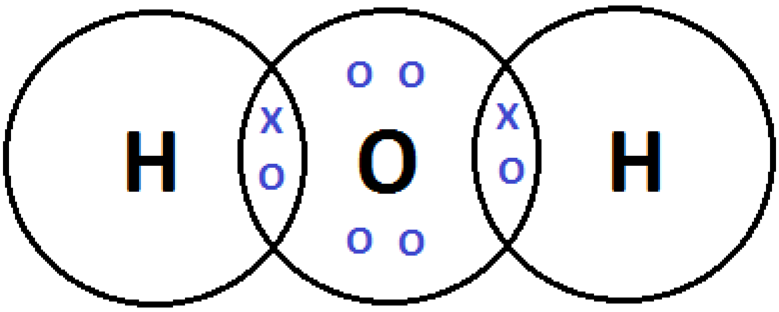
In a single covalent bong, one pair of electrons is shared between the two atoms. One electron comes from each of the two atoms.

A single covalent bond is the force of attraction between a shared [pair of electrons and the nuclei of the two bonded atoms.

Hydrogen



Water (Hydrogen oxide)

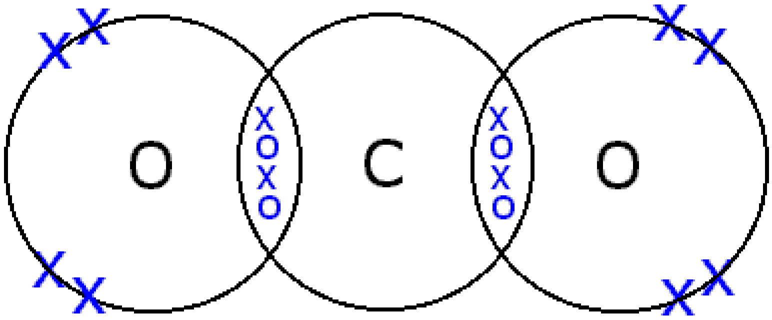


Double covalent bonds:

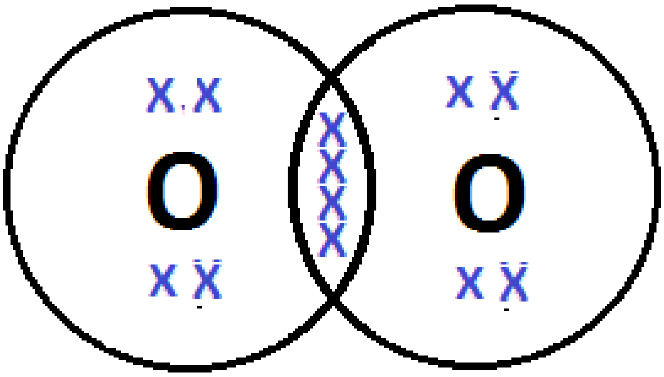
In double covalent bond two pairs of electrons are shared between the two atoms. Two electrons come from each of the two atoms.

A double covalent bond is the force of attraction between 2 shared pairs of electrons and the nuclei of the two bonded atoms.

e.g. carbon dioxide



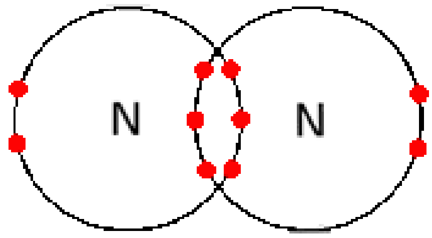
Oxygen



Triple covalent bonds:

In a triple covalent bond three pairs of electrons are shared between the two atoms. Three electrons come from each of the 2 atoms.

Triple covalent bonds are the force of attraction between three shared pairs of electrons and the nuclei of the two bonded atoms.



A covalent bond is the forces of attraction between the shared pairs of electrons and the nuclei of the two bonded atoms.

Covalency is the number of electrons which an atom shares when a bond is formed.

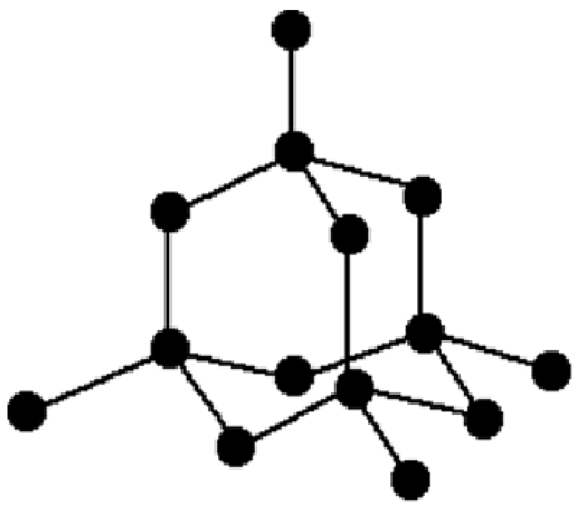
Properties of covalent compounds:

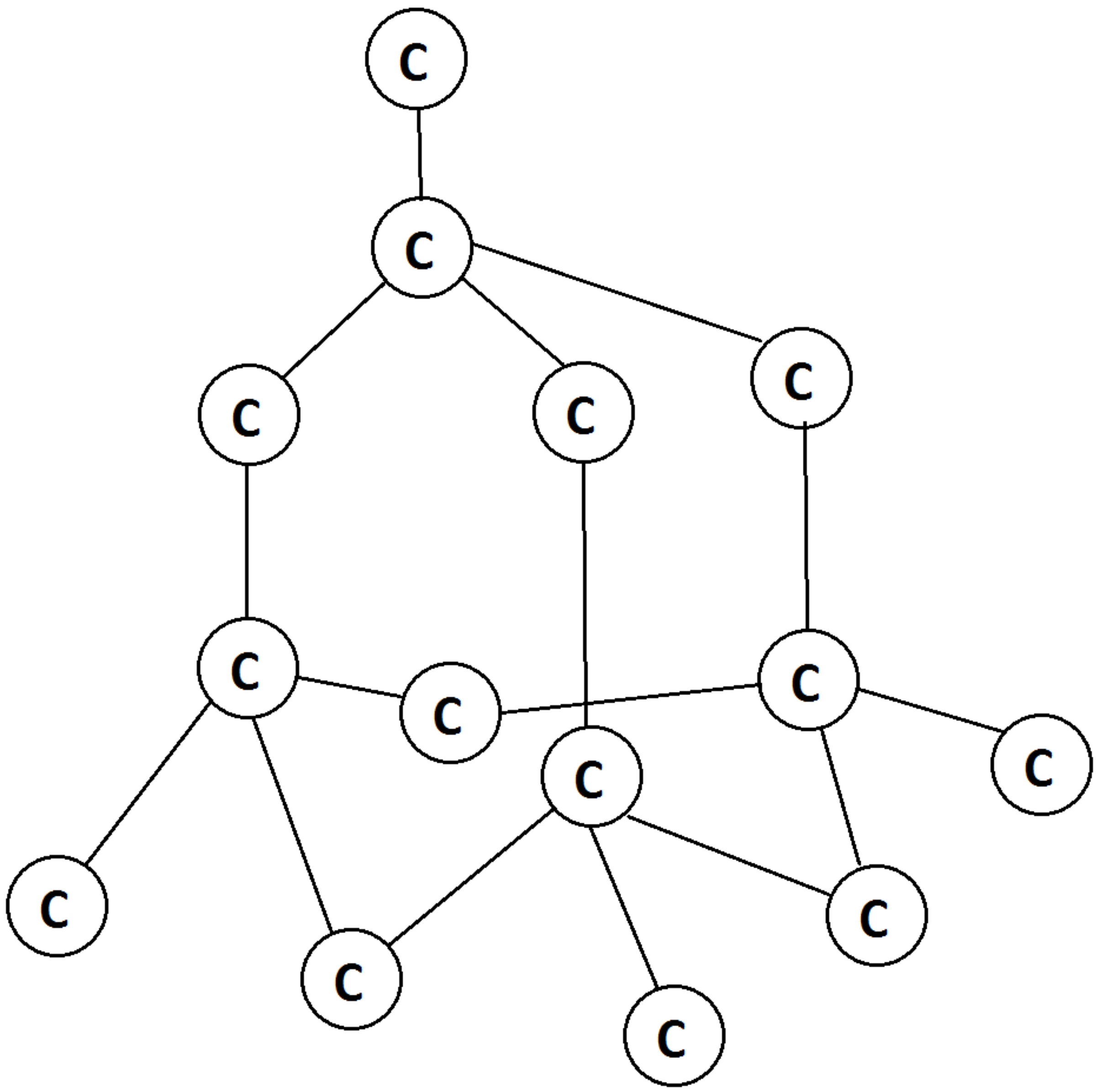
- May be a solid, a liquid or a gas.
- Solids are not very hard and have low melting and boiling points because the forces of attraction between the molecules are very weak.
- Do not dissolve in water (a polar solvent) but dissolve in organic solvent (non-polar) solvents.
- Do not conduct electricity because there are no free electrons to carry the charge.

3.2 (c) Macromolecules

1. Diamond

- Diamond is a macromolecular solid in which each carbon atom is covalently bonded to four other carbon atoms terahedrally.
- It has very high melting and boiling points and is very hard, the hardest substance known, and is mainly used in cutting and drilling equipment because all the atoms in the lattice are bonded together by rigid strong covalent bonds.
- It does not conduct electricity because there are no free electrons in the lattice structure to conduct electric charge.

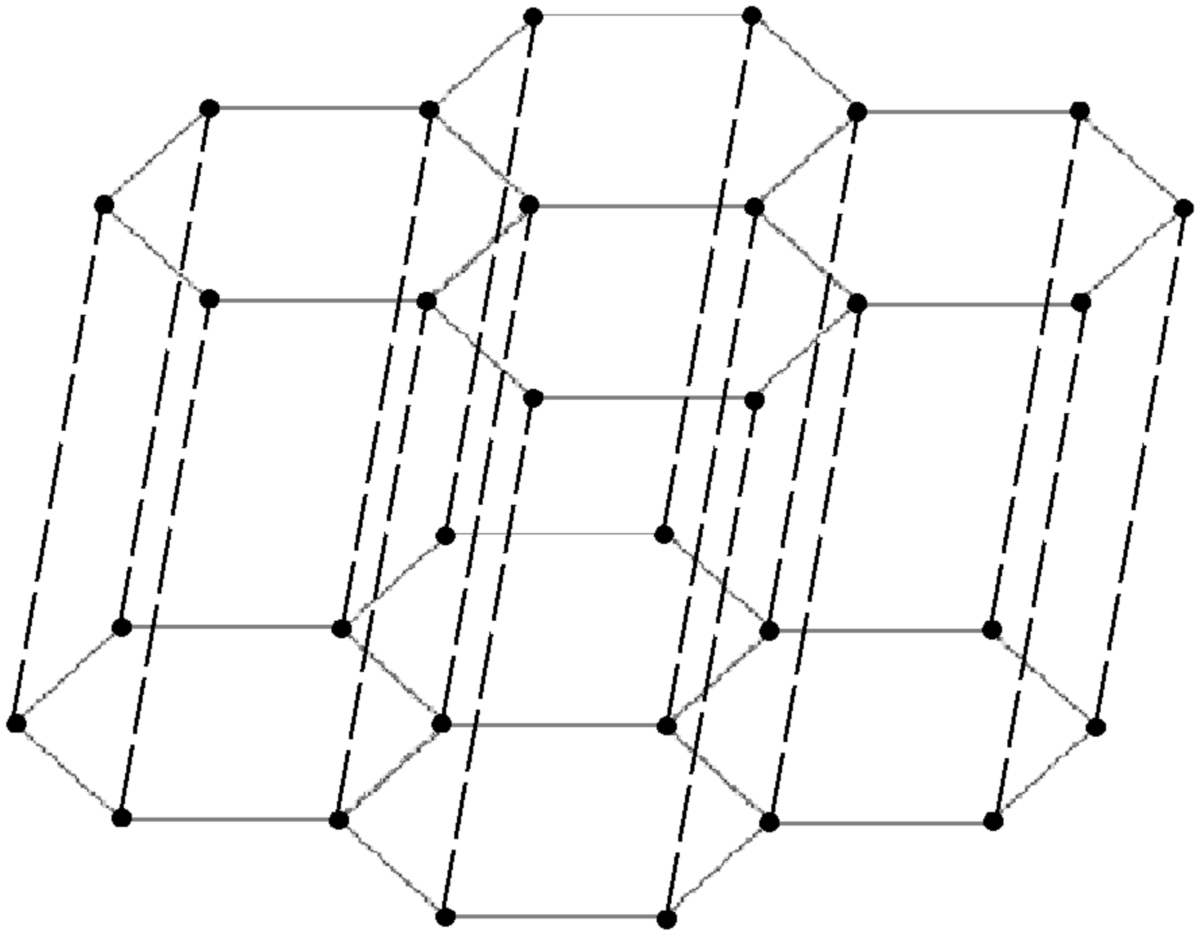




2. Graphite

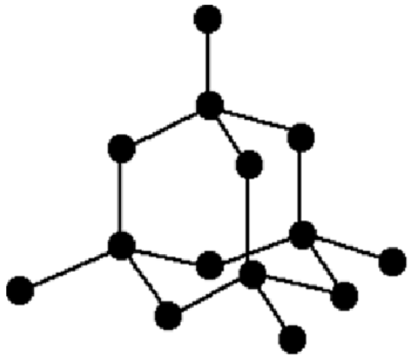
- Graphite has a layer structure. In each layer, each carbon atom is covalently bonded to other three carbon atoms. The remaining electron from each carbon atom is delocalized between the layers. It is these free electrons which allow graphite to conduct electricity.
- Since the bonds between the layers in graphite are very weak, the layers can slide past each other giving graphite its slippery feel and the ability of being used as a lubricant.

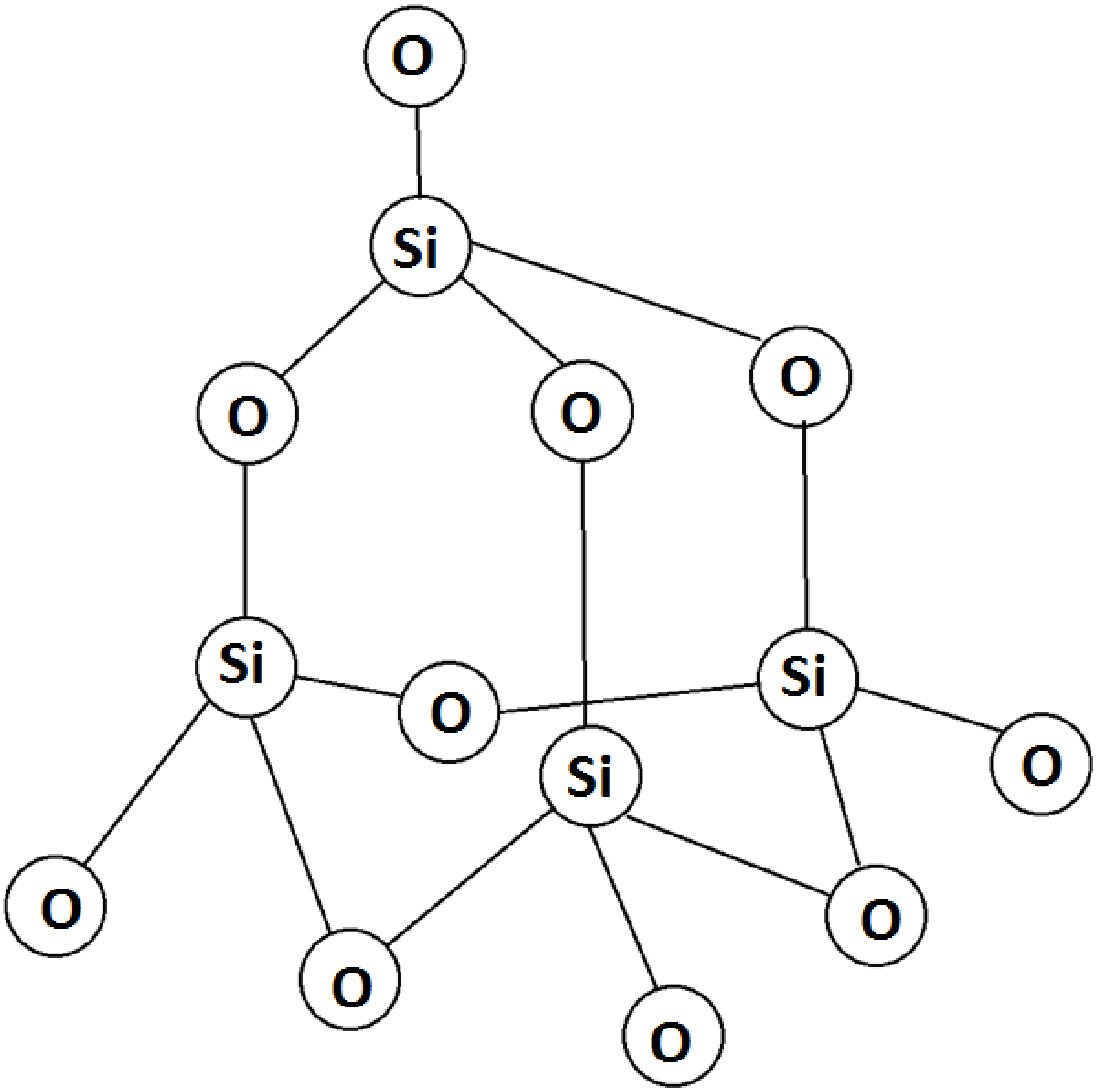
The broken lines show the weak bonds and the lines show the strong bonds.



3. Silicon (IV) oxide

- Silicon dioxide is a macromolecular solid in which each silicon atom is covalently bonded with 4 other oxygen atoms and each oxygen atom to 2 silicon atoms in such a way that each silicon atom is at the centre of a regular tetrahedron of oxygen atoms.
- This structure is similar to the macromolecular structure of diamond.
- Silicon dioxide is hard has a high melting point and does not conduct electricity.

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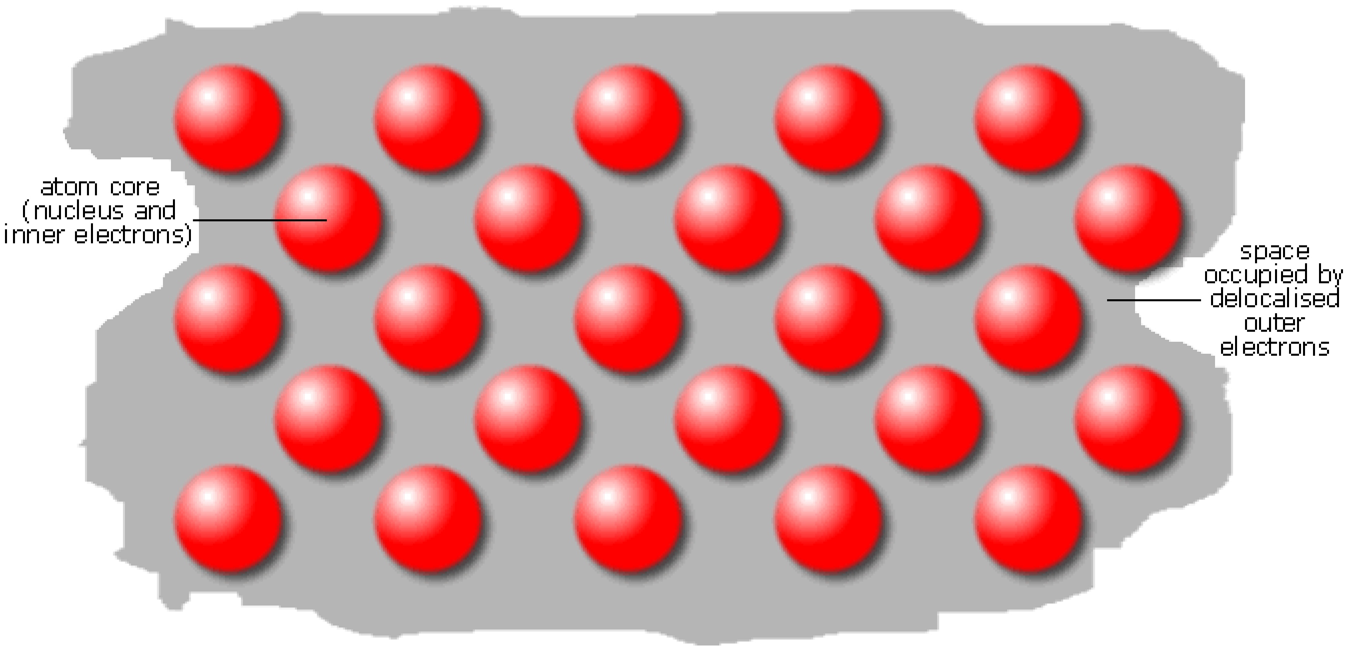
3.2 (d) Metallic bonding

Atoms of a metal can form lattices. All metal lattices consist of a close packed arrangement of positive ions, which are surrounded by a sea of delocalized electrons that bind the ions together.



Definition of lattice: a regular three-dimensional arrangement of atoms, molecules or ions in a crystalline solid.

Properties of metals:

- Metals generally have high densities because thee ions are close packed in the lattice
- Metals generally have high melting and boiling points because of the strong metallic bonds holding the lattice.
- Metals are good conductors of heat and electricity, because the delocalized electrons are free to move through the lattice.
- Metallic bond is the force of attraction between two positive metal ions and the delocalized electrons in the lattice between them.