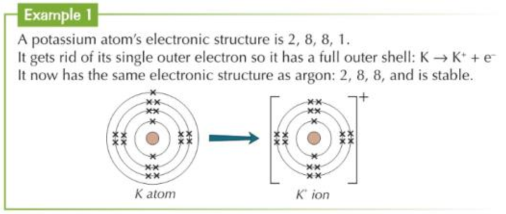
Chemistry

2. Bonding, Structure and the Properties of matter

Bonding and Structure

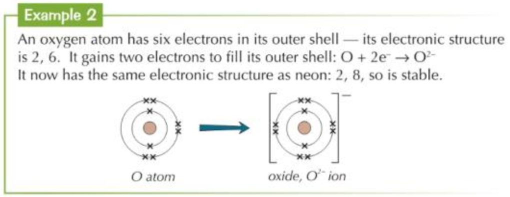
1: Ions

Ions are charged particles that are made when electrons are lost or gained. Metals atoms will lose electrons to from positive ions and non-metals atoms will gain electrons to form negative ion. They do this so they can have a full outer shell like the noble gases.



Example 1

A potassium atom's electronic structure is 2, 8, 8, 1.
It gets rid of its single outer electron so it has a full outer shell: $K \rightarrow K^+ + e^-$
It now has the same electronic structure as argon: 2, 8, 8, and is stable.

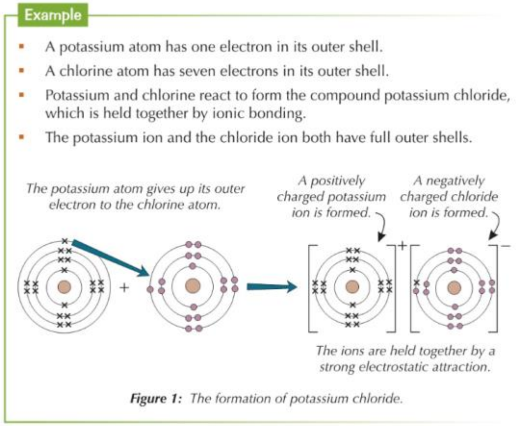


Example 2

An oxygen atom has six electrons in its outer shell — its electronic structure is 2, 6. It gains two electrons to fill its outer shell: $O + 2e^- \rightarrow O^{2-}$
It now has the same electronic structure as neon: 2, 8, so is stable.

2: Ionic Bonding

When metals react with non-metals, electrons are transferred. The oppositely charged ions are strongly attracted to each other and this strong electrostatic attraction holds the ions together in the ionic compound – known as ionic bonding. These are represented by dot and cross diagrams.



Example

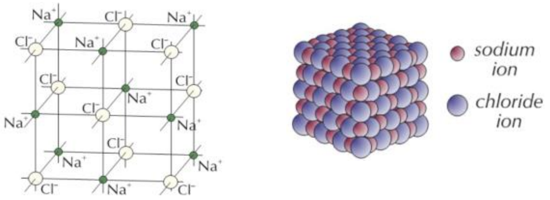
- A potassium atom has one electron in its outer shell.
- A chlorine atom has seven electrons in its outer shell.
- Potassium and chlorine react to form the compound potassium chloride, which is held together by ionic bonding.
- The potassium ion and the chloride ion both have full outer shells.

Figure 1: The formation of potassium chloride.

3: Ionic Compounds

Ionic compounds have a structure called a giant ionic lattice. There are very strong electrostatic forces of attraction between oppositely charged ions which act in all directions. This can be represented in 3 ways:

1) Dot and cross diagrams – These are useful for showing how ionic compounds are formed; but they don't show the structure, relative sizes of the ions, or how they are arranged.
2) 3D Models – These can show the relative sizes of the ions, as well as the regular pattern in an ionic crystal. However, they only let you see the outer layer of the compound.
3) Ball and stick models – Like 3D models, ball and stick models show the regular pattern in an ionic lattice, as well as how all the ions are arranged. In addition, they suggest that the crystal extends beyond what is shown in the diagram. They may show the relative sizes of the ions, but sometimes the ions are not shown to scale. Another disadvantage of them is that they suggest that there are gaps between the ions, when in reality there aren't.



To work out the empirical formula of an ionic compound, you can look at the diagram and the ions in it. E.g. If there are Potassium +1 ions and Oxygen 2- ions, then the formula is K_2O.

Ionic compounds all have high melting and boiling points due to the strong electrostatic attraction between the ions. It takes a large amount of energy to overcome this attraction and break the many strong bonds. Most ionic compounds will also dissolve really easily in water.

Ionic compounds can't conduct electricity when solid because the ions are all held in fixed positions. However, hen they are melted or dissolved, the ions are free to move and they'll carry electric current.

4: Covalent Bonding

A covalent bond is formed when a pair of electrons is shared between 2 atoms, to get a full outer shell. The positively charged nuclei of the bonded atoms are attracted to the shared pair of electrons by electrostatic forces, making covalent bonds very strong. There are a few different ways to show covalent bonding:

1) Dot and Cross Diagrams – These are useful for showing which atoms the electrons in a covalent bond come from, but they don't show the relative sizes of the atoms, or how the atoms are arranged in space.
2) Displayed formulas – This is a great way of showing how atoms are connected in large molecules. However, they don't show the 3D structure of the molecule, or which atoms the electrons in the covalent bond have come from
3) 3D and ball and stick models – A 3D model shows the atoms and their arrangement in space. Ball and stick models show the bonds, whereas 3D models don't. Ball and stick models can also show double bonds clearly. A disadvantage of 3D models is that they can quickly get confusing for large molecules where there are lots of atoms to include. They don't show where the electrons in the bonds have come from, either.

You can find the molecular formula of a simple molecular compound by counting up how many atoms of each element there are in a diagram.

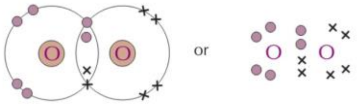
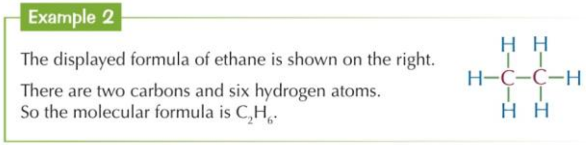


Figure 4: Dot and cross diagrams showing the double covalent bond in oxygen.



Example 2

The displayed formula of ethane is shown on the right.

There are two carbons and six hydrogen atoms.
So the molecular formula is C_2H_6.

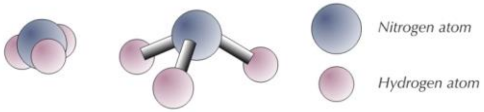


Figure 6: 3D models of ammonia. The second is a ball and stick model showing the bonds.

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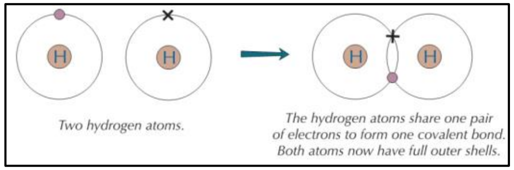
Bonding and Structure

5: Simple Molecular Substances

Simple molecules are made up of only a few atoms joined by covalent bonds. Examples are:

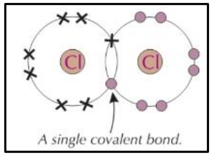
1) Hydrogen (H_2)
2) Chlorine (Cl_2)
3) Hydrogen Chloride (HCl)
4) Methane (CH_4)
5) Water (H_2O)
6) Nitrogen (N_2)
7) Ammonia (NH_3)
8) Oxygen (O_2)

Covalent substances made up of simple molecules don't conduct electricity in any state, as there are no free ions or electrons to carry a charge. They also have low melting and boiling points, so they are mostly gases, or liquids at room temperature. This is because, even though they have strong covalent bonds, the intermolecular forces between them are very weak. It is these forces that need to be overcome in order to melt/boil a simple molecular substance and this doesn't require much energy. As molecules get bigger, the strength of the intermolecular forces increases, so more energy is needed to break them, so boiling points increase.

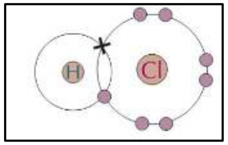


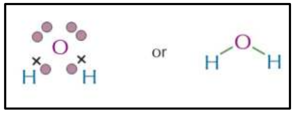
Two hydrogen atoms.

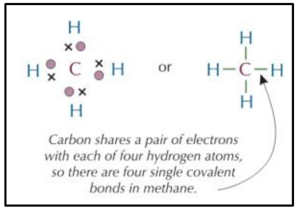
The hydrogen atoms share one pair of electrons to form one covalent bond. Both atoms now have full outer shells.



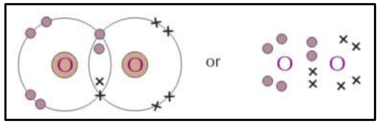
A single covalent bond.

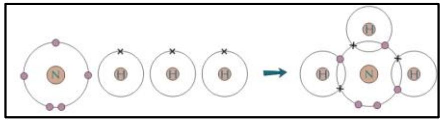


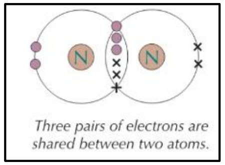




Carbon shares a pair of electrons with each of four hydrogen atoms, so there are four single covalent bonds in methane.







Three pairs of electrons are shared between two atoms.

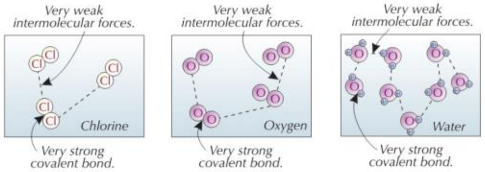
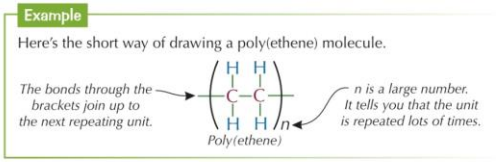


Figure 10: The bonding within and between simple molecules.

6: Larger Covalent Substances

A polymer consists of lots of long molecules made up of repeating sections. All the atoms in a polymer molecule are joined together by strong covalent bonds. We can show this by using a repeating unit. Polymers have higher melting and boiling points than simple covalent molecules, this is because the intermolecular forces are stronger, so more energy is needed to break them. However, the intermolecular forces are still weaker than ionic or covalent bonds.


Example

Here's the short way of drawing a poly(ethene) molecule.

The bonds through the brackets join up to the next repeating unit.

n is a large number. It tells you that the unit is repeated lots of times.

Poly(ethene)

Giant Covalent Structures (macromolecules) are similar to giant ionic structures (lattices), but there are no charged ions. Instead, all of the atoms are bonded to each other by strong covalent bonds. To melt or boil a giant covalent molecule, you need to overcome the strong covalent bonds between the atoms. This takes a lot of energy, so giant molecules have very high melting and boiling points.

e.g. Silicon Dioxide is silicon and oxygen. It is insoluble in all solvents, because the solution process doesn't release enough energy to break the strong covalent bond.

8: Metallic Bonding

A metal consists of a giant structure, where the metals are arranged in a regular pattern. The outer shells of the atoms are delocalized meaning that they are free to move about the whole structure, so are good conductors of heat and electricity. There are also strong electrostatic forces between the positive metal ions and negative electrons, known as metallic bonding, this keeps the structure together. It also means that there are high melting and boiling points and they are solids at room temperature. Metals are also malleable. However, most metals we use everyday are alloys (a mixture of metals). They are harder and more useful than pure metals, as the different sized atoms distort the layers.

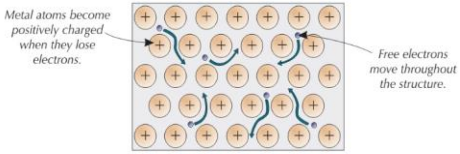


Figure 2: Delocalised electrons within a giant metallic structure.

7: Allotropes of Carbon

- Diamond – Each carbon atom is covalently bonded to 4 others. This forms a rigid structure, making diamond very strong and hard. It also has a very high melting point because the strong covalent bonds take a lot of energy to overcome. However, It doesn't conduct electricity as there are no free electrons.
- Graphite – Each carbon atom is covalently bonded to 3 others. This creates sheets of carbon atoms arranged in hexagons. There aren't any covalent bonds between the layers, just weak intermolecular forces, so they are free to move over each other. It has a high melting point because the covalent bonds need a lot of energy to break. Graphite also has 1 free delocalized electron, meaning graphite conducts electricity.

Fullerenes are hollow molecules of carbon, shaped like tubes or ball. They are mainly made up of carbon atoms arranged in hexagons but can sometimes be pentagons and heptagons. Buckminsterfullerene (C_{60}) was the first fullerene to be discovered. Nanotubes are fullerenes which are tiny carbon cylinders. Fullerenes can be used in different ways, such as; in medicine (to cage other molecules); as catalysts (they have a huge surface area); as lubricants (they reduce friction); to strengthen materials (nanotubes have a high tensile strength); and in electronics (they are small and can conduct electricity).

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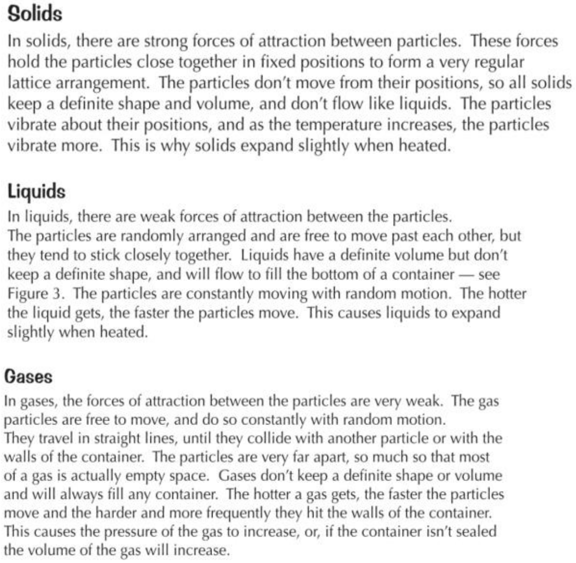
Types of Matter

1: States of Matter

Materials come in 3 different forms of solid liquid, or gas. Which sate a material is in depends on how strong the forces of attraction are between the particles of the the material. The strength of forces between particles is determined by the material, the temperature and the pressure. You can use a model called the particle theory to explain how the particles in a material behave in the 3 states. In it, each particle is considered to be a small, solid, inelastic sphere.



Solids

In solids, there are strong forces of attraction between particles. These forces hold the particles close together in fixed positions to form a very regular lattice arrangement. The particles don't move from their positions, so all solids keep a definite shape and volume, and don't flow like liquids. The particles vibrate about their positions, and as the temperature increases, the particles vibrate more. This is why solids expand slightly when heated.

Liquids

In liquids, there are weak forces of attraction between the particles. The particles are randomly arranged and are free to move past each other, but they tend to stick closely together. Liquids have a definite volume but don't keep a definite shape, and will flow to fill the bottom of a container — see Figure 3. The particles are constantly moving with random motion. The hotter the liquid gets, the faster the particles move. This causes liquids to expand slightly when heated.

Gases

In gases, the forces of attraction between the particles are very weak. The gas particles are free to move, and do so constantly with random motion. They travel in straight lines, until they collide with another particle or with the walls of the container. The particles are very far apart, so much so that most of a gas is actually empty space. Gases don't keep a definite shape or volume and will always fill any container. The hotter a gas gets, the faster the particles move and the harder and more frequently they hit the walls of the container. This causes the pressure of the gas to increase, or, if the container isn't sealed the volume of the gas will increase.

The particle theory is a great model for explaining the different sates, but it isn't perfect. In reality, the particles aren't solid or inelastic and they aren't spheres. Also, the model doesn't show the forces between particles, so there's no way of knowing how strong they are. The size of the particles and distance between them also isn't shown to scale.

If you have a sample of a substance, it will contain billions of atoms or molecules. It has 'bulk properties' such as density and ,melting point which will always be the same, no mater the sample. These properties depend on how the particles interact with each other, so a single atom or molecule would behave differently.

A chemical reactions can also sometime include state symbols next to each substance, to tell you what physical state the reactants and products are in.

(s) — solid (l) — liquid (g) — gas (aq) — aqueous

2: Changing State

Changes of state are physical changes – only the arrangement or the energy of the particles changes, not the particles themselves. When something is heated, the particles gain more energy. This makes them vibrate more, which weakens the forces that hold the particle together.

When something is cooled, the particles have less energy. This energy is not enough to overcome the attraction between the particles.

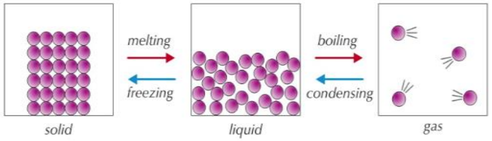


Figure 1: Particle theory model showing changes of state.

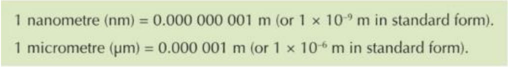
The amount of energy needed for a substance to change state depends on how strong the forces of attraction are between the particles, The strength of the forces depends on the structure of the substance and type of bonding.

4: Uses of Nanoparticles

- As catalysts for fuel cells – platinum is typically used, but it is really expensive, so less are needed.
- In Nano medicine – tiny particles can be absorbed more by the body than most particles.
- In electronics – Some conduct electricity.
- In deodorants – Silver nanoparticles are added as they have antibacterial properties.
- In sun cream – They give better skin coverage and and are better at protecting the skin from harmful UV rays
- In cosmetics – They can improve moisturizers without making them oily and can deliver active ingredients to lower layers of skin in anti-aging cream.

However, some people are worried that nanoparticles have been made available before the affects on human health have been investigated properly – long term and short term. There are also concerns that they can cause environmental damage.

3: Nanoparticles



1 nanometre (nm) = 0.000 000 001 m (or 1×10^{-9} m in standard form).

1 micrometre (μm) = 0.000 001 m (or 1×10^{-6} m in standard form).

Particles are put into categories depending on their diameter and there are 3 types:

1) Coarse Particles – These have a diameter between 2500nm and 10,000nm. They are also referred to as dust particles or PM_{10} which stands for particulate matter up to 10 micrometers in diameter.
2) Fine Particles – These have diameters between 100nm and 2500nm. They are also know as $PM_{2.5}$ which stands for particulate matter up to 2.5 micrometers in diameter.
3) Nanoparticles – These have diameters between 1nm and 100nm. Nanoparticles contain only a few hundred atoms. A typical atom has a diameter of about 0.1 nm and small molecules generally have diameters less than 1nm.

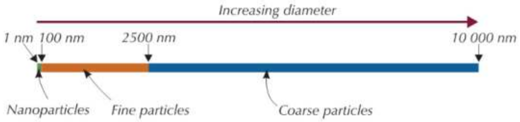
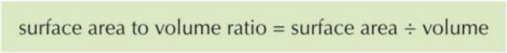


Figure 1: The relative diameters of nanoparticles, fine particles and coarse particles.

Nanoparticles shave a very high surface to volume ratio – this means that the surface area is very large compared to the volume. As particles decrease in size, the size of their surface area increases in relation to their volume, assuming they stay in similar shape.



surface area to volume ratio = surface area ÷ volume

The study of nanoparticles is called Nano science and it can show us different things about nanoparticles.

- Nanoparticles may have different properties to the material in bulk.
- Nanoparticles can make good catalysts because of their high surface area to volume ratio. This is because more atoms of each particle are at the surface and so are able to interact with the reactants compared to a catalyst made from bulk material.

This means that you'll often need less of a material that's made up of nanoparticles to work as an effective catalyst compared to a material made up of 'normal' sized particles (containing billions of atoms rather than a few hundred).