Chemical Bonds

CHEMISTRY • ATOMS AND BONDING • CHEMICAL BONDS

Section 1: Bonding Introduction

• What holds the particles together in chemical substances?

Particles can be bonded together like people holding hands

The forces of attraction that hold particles together are called bonds. All particles attract one another to some extent, and so they always need energy to pull them apart. That is why we need to heat substances to make them melt or boil. We are supplying energy to break the bonds between the particles, so they can move apart.

• Suggested Film

– Introduction to Chemical Bonding

Extension Question

Q1. What sorts of processes involve breaking bonds?

All chemical reactions involve the breaking of bonds. During the reaction, bonds between some atoms are broken, and new bonds are being made. Energy is being taken in as the old bonds are broken, and released as new bonds are made.

• Are all bonds the same strength?

No. Some bonds are very strong, some are very weak. For example, in metals such as iron, or in hard substances such as diamond, the bonds are very strong, so they have very high melting points. A great deal of energy is needed to break the bonds between their particles.

By contrast, the bonds between the atoms in helium gas are very weak. Very little energy is needed to break these bonds, so helium will remain a gas unless you cool it to very low temperatures.

In between these two extremes are substances like water, which are not hard solids like iron, or gases like helium. The forces of attraction between particles in liquid water must be much stronger than the forces between helium atoms, but much weaker than those between iron atoms.

• Suggested Film

– Introduction to Chemical Bonding

Extension Question

Q2. When we boil water, are we breaking bonds?

Boiling is not a chemical process, as no new substances are being made. The strong covalent O-H bonds inside the water molecules are not being broken. However, when we boil water, the relatively weak forces of attraction between the water molecules are overcome, as the water molecules are pulled apart. We need to supply the energy to do this.

Section 2: Types of Bonding

• What holds the atoms together in metals?

Metal atoms can lose their outer electrons fairly easily, and these merge together to form a 'sea' of electrons. The atoms that have lost their electrons are now positive ions, known as cations. These cations are in a huge, regular, three-dimensional arrangement called a lattice.

The bonding in metals, known as metallic bonding, is the attraction between the sea of electrons and the positive metal cations. The bonding is usually quite strong, so metals generally have high melting points.

The atoms in this copper piping are held together by metallic bonding

The electrons can move freely, as they are not attached to any particular atom any more. If we connect a metal to a battery, the electrons drift in one direction, and we call this movement of charge an electric current. All metals are therefore good conductors of electricity.

• Suggested Film

– Metallic Bonding

Extension Questions

Q3. Why are metals malleable (easy to squash into shape)?

When a metal is squashed, the layers of metal cations slide over one another, and the sea of electrons flows into the empty spaces. The metal does not break or snap, it just changes its shape.

Q4. Why are gold rings not made of pure gold?

Alloys are mixtures of a metal and another element, usually one metal and another metal. Examples of alloys are bronze (copper + tin), brass (copper +zinc), solder (lead + tin) and steel (iron + carbon).

Pure metals are usually soft (for the reason given in Q3), but if we introduce some different atoms into the metal, it becomes harder for the atoms to slide over one another. Alloys are therefore much harder than the pure metal. Pure gold is not used in jewellery because it is too soft. Gold rings are made of gold alloyed with copper or silver, as otherwise they would lose their shape too easily.

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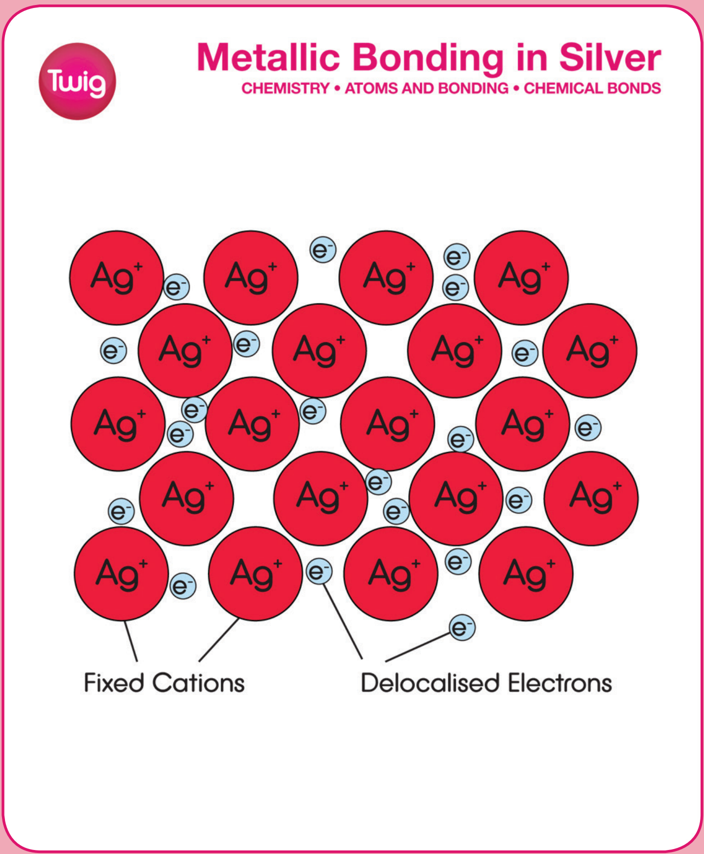
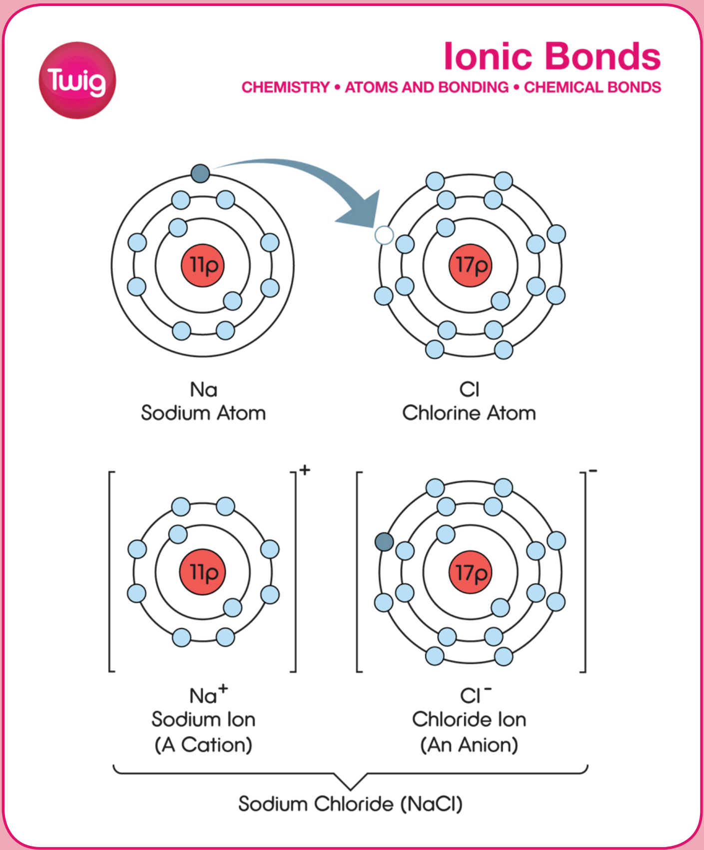


• What is ionic bonding?

DIAGRAM 02:



Ionic bonding is the attraction between positive (usually metal) ions, such as sodium ions Na^+, and negative (usually non-metal) ions, such as chloride ions Cl^-. Compounds that are made of ions contain a huge lattice of positive and negative ions. The attraction between the ions is called electrostatic attraction.

Pulling ions apart requires a lot of energy, so most compounds made of ions, such as table salt or sodium chloride (NaCl), have high melting points and boiling points. This is why when we boil salty water the salt is left behind, whilst the water with a much lower boiling point, evaporates.

• Suggested Film

– Ionic Bonding

Extension Questions

Q5. If table salt is made of ions, why don't we get an electric shock from salty food?

There are billions of positive ions and billions of negative ions in ionic compounds. However, the numbers of positive and negative ions are exactly equal, so the total charge is zero.

Q6. Why can't ionic compounds like salt conduct electricity in the same way as metals?

Ionic compounds can conduct electricity but not when they are solids. Solid sodium chloride cannot conduct electricity, because the sodium ions and chloride ions are fixed in position and cannot move.

However, if the sodium chloride is melted or dissolved in water, the ions break apart and are free to move. Molten sodium chloride and sodium chloride solution are both good conductors of electricity.

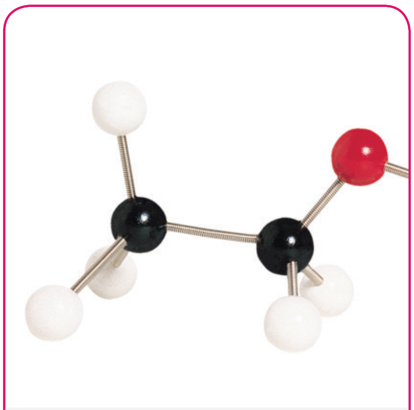
Metals are excellent conductors because electrons are free to move through the metal structure.

• What is covalent bonding?

Covalent bonding usually takes place between non-metal atoms and other non-metal atoms. Non-metals include elements such as carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus.

In a covalent bond, the outer electrons of one atom are shared with another atom, so that both atoms acquire full shells of electrons. The shared electrons are then attracted by the nuclei of both atoms; this electrostatic attraction is known as a covalent bond.

Covalent bonds are strong and require a great deal of energy to break apart. Many important small molecules such as oxygen O_2, nitrogen N_2, carbon dioxide CO_2, water H_2O, and methane CH_4 are held together by covalent bonds. As are all the large molecules in our bodies, such as hormones, enzymes, haemoglobin, fats, vitamins and DNA. Life on Earth would be impossible without covalent bonding.



In this model of ethanol, the covalent bonds are represented by sticks

• Suggested Film

– Covalent Bonding

Extension Question

Q7. If covalent bonds are so strong, how can they be broken without using huge amounts of energy?

In our bodies covalent bonds are being broken all the time, for instance, during digestion when starch is broken down into glucose in our intestines. Some energy is used up during digestion, but energy is later released, as the glucose molecules react with oxygen during respiration. We have to look at all the energy changes in a process to understand why chemical reactions take place.

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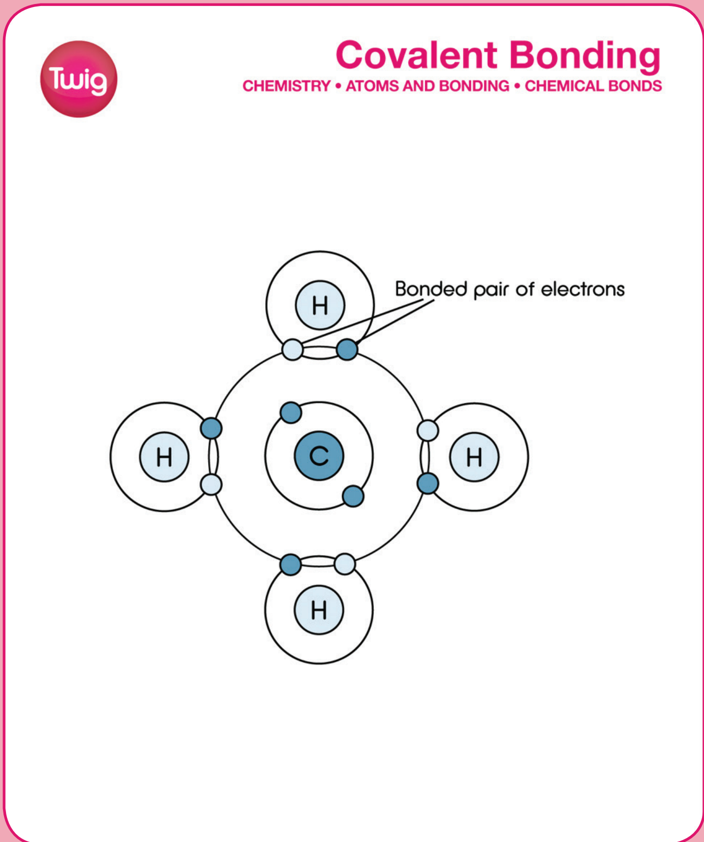


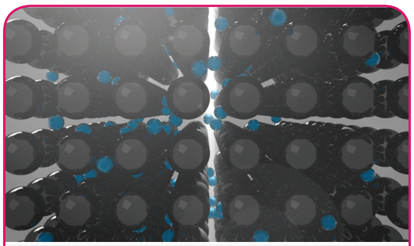
Section 3: Carbon Bonding

• What makes carbon such a special element?

Carbon is element number 6. It has 6 protons in its nucleus, and therefore 6 electrons, with 2 in the first shell and 4 in the second shell; the electron configuration is 2,4.

Carbon therefore has 4 outer electrons, and can form 4 covalent bonds by sharing these electrons with other atoms.

Carbon atoms can form bonds to other carbon atoms: single, double or even triple covalent bonds. This allows it to form long, branched chains and rings of carbon atoms. No other element can form so many different types of molecule, and that is why carbon is the key element in the chemistry of all living organisms. People used to think that carbon compounds had some sort of special 'life force' inside them. We no longer believe this, but the chemistry of carbon is still called organic chemistry, showing its connection with the living world.



Carbon has 6 protons and 6 electrons

• Suggested Film

– Carbon: Introduction

Extension Question

Q8. Carbon has exactly FOUR outer electrons: why is that so important?

FOUR outer electrons mean that each carbon atom can form FOUR covalent bonds. Each carbon atom thus can link to up to FOUR other carbon atoms. No other element has atoms which can bond together to make such complex structures, including long straight chains, branched chains and rings, in an almost infinite variety of combinations. This makes the chemistry of carbon easily the richest of all the elements in the periodic table, and is directly related to carbon's vital role in all living things.

• What are the different forms of carbon?

The different forms of carbon are graphite, diamond and buckminsterfullerene.

Graphite:

Graphite is a very unusual material. It is one of the softest natural materials, but it has a very high melting point. It is made of carbon, a non-metal, yet it is a good conductor of electricity and feels cold to the touch, like a metal.

Graphite is made of layers of carbon atoms. The carbon atoms within these layers are arranged in a honeycomb-like pattern of hexagons. Each carbon atom is bonded to three adjacent carbon atoms by covalent bonds at angles of 120° to each other. These covalent bonds use three of the four outer electrons in the carbon atom; the fourth electron is free to move between the layers. These free, delocalised electrons merge together to form a sea of electrons which can flow between the layers. Graphite is therefore a good conductor of electricity, rather like a metal.

The layers of carbon atoms have relatively weak forces of attraction, so they can slide over one another. When we write with a pencil, we are forcing layers of carbon atoms to slide off the graphite and stick onto the piece of paper we are writing on.

The 2010 Nobel prize for physics was given for studies of a layer of graphite just one atom thick, called graphene. It has even more amazing properties than graphite itself. It is the strongest, stiffest material yet discovered. It is almost transparent, is the best conductor of heat of all known materials, and is as good a conductor of electricity as copper.

Diamond:

Diamond is the hardest known natural material; meaning that it is able to scratch all other substances, but it cannot be scratched by them. The reason for its hardness is that each one of the trillions of carbon atoms is covalently bonded to four other carbon atoms, in a huge three-dimensional network or lattice. To break these covalent bonds takes a vast amount of energy, which is why it is hard to scratch diamond, and also accounts for the very high melting point of diamond.

Diamonds are a precious gemstone made from carbon

Buckminsterfullerene:

Buckminsterfullerene is a third structural form, or allotrope, of carbon, discovered in 1985. It contains spherical C_{60} molecules, made of 60 carbon atoms. The carbon atoms are arranged in hexagons and pentagons, exactly the same pattern as you see on a modern soccer ball. The discovery has led to discoveries of molecules related to C_{60}, known as fullerenes, which have great potential in medicine and in making minute electronic devices for computers.

- **Suggested Films**
  - – Carbon: Introduction
  - – Carbon: Synthetic Diamonds
  - – Carbon: Buckminsterfullerene

Extension Questions

Q9. What is graphite used for?

Graphite is used in pencil leads (although they are made of carbon not lead), as layers of carbon atoms rub off onto the paper. The very high melting point of graphite allows it to be used to make vessels, called crucibles, which can withstand very hot molten metals, such as silver and gold. Its excellent thermal (heat) conductivity makes it useful on the nose cone of the space shuttle, as it helps to spread out the heat generated when the shuttle re-enters the atmosphere. Graphite, in the form of carbon fibres bonded in a polymer matrix, is a very strong, low density material used in making tennis rackets, fishing rods, cars, bicycles and aeroplanes. In fact, any application where we need a material that is both very strong and very light.

Q10. Apart from jewellery, what is diamond used for?

About 80% of diamonds are unsuitable for the use as jewels, because they are not of sufficient quality. They have a range of other applications, such as in making drills and sanding tools, as the extreme hardness of diamond allows it to cut through materials, including rock and steel.

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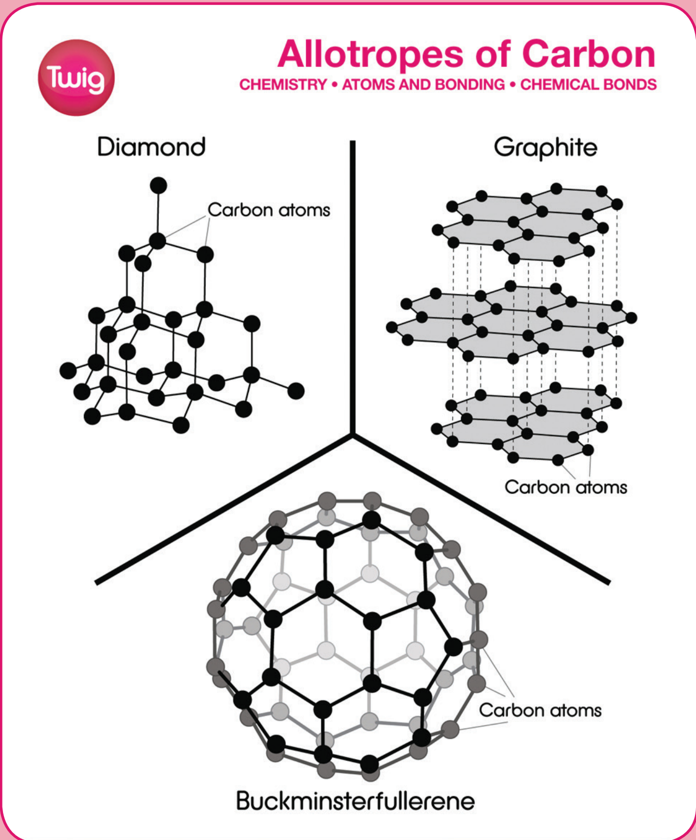
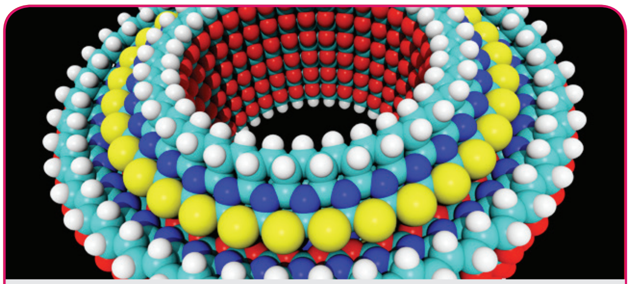


Q11. How useful is buckminsterfullerene?

There have been many suggested uses for buckminsterfullerene and for the fullerene molecules which are related to it, such as the delivery of cancer drugs and making extremely thin nanowires, but so far these ideas have not proved commercial. However, this is still a very new material and there are likely to be real applications in the not-so-distant future.

• What is nanotechnology and is it safe?

Nanotechnology is the study of the manipulation of matter at an atomic or molecular scale, of the order of 1 nanometre (or 1 thousand millionth of a metre), hence the name. Nanotechnology is in its infancy, as we become able to build materials atom by atom, and to make materials which have properties quite different from the same substance in bulk. For example, silver nanoparticles kill bacteria and have been used in socks to kill the bacteria on our feet, which cause feet to smell bad. Nanoparticles of titanium dioxide are used in some sunscreens. There are many other applications in medicine, agriculture and, possibly, in the future we may even be able to make molecular machines called nanobots.


A model of a complex piece of nanotechnology

• Suggested Films

- **– Nanotechnology: What Is It?**
- **– Nanotechnology: Is It safe?**

Socks impregnated with silver nanoparticles have been found to release these into water when washed. This means they could, in theory, find their way into the food chain, and into the wider environment. Nanoparticles are so small they can enter the body relatively easily and cross cell membranes. There are therefore some fears about the safety of this new technology, with guidelines being drawn up about their use, and controlling our exposure to them. It is too soon to judge whether there are any long-term ill effects from using these materials.

Extension Question

Q12. Why does a material like silver change its properties when it is in the form of very small nanoparticles?

Nanoparticles are so small, which means they have an enormous surface area that is able to interact with bacteria far more effectively than that of that a solid piece of silver, such as a silver cup. They act as catalysts; dramatically speeding up chemical reactions. This explains why silver nanoparticles are used in socks to kill the bacteria that feed on sweat and cause the nasty smell.

• Quizzes

Introduction to Bonding

Basic

• Elements are substances

A – that are made of atoms

B – that cannot be made by chemical reactions

C – that cannot be broken down into simpler substances

D – that can only be made by chemical reactions

The number of elements found on Earth is

A – 82

B – 92

C – 102

D – 112

• A compound MUST contain

A – one element

B – more than one element

C – two elements

D – more than two elements

• The properties of water are

A – the same as those of hydrogen gas

B – the same as those of oxygen gas

C – a mixture of the properties of hydrogen gas and oxygen gas

D – completely different from the properties of hydrogen gas and oxygen gas

Advanced

• The number of different elements is the same as the number of types of

A – atom

B – compound

C – molecule

D – nucleus

• If a substance is heated and it decomposes into a colourless gas and a black solid, it CANNOT be

A – a mixture

B – a compound

C – a pure substance

D – an element

• The atoms in a compound

A – are usually in a 1:2 ratio

B – are always in a 1:1 ratio

C – are usually in a 2:1 ratio

D – are always in a fixed ratio

• In water, two hydrogen atoms are always bonded to

A – 1 oxygen atom

B – 2 oxygen atoms

C – 2 chlorine atoms

D – 1 sodium atom

Ionic Bonding

Basic

• An ion is a particle which has a

A – nucleus

B – neutron

C – proton

D – charge

• Ionic bonding usually takes place between

A – two metal elements

B – metal elements and non-metal elements

C – two non-metal elements

D – elements in the same group of the periodic table

• A sodium ion is stable because it has

A – full shells of electrons

B – a positive charge

C – the same number of protons as electrons

D – the same number of neutrons as protons

• Sodium chloride is not as dangerous as the elements sodium and chlorine from which it is made because

A – the charges on sodium ions and chloride ions are equal and opposite

B – there are the same number of sodium ions as chloride ions

C – sodium atoms and chlorine atoms have been converted into stable ions

D – sodium ions are bonded to chloride ions

Advanced

• Which of these statements is NOT true?

A – metal atoms lose electrons to form positive ions

B – non-metal atoms gain electrons to form negative ions

C – metal atoms usually have 1 or 2 outer electrons

D – non-metal atoms usually have 1, 4, or 7 outer electrons

• When a sodium atom reacts with a chlorine atom

A – an electron moves from a sodium atom to a chlorine atom

B – an electron moves from a chlorine atom to a sodium atom

C – the sodium atom shares an electron with the chlorine atom

D – the sodium atom shares a pair of electrons with the chlorine atom

• The electron configuration of a sodium ion is

A – $[2,8]^+$

B – $[2,8,1]^+$

C – $[2,8,8]^+$

D – $[2,8,8,1]^+$

• The chloride ion is negatively charged because it has

A – more protons than neutrons

B – more electrons than protons

C – more neutrons than protons

D – more electrons than neutrons

Metallic Bonding

Basic

• Which of these is NOT a property of metals?

A – good conductors of electricity

B – good conductors of heat

C – malleable

D – brittle

• Which of these elements is NOT a metal?

A – gold

B – carbon

C – copper

D – silver

• In the metal lattice structure there are

A – positive metal ions

B – metal molecules

C – positive metal ions and metal molecules

D – positive metal ions and a sea of electrons

• The metallic bond is the attraction between

A – positive metal ions

B – the electrons

C – the positive metal ions and the electrons

D – the metal molecules and the electrons

Advanced

• Which of these statements is NOT true?

A – positive metal ions are attracted to the sea of electrons

B – when metals conduct electricity, the positive metal ions move

C – the sea of electrons interacts with light

D – the metal ions can slide over one another

• In a metal, the outer electrons of the atoms are

A – delocalised across the whole lattice

B – shared with a neighbouring atom

C – given to a neighbouring atom

D – used to form covalent bonds

• Which of these statements is NOT true?

A – all metals are good conductors of electricity

B – metal atoms can lose their outer electrons fairly easily

C – metal atoms are held together by ionic bonds with light

D – metals have a giant lattice structure

• When a metal is conducting electricity

A – the sea of electrons flows mainly in one direction

B – the metal ions flow mainly in one direction

C – metal ions and the sea of electrons flow in opposite directions

D – metal ions and the sea of electrons flow in the same direction

Covalent Bonding

Basic

• Covalent bonding usually takes place between

A – a metal atom and a non-metal atom

B – two metal atoms

C – two non-metal atoms

D – two ions

• A single covalent bond involves

A – two atoms sharing one electron

B – two atoms sharing a pair of electrons

C – a metal atom losing an electron

D – a non-metal atom gaining an electron

• During covalent bonding, atoms share electrons in order to

A – achieve full shells of electrons

B – gain a negative charge

C – gain a positive charge

D – equalise the number of electrons and protons

• Groups of atoms which are covalently bonded together are called

A – ions

B – non-metals

C – metals

D – molecules

Advanced

• Which of these statements is NOT true?

A – in molecules, the atoms are covalently bonded together

B – carbon, hydrogen, oxygen and nitrogen are all non-metal elements

C – oxygen gas is made of O_2 molecules

D – compounds are always made of ions, not molecules

• During the formation of a chlorine molecule Cl_2, both chlorine atoms

A – share one of their outer electrons

B – share seven of their outer electrons

C – become negatively charged

D – form an ionic bond

• Which of these statements is NOT true?

A – molecules of elements may contain two atoms of the same element bonded together

B – molecules can contain thousands of atoms

C – hydrogen molecules contain two hydrogen atoms

D – sodium chloride (NaCl) is made of molecules

• The two atoms in a covalent bond are held together because

A – they have opposite charges

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• Answers

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