Senior secondary

Physical Science: Revision units

Scholar study workbook

Keeping Girls in School scholarship programme
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‘Keeping Girls in School’ Scholarship Programme

MSCE Resources: 2014–15

Contents

MSCE S1:
Elements and chemical bonding

What you are studying and why

Subject: Physical Science Unit S1

At the end of this unit you should be able to:

1. explain what an element is and give examples of elements and their compounds
2. describe how elements form different sorts of chemical bonds
3. predict the properties of compounds from the type of bonds in them.

Introduction

Welcome to the first Science unit. You have probably been asking questions and observing our world for a long time. You may have wondered why stars shine brightly or why bread changes shape. As you study science you may be surprised by the interesting answers.

In this unit you will find out about what the substances in the world around us are made of. There are lots of ideas in this unit and we suggest you work through it slowly.

Elements

What is an element?

Everything around us is made up of matter. The air, our clothes, our food, the ground we walk on and our bodies. We can divide up all the different sorts of matter into two groups:

- pure substances
- mixtures.

Sugar and salt are two pure substances. Mixtures around us include air, oil and soil.

Pure substances can be divided into two groups:

- elements
- compounds.

In an element, all the atoms in the substance are of just one particular sort. The atoms in any element are different to the atoms of any other element. So iron is made from a different sort of atom to chlorine and carbon atoms are different to oxygen atoms.

There are over 100 different elements on earth. Can you name some?

You might have thought of oxygen (needed for breathing), calcium (needed to make our bones strong) and iron (to make steel for cars and bridges).

All the elements are listed in the chart called the periodic table. A periodic table is printed at the end of this unit. Find this now.

This is a chart showing all the elements arranged in a particular way. The vertical columns in the periodic table are called groups. Look at this now and try to read the names of some of the elements. Don't worry – you don't need to know them all! There are about 20 elements that are very common and these are the ones we will be looking at in this unit.

In the periodic table each element has a symbol. Some common symbols are O (oxygen), Mg (magnesium) and H (hydrogen). The first letter in a chemical symbol is always an upper case letter, and the other letters are always lower case. Sometimes the symbol is very different to the name, for example the symbol for iron is Fe. This is because the symbol comes from the Latin name for iron – ferrum. Can you find two more elements that have a symbol that is very different to the name?

Activity 1

Find your periodic table. On the periodic table find the first 20 elements.

Make a card game to help you learn these symbols. Cut out 40 cards – perhaps from packaging or from newsprint. On 20 cards write the names of the first 20 elements. On the other 20 cards write the symbols for the first 20 elements, Now mix up all the cards and then try to match up the symbols and the names of the elements.

Looking at elements: metals and non-metals

We can divide up all the elements into two groups: metals and non-metals. In the periodic table the metals are on the left-hand side. Non-metals are on the right-hand side. Look at your periodic table. Can you find the zig-zag line? This shows the division between metals and non-metals. Write metals and non-metals on your periodic table to show the two groups.

All metals share the same useful properties:

- shiny
- good conductors of electricity
- good conductors of heat
- malleable (can be bent into shape without breaking)
- ductile (can be stretched into thin wires)
- have a high melting point (they can be used to make cooking pots and other equipment that needs to become hot; metals don't get damaged at high temperatures).

Non-metals are not good conductors of heat or electricity. They are insulators. Non-metals are not ductile or malleable.

Activity 2

Part a

Look around you and list six objects made from metal.

Part b

Now try to give a reason why metal was used to make each object. Use the properties of metals. For example a bracelet is made from metal because metal is ductile and shiny. An electrical wire is made from copper because it is a good conductor of electricity.

Part c

Draw circles around the metals in this list:

calcium chlorine hydrogen sodium magnesium

copper silver sulphur silicon helium neon

(Use your periodic table to help you.)

Looking at compounds

Compounds are made when elements join together chemically. The name of the compound sometimes tells us which elements are in the compound. So calcium chloride is made up of calcium and chlorine joined together. When iron and sulphur join together they form a compound called iron sulphide.

Sometimes we have everyday names for compounds which don't tell us the elements in the compound. For example water is made up of hydrogen and oxygen. The scientific name is hydrogen oxide. But we don't use this in everyday talking! Similarly sugar is a compound of oxygen, carbon and hydrogen.

A compound of sodium and bromine is called sodium brom**ide (-ide at the end tells us that the two elements are joined together).**

A compound of sulphur and oxygen is called sulphur dioxide (the 'di' tells us there are two oxygen atoms in the compound).

A compound of copper and iodine is called copper iodide.

A compound of copper, oxygen and carbon is called copper carbonate (-ate tells us that there is oxygen as well as the copper and carbon).

What do you think are the three elements in copper sulphate? (Clue: remember, -ate shows that there is oxygen in the compound).

When we are naming a compound the element on the left hand side of the periodic table comes first, so a compound of sodium and chlorine will be called 'sodium chloride'.

Activity 3

Part a

Draw a table and write down the names of the elements in each of these compounds:

iron chloride

carbon dioxide

potassium bromide

hydrogen chloride

calcium sulphate

sodium iodide

lithium nitrate

nitrogen dioxide

There are many thousands of different compounds around us; some examples are salt, sugar, water, alcohol, glass, plastics and nylon. They all have different properties. Some will dissolve in water, some melt very easily when we heat them and some will conduct electricity when they are molten or dissolved in water. The properties of a compound are usually different to the properties of the elements they contain. For example, water is made up of hydrogen and oxygen. Hydrogen and oxygen are both gases at room temperature but water is a liquid.

Compounds can be organised into two groups:

In group one compounds have these properties:

- dissolve in water
- high melting point
- conduct electricity when molten or dissolved in water.

Compounds in this group are called **ionic**. They are made up of ions (charged particles). These charged particles can carry the electric current. An example is salt – sodium chloride. Another example is calcium carbonate.

Ionic compounds are made when metals join with non-metals.

In group two compounds have these properties:

- do not easily dissolve in water
- melt easily
- do not conduct electricity even when molten.

Compounds in this group are **covalent**. They are made when non-metals join together. An example is natural gas – methane. This is carbon joined with hydrogen. Another example is carbon dioxide.

Activity 4

Using your periodic table to help you, circle the ionic compounds in this list:

silver chloride   sulphur dioxide
hydrogen chloride   calcium carbonate
magnesium bromide   carbon monoxide

How did you identify the ionic compounds? What do they all contain?

Looking at atoms

All elements are different – but why? What makes elements different from each other? We can understand why oxygen is different to copper by looking at the building blocks of elements – atoms.

Scientists now know that atoms have two main parts:

- a very small nucleus at the centre with a positive charge (made up of two sorts of particles: neutrons and protons – see MSCE Unit S6)
- even smaller electrons, with a negative charge, which orbit the nucleus.

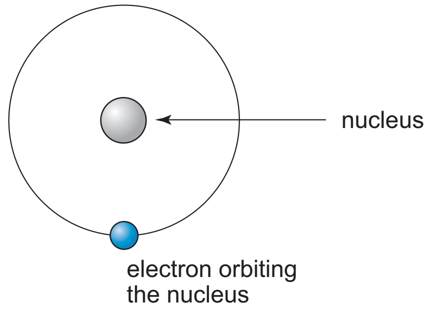

Figure 1: Structure of an atom

An atom of each element has a specific number of electrons and a specific number of protons and neutrons in its nucleus. Electrons are very important. The number and arrangement of the electrons gives the element its chemical properties – this is what determines how the element will react with other elements. In the atom the number of negative charges (electrons) is the same as the number of positive charges (in the nucleus) – the atom is electrically neutral (has no overall charge).

Scientists have worked out the number of electrons in each element in the periodic table. The number of electrons in an atom is the same as its 'atomic number' in the periodic table. This is often given the symbol Z. For example the atomic number of iron is 26. This tells us that iron has 26 electrons.

You can find out how many electrons are in each element by looking at the periodic table. The atomic number for each element is written above the element.

Activity 5

Find your periodic table. Find the number of electrons in

- magnesium
- oxygen
- carbon
- sodium
- calcium.

1. Which element has seven electrons?
2. Which element has 20 electrons?
3. Which element has only one electron?

In an atom the electrons are organised in energy levels around the nucleus. We can imagine these as shells of electrons. Each shell can only take a fixed number of electrons. In the first shell, nearest to the nucleus we can put two electrons. In the second shell we can put eight electrons and in the third shell we can put eight electrons. We always fill up the shells from the lowest to the highest levels.

So if helium has two electrons, these are both in the first shell (as shown in Figure 2) and we write the electron configuration as 2.

But carbon has four electrons. We can only put two electrons in the first shell so the other two electrons have to go in the second shell (as shown in Figure 3). We write the electron configuration as 2.2.

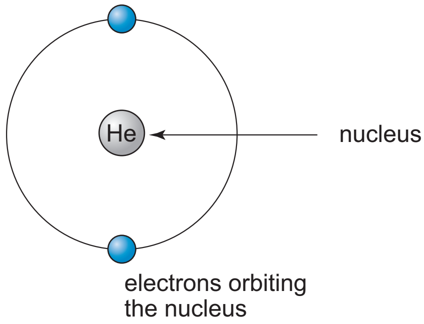

Figure 2: Helium atom

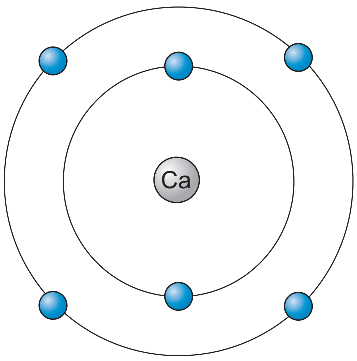

Figure 3: Carbon atom

Activity 6

Write a list of the first 20 elements in the periodic table. Then write the atomic number next to each element. Now write down the electron configuration for each element. (Remember when one shell is full you have to go to the next shell).

....
....
....
....
....
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....
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....

Now look again at the periodic table. You will notice that the first column of elements (lithium, sodium, potassium) has the number 1. These are known as the group I elements.

Find and list the group II elements:

....
....
....

Find and list the group VII elements:

....

....

....

Now look back at your electron configurations. What do you notice?

You should see that elements in group I of the periodic table have one electron in their outer shell. (All the electron configurations end in 1.)

Elements in group VII of the periodic table have seven electrons in their outer shell.

How many electrons are in the outer shell of group II elements?

....

How many electrons are in the outer shell of group VI elements?

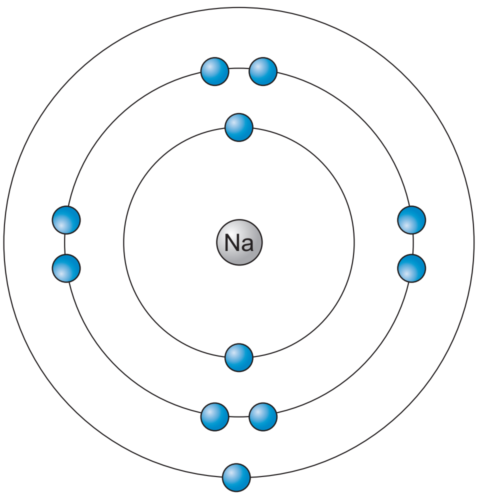
....

Forming ions

Look at your periodic table. Elements with a full outer shell are in group 0 (or group VIII – it depends on the periodic table). These elements include neon, helium and argon. These are all gases which do not react. These elements are very stable. When other elements react they are trying to achieve a more stable electronic configuration, a full outer shell. They are trying to be stable like the group 0 gases.

Elements can achieve a full outer shell of electrons by losing electrons, gaining electrons or sharing electrons – this is called bonding. Bonding holds atoms together.

Let's look at sodium. Sodium has 11 electrons. They are organised 2.8.1.



From the second shell upwards, electrons are usually shown as pairs.

Figure 4: Sodium atom

So to achieve a full outer shell of electrons sodium can either lose one electron (to give 2.8) or gain seven electrons (to give 2.8.8). Which do you think will be easier?

That's correct – losing one electron is much easier than trying to find another seven electrons. So when sodium joins with other elements it loses one electron. Sodium now has one less electron, one less negative charge. But it still has the same number of positive charges so overall it now has a positive charge. We call it the sodium ion and write it Na^+.

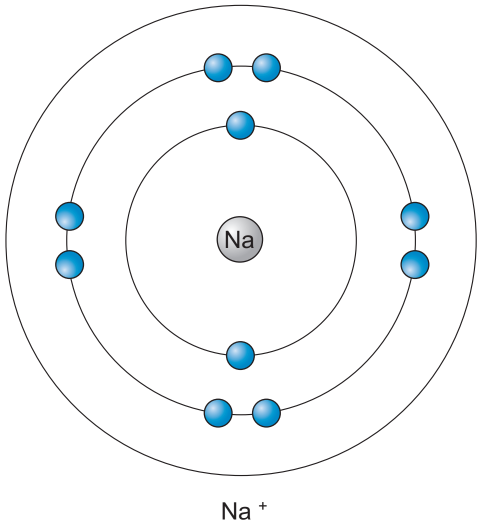


Figure 5: Sodium ion (Na^+)

Similarly, magnesium, in group II, has the electron configuration, 2.8.2. It can lose two electrons to gain a full outer shell – 2.8. It too will then have the same electron configuration of its next nearest noble gas neighbour, neon, of 2.8. Again this can be illustrated diagrammatically. Since the magnesium has lost two negative charges there will be only 10 electrons remaining and it will have a double-positive charge, $Mg2^+$.

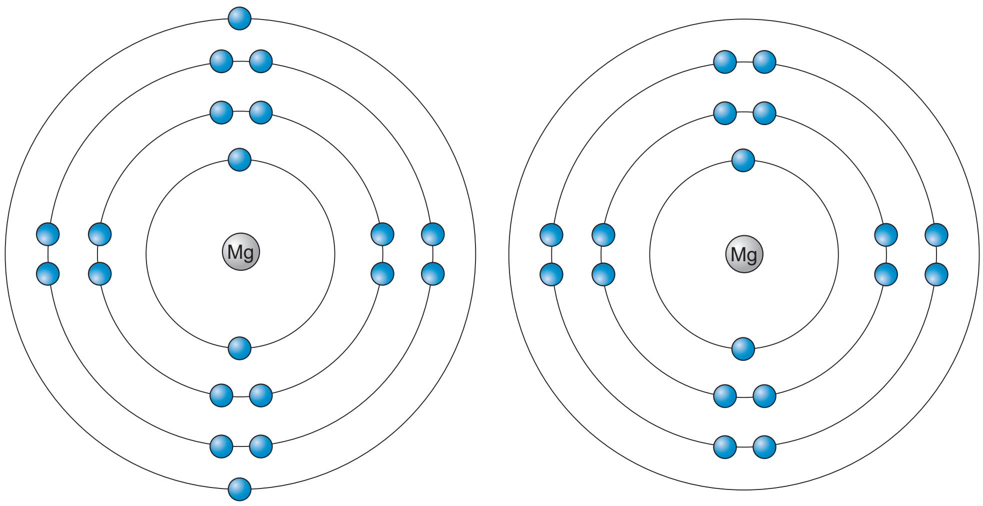


Figure 6: Magnesium atom and magnesium ion ($Mg2^+$)

Usually all the metals form positive ions in compounds. They lose electrons to achieve full outer shells.

At the other end of the periodic table, in group VII, elements gain electrons to achieve a full outer shell.

Let's now look at chlorine. Chlorine has 17 electrons. They are organised 2.8.7.

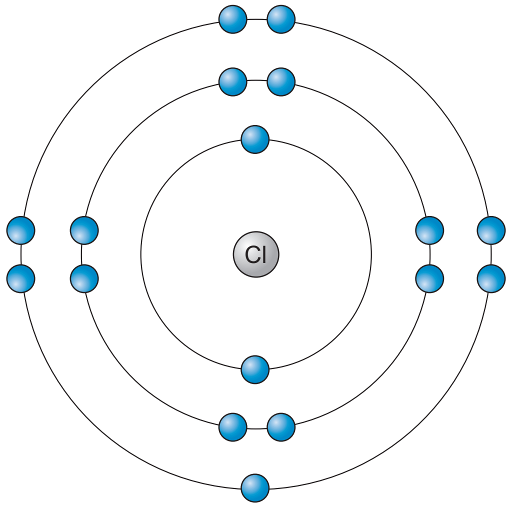


Figure 7: Chlorine atom

When chlorine bonds it needs to either gain 1 electron (to give 2.8.8) or lose seven electrons (to give 2.8). Which do you think is easier for chlorine?

Yes, chlorine reacts by finding an extra electron to give it an electronic configuration of 2.8.8. Since chlorine has now gained an electron it now has a negative charge. It has one more electron than it did when it was an electrically neutral atom. It is called a chloride ion, Cl^-.

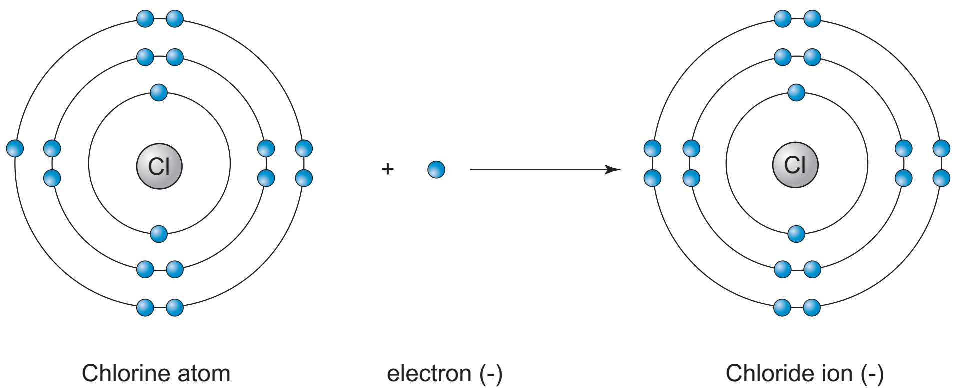


Figure 8: Chloride ion

So when sodium and chlorine react together they form the compound sodium chloride. In this compound sodium gives one electron to chlorine (see Figure 9).

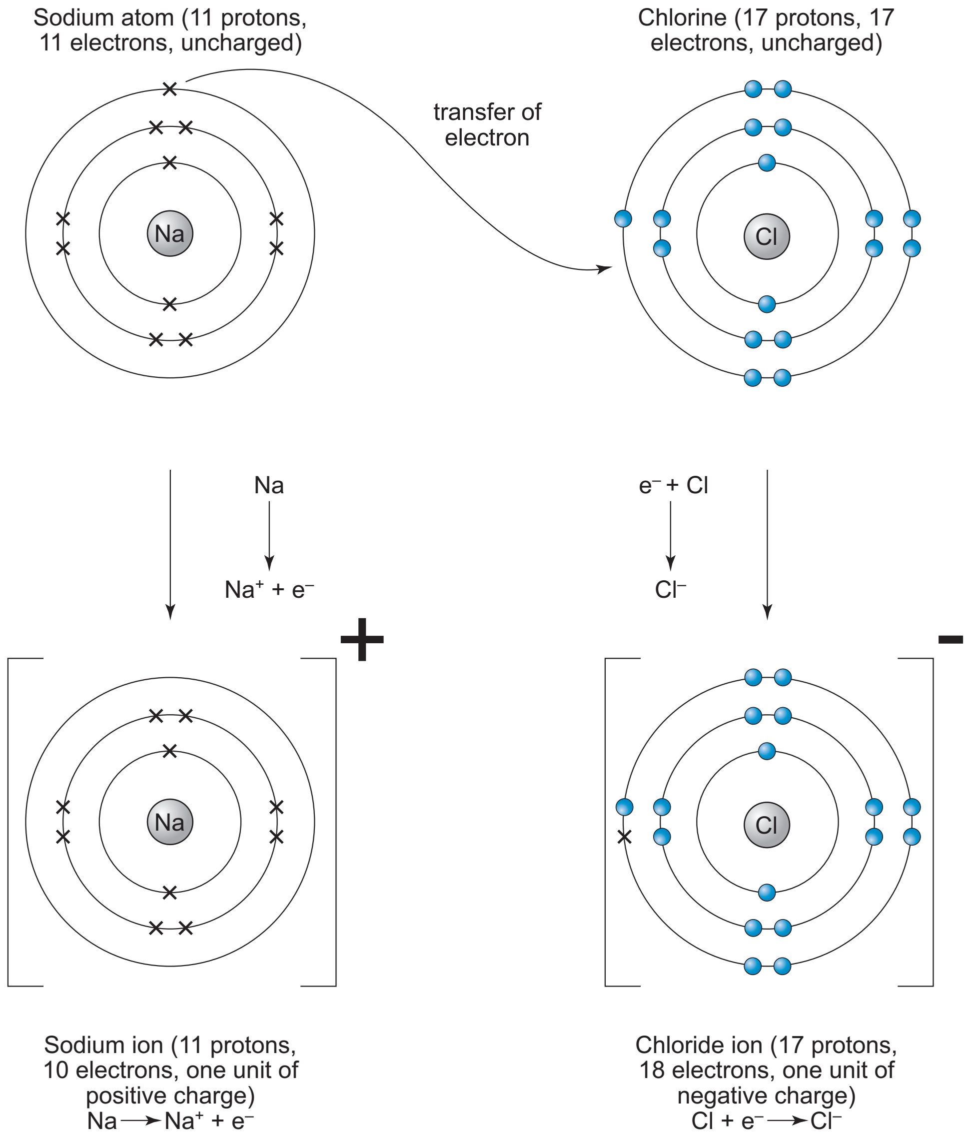


Figure 9: Sodium chloride

Compounds which have ions in them are called ionic compounds. You have met these earlier. Ionic compounds are formed when metals react with non-metals. (Remember that metals are on the left hand side of the periodic table.)

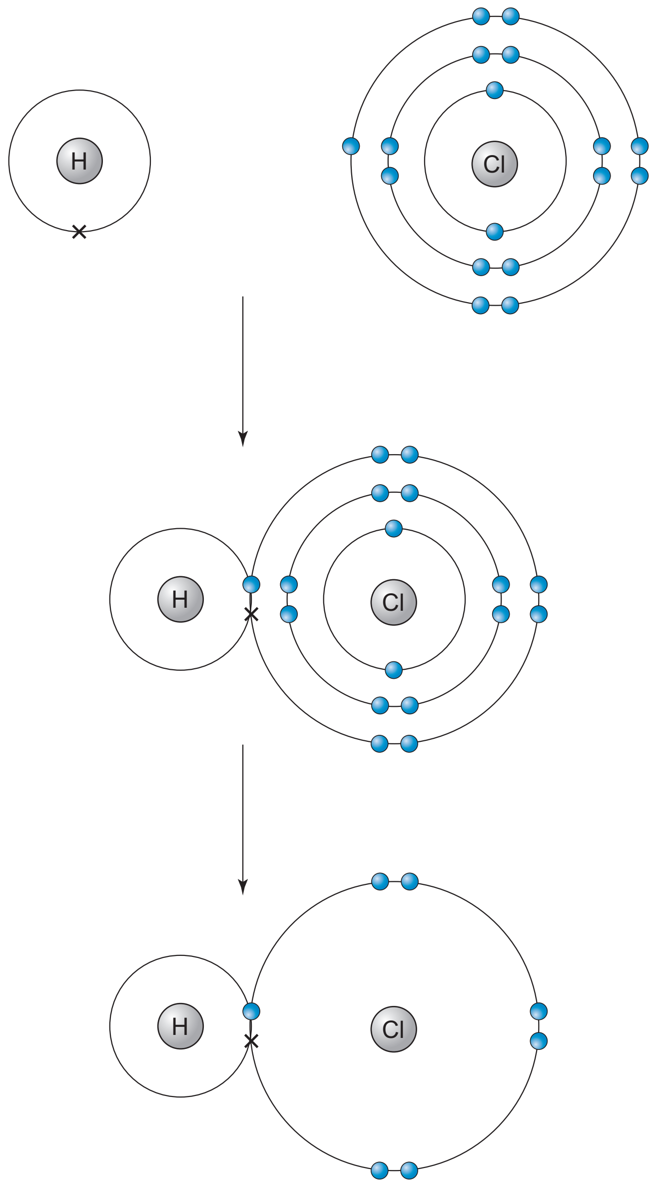
Oppositely charged ions are strongly attracted to one another. So, very strong forces hold ionic compounds together, which explains why, for example, they have high melting temperatures. When they are solids the ions are organised into a regular arrangement and the ions can't move. This also explains why ionic compounds can conduct electricity when in the liquid state or when dissolved in water but not in their solid state: in the liquid state or when in water ions are not 'locked into' their normal fixed positions but are free to 'wander' round the liquid, they can carry the electric charge.

Sharing electrons

Not all atoms find it easy to lose or gain electrons. Atoms in the middle of the periodic table find it easier to achieve a full outer shell of electrons by sharing electrons. They do this by overlapping the outer shells of their atoms with one another.

We can use diagrams to show how the atoms share electrons. We show the electrons of one atom as 'dots', the electrons from the other atom are shown as 'crosses'.

In Figure 10 we see one hydrogen and one chlorine atom overlapping their outer shells to share atoms so that they can each achieve full outer shells of electrons.



When drawing dot and cross diagrams for covalent bonds you only need to show the electrons in the highest occupied shell, as only these are involved.

Figure 10: Covalent bond

A single covalent bond is formed between the two atoms. Bonds formed by sharing of electrons are called **covalent bonds**. Covalent bonds are formed between non-metals such as carbon, oxygen and hydrogen.

Figure 11 shows how hydrogen and carbon atoms share electrons in the compound, methane, CH_4, so that all of the atoms achieve a full outer shell of electrons

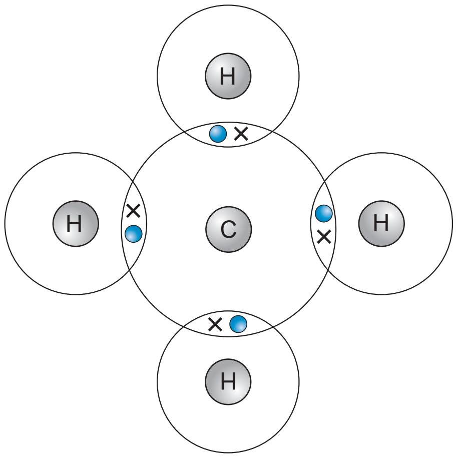


Figure 11: Methane

In summary there are two ways in which elements can bond together in compounds.

- Ionic bonding where electrons are transferred from one atom to another so that one gives electrons and the other takes electrons.
- Covalent bonding where electrons are shared between two atoms.

Practice questions

1. Use your periodic table to say which elements are in the following compounds: (a) potassium iodide; (b) lithium chloride; (c) magnesium oxide; (d) aluminium oxide; (e) iron (II) oxide; (f) boron sulphide.
2. What are the names of the compounds formed between (a) magnesium and chlorine, and (b) lithium and oxygen?
3. Use your periodic table to write out the electron configurations of the following elements: boron, sulphur, chlorine and calcium.
4. Look at the example of bonds in sodium chloride given in the revision notes. Now try to show what happens to the electrons when (a) calcium reacts with fluorine to form calcium fluoride and (b) when magnesium reacts with oxygen to form magnesium oxide.

How am I doing?

This section is a study tool.

Now look back over this unit and be honest about what was difficult.

Later use it to discuss with your tutor any extra help you need.

Before the exam use this tool to revise.

	☺ **Easy** (Tick this box if you feel confident that you **understand this section well**)	**Fine** (Tick this box if you still **need a little work** on this section)	☹ **Difficult** (Tick this box if you **still need a lot** of work on this section)
Elements			
Compounds			
The Periodic Table			
Atoms *Ions*			
Ionic bonding			
Covalent bonding *Nitrogen* *Sulphur*			

Notes on what to do next:

Signed (by Scholar): .... Date: ....

Signed (by Tutor): .... Date: ....

The Periodic Table

key

atomic number	17
symbol	Cl
name	chlorine
relative atomic mass	35.5

- metals
- semi-metals
- non-metals

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen 1.01																	2 He helium 4.00
3 Li lithium 6.94	4 Be beryllium 9.01											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium 98.9	44 Ru ruthenium 101	45 Rh rhodium 103	46 Pd palladium 106	47 Ag silver 108	48 Cd cadmium 112	49 In indium 115	50 Sn tin 119	51 Sb antimony 122	52 Te tellurium 128	53 I iodine 127	54 Xe xenon 131
55 Cs caesium 133	56 Ba barium 137	71 Lu lutetium 175	72 Hf hafnium 178	73 Ta tantalum 181	74 W tungsten 184	75 Re rhenium 186	76 Os osmium 190	77 Ir iridium 192	78 Pt platinum 195	79 Au gold 197	80 Hg mercury 201	81 Tl thallium 204	82 Pb lead 207	83 Bi bismuth 209	84 Po polonium 209	85 At astatine 210	86 Rn radon 222
87 Fr francium 223	88 Ra radium 226	103 Lr lawrencium 262	104	105	106	107	108	109									

57 La lanthanum 139	58 Ce cerium 140	59 Pr praseodymium 141	60 Nd neodymium 144	61 Pm promethium 145	62 Sm samarium 150	63 Eu europium 152	64 Gd gadolinium 157	65 Tb terbium 159	66 Dy dysprosium 163	67 Ho holmium 165	68 Er erbium 167	69 Tm thulium 169	70 Yb ytterbium 173
89 Ac actinium 227	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	93 Np neptunium 237	94 Pu plutonium 244	95 Am americium 243	96 Cm curium 247	97 Bk berkelium 247	98 Cf californium 251	99 Es einsteinium 254	100 Fm fermium 257	101 Md mendelevium 258	102 No nobelium 259

Glossary

Atom	An atom is the smallest unit of a substance that still has all the properties of that substance. In most cases, an atom consists of protons, neutrons, and electrons.
Atomic number	The atomic number of an atom is equal to the number of protons contained within the atom.
Atomic weight	The atomic weight of an atom is a measure of how much mass an atom has. The atomic weight is calculated by adding the number of protons and neutrons together.
Compound	A substance made up of two or more elements that are combined chemically.
Covalent bond	The type of bond formed between non-metal atoms, where electrons are shared in order to complete the outer shell of each atom. Covalent bonds are strong.
Electron	An electron is a negatively charged particle found circling or orbiting an atomic nucleus. An electron has negligible atomic mass.
Electron configuration	The electron configuration is the arrangement of electrons of an atom or a molecule.
Electron shells	A series of hierarchical energy levels for electrons orbiting the nucleus in an atom. Each energy level or shell has a maximum energy limiting how many electrons it can take. On a diagram, shells are shown as concentric circles.
Ion	An ion is an atom that has been charged either by the addition of electrons or by the removal of electrons.
Ionic bond	The type of bond formed between atoms of metals and non-metals, where electrons are gained by the non-metal atom and lost by the metal atom. The ionic bond is very strong because of the electrostatic force of attraction between the resulting ions.
Metal	Metals are sometimes described as an arrangement of positive ions surrounded by a sea of delocalised electrons. Metals occupy the bulk of the periodic table, while non-metallic elements can only be found on its right-hand side. A diagonal line, drawn from boron (B) to polonium (Po), separates the metals from the non-metals. All metals display a particular range of characteristics, which include being good conductors of both electricity and heat, and usually being malleable and shiny.
Mixture	A combination of substances that can be separated by physical means.
Neutron	A neutron is an uncharged particle found in the nucleus of an atom. A neutron, like a proton, contributes one atomic mass unit to the total atomic weight of an atom.
Non-metal	A non-metal is an element on the periodic table that does not have the properties of a metallic element, such as malleability. Non-metals are usually found in nature as gases or weak, brittle solids.
Nucleus	The central part of an atom containing neutrons and protons. Most of the mass of an atom is contained within the nucleus.
Orbit	An orbit is the curved path of an object around a point in space, for example, the orbit of a planet around the centre of a star system, such as the Solar System.
Periodic table	The periodic table is a chart of all the known elements in order of increasing atomic number. The table puts elements into groups with similar characteristics, allowing us to recognise trends over the whole array of elements.
Proton	A proton is a positively charged particle found in the nucleus of an atom. A proton contributes one atomic mass unit to the total atomic weight of an atom.

MSCE S2: Forces and motion

What you are studying and why

Subject: Physical Science Unit S2

This is the second Physical Science unit for your MSCE Revision. It looks at motion – how fast things move and how we can show this movement on different graphs.

At the end of this unit you should be able to:

1. explain the difference between speed, velocity and acceleration
2. explain what happens in various situations with moving and stationary objects
3. interpret velocity–time graphs to determine the total distance travelled and the acceleration.

Basic motion

Forces cause objects to move. When objects move we are often interested in how far the object has moved and how fast it has moved. How far you travel along a particular path is called the **distance**.

Displacement is the change in position of an object. This is the most direct, shortest straight line route between one point and another; it doesn't matter which path the object took to move from one position to the next. Displacement has a specific direction.

For example, Joan is walking to school. Her school is 500 m from her house. But instead of going straight to school she walks first to her friend's house. It is 300 m to her friend's house. They then walk together to school. It is another 400 m from her friend's house to school. All together she has walked

300 + 400 = 700 m

but her displacement is only 500 m towards the school. (This is because displacement only looks at the starting position and the end position.)

The measure of how fast or slow an object moves is called its **speed**.

When we know the direction in which the object is moving as well as its speed we know its **velocity**.

If the bus travels down a straight road at a constant velocity of 15 m s^{-1}, it means that it travels a distance of 15 metres every second in the same direction. If the driver presses harder on the accelerator pedal, the bus will increase its velocity – it goes faster or accelerates.

Velocity = distance travelled in a certain direction divided by the time taken to travel the distance;

velocity = displacement/time

As distance is measured in m and time in s then the units of velocity are **m s^{-1}**.

Read this example carefully: Average speed and average velocity

Question: Joyce walks 2 km away from home in 30 minutes. She then turns around and walks back home along the same path, also in 30 minutes. Calculate Joyce's average speed and average velocity.

Answer:

Step 1: Identify what information is given and what is asked for

The question explicitly gives:

- the distance and time out (2 km in 30 minutes)
- the distance and time back (2 km in 30 minutes).

Step 2: Check that all units are standard SI units

The information is not in standard SI units and must therefore be converted. We measure speed in m/s. To convert km into m, we know that:

1 km = 1000 m

So 2 km = 2000 m (multiply both sides by 2 as we want to convert 2 km into m)

Similarly, to convert 30 minutes into seconds,

1 min = 60 s

So 30 min = 1800 s (multiply both sides by 30).

Step 3: Determine Joyce's displacement and distance

Joyce started at home and returned home, so her displacement is 0 m.

Joyce walked a total distance of 4000 m (2000 m out and 2000 m back).

Step 4: Determine her total time

Joyce took 1800 s to walk out and 1800 s to walk back.

Her total time is 3600 s.

Step 5: Determine her average speed

Speed = distance/time

Speed = 4000 m/3600 s

Speed = 1.11 $m\ s^{-1}$

Step 6: Determine her average velocity

This is a bit tricky... Joyce's total displacement is 0 so her average velocity is 0 (velocity = displacement/time).

Activity 1

Now try this example:

Theresa has to walk to the shop to buy some milk. After walking 100 m, she realises that she does not have enough money and goes back home. If it took her two minutes to leave and come back, calculate the following:

a) How long was she out of the house?

b) How far did she walk in total?

c) What was her displacement?

d) What was her average velocity (in $m\ s^{-1}$)?

e) What was her average speed (in $m\ s^{-1}$)?

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Using simple motion graphs

Using graphs: We can show the movement of an object on a distance–time graph.

Background information – the vertical axis of a distance–time graph is the distance travelled from the start, and the horizontal axis is the time taken from the start.

Features of the graphs – when an object is stationary, the line on the graph is horizontal. When an object is moving at a steady speed, the line on the graph is straight, but sloped.

Figure 1 shows some typical lines on a distance–time graph.

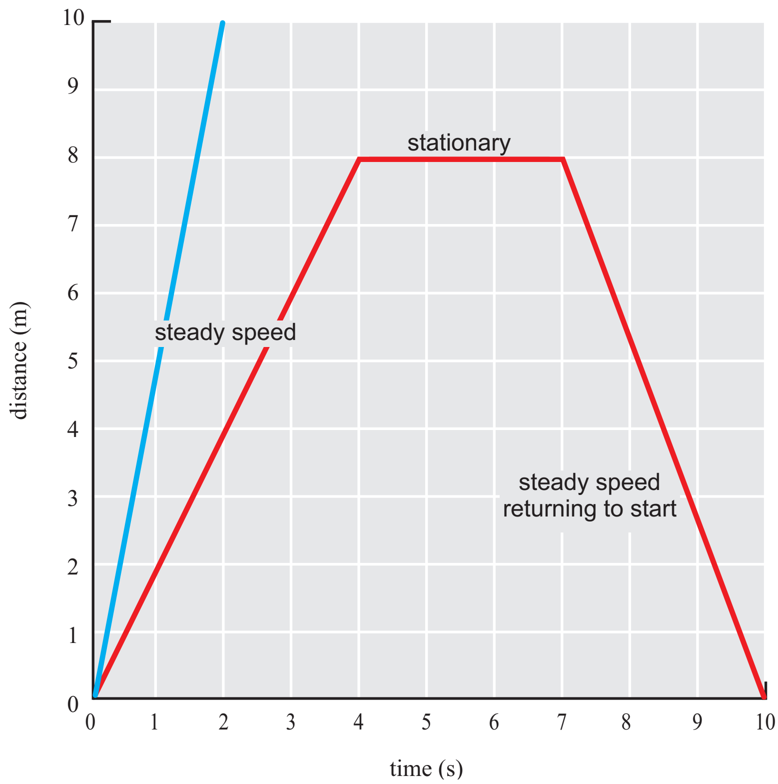

Figure 1: Distance–time graph

Note that the **steeper** the line, the greater the **speed** of the object. The blue line is steeper than the red line because it represents an object moving faster than the object represented by the red line.

The line slopes upwards or downwards depending on the direction of travel. Changes in distances in one direction are positive, and negative in the other direction. If you walk 10 m away from me, that can be written as +10 m; if you walk 3 m towards me, that can be written as –3 m.

The red lines on the graph represent a typical journey where an object returns to the start again. Notice that the line representing the return journey slopes downwards – this is because the direction of travel has changed.

Changing speed

When we are travelling our speed often changes. A change in speed is called **acceleration**.

When an object speeds up the acceleration is positive, when the object slows down the acceleration is negative.

Acceleration = change in velocity/time over which change occurs

As velocity is measured in m s^{-1} and time in s, then the units of acceleration are m s^{-2}. As velocity is a vector, acceleration is also a vector.

Look carefully at this example:

A car starts from a state of rest and accelerates for 10 seconds at a rate of 2 m s^{-2}. Calculate its final velocity.

We can use the equation for acceleration to find the final velocity.

Acceleration = change in velocity/time

but the car starts from rest so the final velocity is the same as the change in velocity.

$2 = v/10$ so $v = 2 \times 10$

Final velocity is 20 m s^{-1}

Activity 2

Now try these examples:

1. An athlete is accelerating uniformly from an initial velocity of 0 m s^{-1} to a final velocity of 4 m s^{-1} in 2 seconds. Calculate his acceleration. Let the direction that the athlete is running in be the positive direction.
2. A bus accelerates uniformly from an initial velocity of 15 m s^{-1} to a final velocity of 7 m s^{-1} in 4 seconds. Calculate the acceleration of the bus. Let the direction of motion of the bus be the positive direction.

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Using advanced motion graphs

Constant velocity

Assume that Mary takes 100 s to walk 100 m to the taxi stop every morning. We can calculate Mary's velocity:

Velocity = displacement/time

Velocity = 100/100

Velocity = 1 m s^{-1}

Mary's velocity is 1 m s^{-1}. This means that she walks 1 m in the first second, another metre in the second second, and another metre in the third second, and so on. For example, after 50 s she will be 50 m from home. Her displacement increases by 1 m every 1 s. Figure 2 shows Mary's displacement.

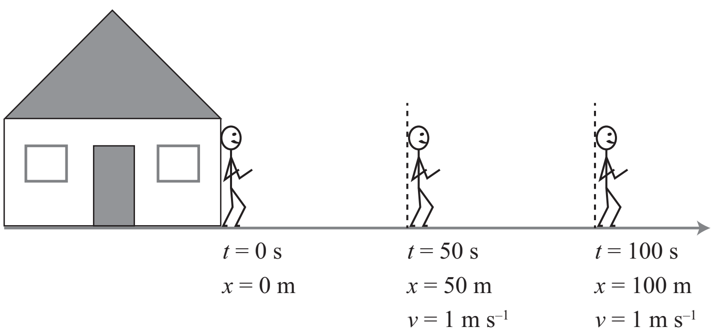


Figure 2: Mary's motion at a constant velocity of 1 m s^{-1}

We can now draw displacement–time, velocity–time and acceleration–time graphs for Mary moving at a constant velocity (Figure 3).

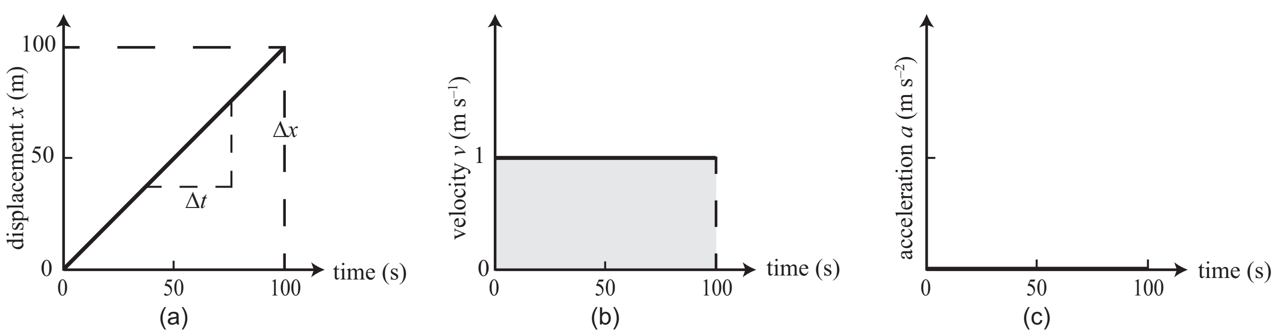


Figure 3: Graphs for motion at constant velocity: (a) displacement–time, (b) velocity–time and (c) acceleration–time

Look at the shape of the graphs. When you are travelling at a constant speed, the displacement–time graph (a) will be a straight line. The velocity–time line (b) will be horizontal – the velocity does not change. And the acceleration–time graph (c) will be 0 – there is no acceleration.

The area of the shaded portion in the velocity–time graph (b) corresponds to the object's displacement. This is the distance Mary walked 100 × 1 = 100 m.

This is important to learn. **In a velocity–time graph, the area under the line or curve gives you the total distance travelled**.

Constant acceleration

Now we will look at motion at constant acceleration. We know that acceleration is the change of velocity. So, if we have a constant acceleration, this means that the velocity changes at a constant rate.

Let's now imagine Mary waiting at the taxi stop. A taxi arrives and Mary gets in. The taxi stopped at the stop street and then accelerated as follows: After 1 s the taxi covered a distance of 2.5 m, after 2 s it covered 10 m, after 3 seconds it covered 22.5 m and after 4 s it covered 40 m (Figure 4). The taxi is covering a larger distance every second. This means that the taxi is accelerating.

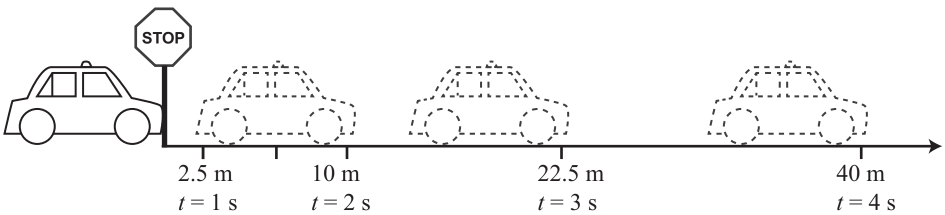


Figure 4: The moving taxi

We can calculate the velocity of the taxi in each second:

Between 1 s and 2 s the change in distance is (10 – 2.5 = 7.5 m) so the average velocity is displacement/time = 7.5 m s^{-1}

Between 2 s and 3 s the change in distance is (22.5 – 10 = 12.5 m) so the average velocity is 12.5 m s^{-1}

Between 3 s and 4 s the change in distance is (40 – 22.5 = 17.5 m) so the velocity is 17.5 m s^{-1}

We can see that every second the velocity increases by 5 m s^{-1}. The acceleration is 5 m s^{-2}.

So we can now use these calculated figures to draw the same graphs as before (Figure 5). At 1 second the velocity will be 5 m s^{-1}; at 2 seconds it will be 10 m s^{-1} and so on.

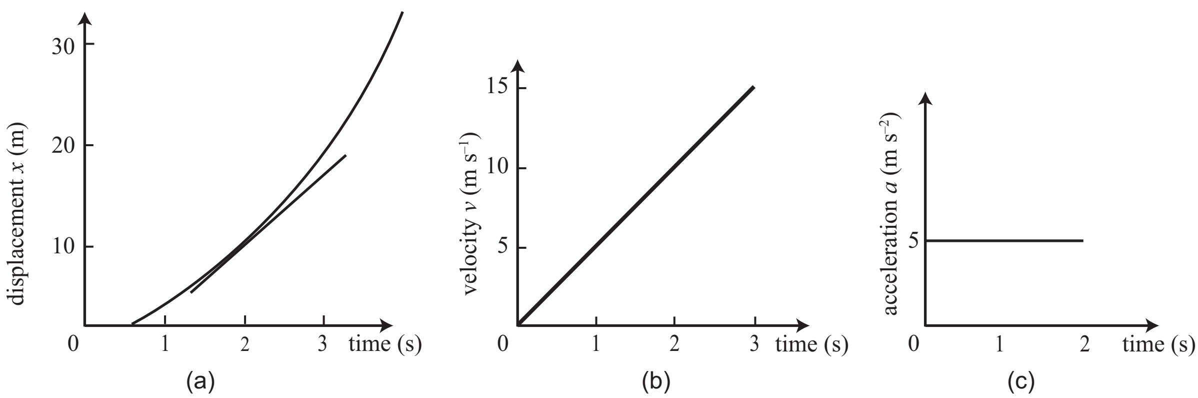


Figure 5: Graphs for motion at constant acceleration: (a) displacement–time, (b) velocity–time and (c) acceleration–time

Calculations from a velocity–time graph

Question: The velocity–time graph of a truck is plotted in Figure 6. Calculate the distance and displacement of the truck after 15 seconds.

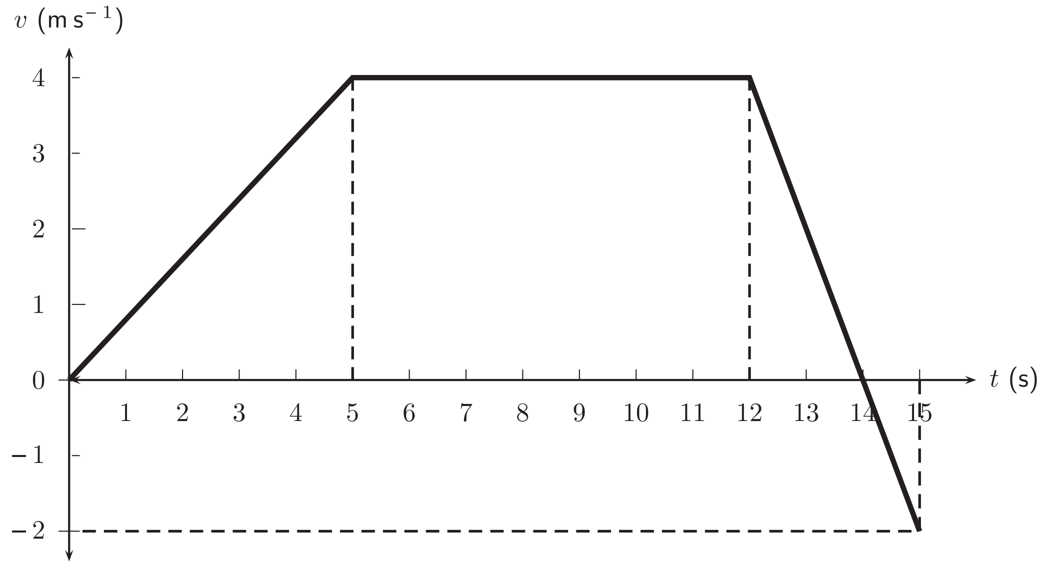


Figure 6: Velocity–time graph of a truck

Answer:

Step 1: Decide how to tackle the problem

We are asked to calculate the distance and displacement of the truck. All we need to remember here is that we can use the area between the velocity–time graph and the time axis to determine the distance and displacement.

Step 2: Determine the area under the velocity–time graph

Break the motion up: 0–5 seconds, 5–12 seconds, 12–14 seconds and 14–15 seconds.

For 0–5 seconds, the displacement is equal to the area of the triangle on the left:

Area = ½ × base × height

= ½ × 5 m × 4 m

= 10 m^2

For 5–12 seconds, the displacement is equal to the area of the rectangle:

Area = length × width

= 7 m × 4 m

= 28 m^2

For 12–14 seconds, the displacement is equal to the area of the triangle above the time axis on the right:

Area = ½ × base × height

= ½ × 2 m × 4 m

= 4 m^2

For 14–15 seconds, the displacement is equal to the area of the triangle below the time axis:

Area = ½ × base × height

= ½ × 1 m × 2 m

= 1 m^2

Step 3: Determine the total distance of the truck

Now the total distance of the truck is the sum of all of these areas:

Distance = 10 + 28 + 4 + 1

= 43 m

Step 4: Determine the total displacement of the truck

Now the total displacement of the truck is just the sum of all of these areas. However, because in the last second (from $t = 14$ s to $t = 15$ s) the velocity of the truck is negative, it means that the truck was going in the opposite direction, i.e. back where it came from. So, to find the total displacement, we have to add the first three areas (those with positive displacements) and subtract the last one (because it is a displacement in the opposite direction).

Displacement = 10 + 28 + 4 – 1

= 41 m in the positive direction.

Practice questions

1. A bus travels at a constant velocity of 12 m s^{-1} for 6 seconds. Draw the displacement–time, velocity–time and acceleration–time graph for the motion. Label all the axes.

2. The velocity–time graph in Figure 7 describes the motion of a car. Draw the displacement–time and acceleration–time graphs and explain the motion of the car according to the three graphs.

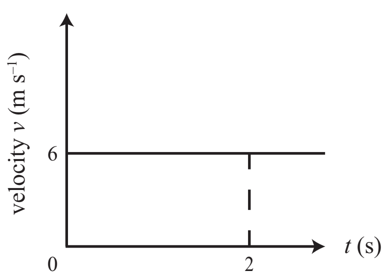


Figure 7: Velocity–time graph of a car

3. A car travels 100 m in 5 s. What is its average speed?

   - ☐ 500 m s^{-1}
   - ☐ 20 m s^{-1}
   - ☐ 0.05 m s^{-1}

4. What does a horizontal line on a distance–time graph represent?

   - ☐ Constant speed
   - ☐ Steady increase in speed
   - ☐ Stationary object

5. Which line on the graph in Figure 8 represents the greatest speed?

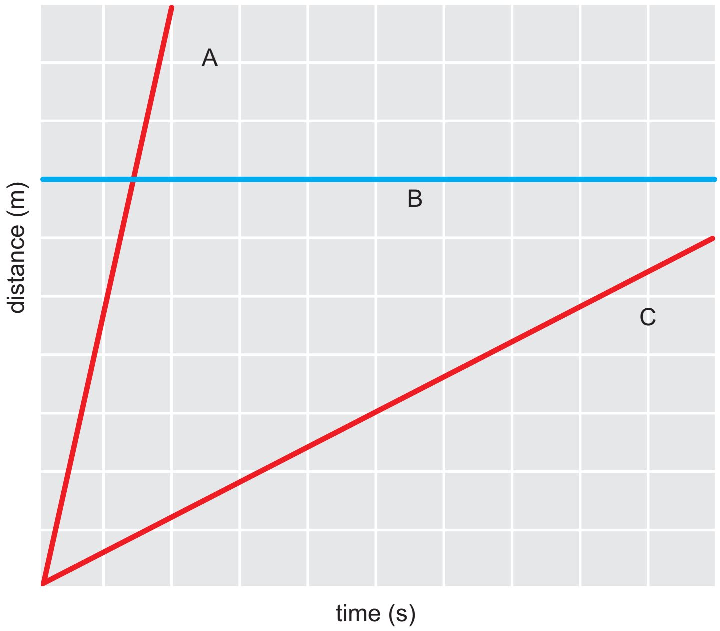


Figure 8: Distance–time graph

- ☐ A
- ☐ B
- ☐ C

6. Which line on the graph in Figure 8 represents an object travelling with a constant velocity?

- ☐ A
- ☐ B
- ☐ C

7. What is the difference between vector and scalar quantities?

8. Classify the following as scalar or vector:

   displacement, speed, acceleration, distance, force, velocity, mass and weight.

9. What are the SI units of:

   a) distance

   b) velocity

   c) acceleration.

10. Define the following terms:

    a) constant velocity

    b) constant acceleration.

How am I doing?

	☺ **Easy** (Tick this box if you feel confident that you **understand this section well**)	**Fine** (Tick this box if you still **need a little work** on this section)	☹ **Difficult** (Tick this box if you **still need a lot** of work on this section)
I know the meaning of distance and displacement			
I can calculate the speed of a moving object			
I know the difference between speed and velocity			
I can calculate the acceleration of an object			
I can draw displacement–time, velocity–time and acceleration–time graphs for a moving object			
I can calculate the distance travelled from a velocity–time graph			

Notes on what to do next:

Signed (by Scholar): .... Date:..................

Signed (by Tutor): .... Date:..................

Answers

Activity 1

a) 4 min, 240 s (remember you need to use standard SI units)

b) 200 m

c) 0 m

d) 0 m s^{-1} (remember her overall displacement is 0 so her average velocity is 0)

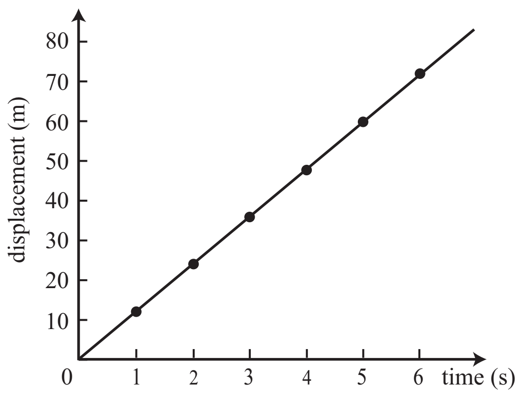
e) 200/240 = 0.83 m s^{-1}

Activity 2

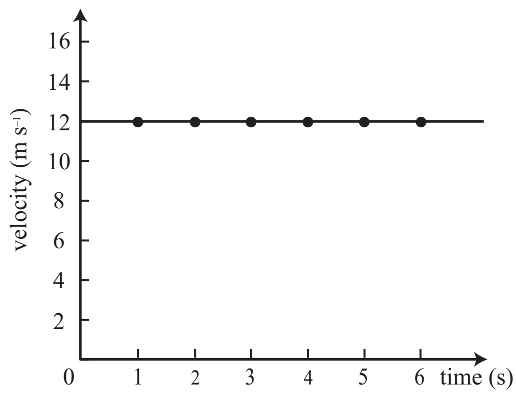
1. Change in velocity is 4 m s^{-1}. Time is 2 s. Acceleration is 4/2 = 2 m s^{-2}
2. Change in velocity is –8 m s^{-1}. Time is 4 s. Acceleration is –8/4 = 2 m s^{-2}

Answers to practice questions

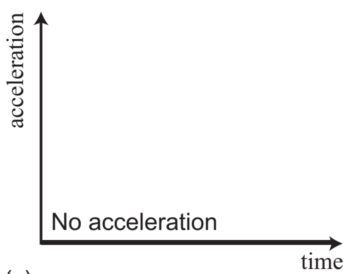
1.



(a)

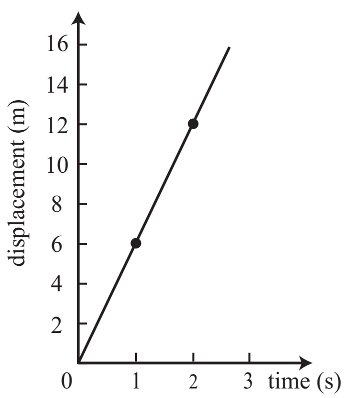


(b)

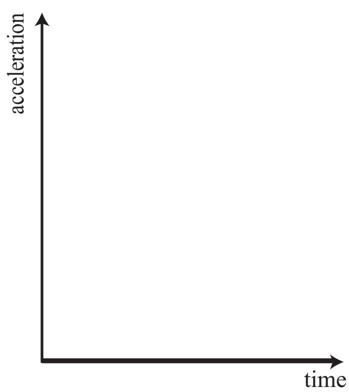


(c)

2.



(a)



(b)

The car is travelling at a constant speed in the same direction. It is not accelerating and every second the car travels 6m.

3. 20 m s^{-1}
4. Stationary object
5. Line A
6. Line B
7. A scalar quantity is fully described by its magnitude or size whereas a vector quantity is only fully described by its magnitude and its direction. You can think about scalars being 'ignorant of direction' and vectors being 'direction aware'.
8.

Scalar	**Vectors**
speed	displacement
distance	acceleration
mass	force
	velocity
	weight

9. a) metres, m

   b) metres per second, ms^{-1}

   c) metres per second squared, ms^{-2}

10. a) Velocity is a vector quantity that refers to 'the rate at which an object changes its position'. If a body has constant velocity then its velocity remains unchanged, in other words its displacement is changing by a constant amount each second.

    b) Acceleration is a vector quantity that is defined as the rate at which an object changes its velocity. An object is accelerating if it is changing its velocity. If a body has constant acceleration then its velocity is changing by a constant amount each second.

Glossary

Acceleration	The rate of change of speed or velocity. It is measured in ms^{-2} (metres per second squared) and given the symbol 'a'.
Displacement	The change in position of an object. You can think about displacement as being the vector of distance. Its SI unit of measurement is metres.
Force	The 'external agency' required to alter the state of rest or motion of a body. It is a vector quantity and is measured in newtons.
Scalar	A scalar quantity is any quantity that is sufficiently defined when the magnitude is given, e.g. distance or speed.
SI units	The International System of Units (SI abbreviated from French: Système International d'Unités) is the modern form of the metric system. It's a system of units of measurement devised around seven base units and the convenience of the number ten.
Speed	The ratio of the distance covered to the time taken by a moving body. It is a scalar quantity and the SI unit for speed is ms^{-1} (metres per second). $\text{speed} = \frac{\text{distance}}{\text{time}}$
Vector	Any physical quantity that requires a direction to be given in order to define it completely.
Velocity	Speed in a specified direction. Velocity is a vector quantity and its SI units are ms^{-1}. $\text{Velocity} = \frac{\text{Distance (in a particular direction)}}{\text{Time}}$

MSCE S3:
Periodic table and reactions

What you are studying and why

Subject: Physical Science Unit S3

This is the third science unit for your MSCE revision. At the end of this unit you should be able to:

1. write word, symbol and balanced chemical equations
2. classify reactions as exothermic or endothermic
3. draw the energy profile of a reaction and mark on the bond making and bond breaking
4. interpret units for concentration of solutions.

Chemical reactions: introduction

What are chemical reactions? Well, they obviously involve chemicals – what do you think of when you read the word ‘chemicals’?

Chemicals are everything around us; they can be solid or liquid or gas. As you learned in *Elements and chemical bonding*, all substances are made up of elements. All the elements are listed in the periodic table. **Elements** join together to form **compounds:** water is a compound made up of hydrogen and oxygen. The symbol for hydrogen is H and the symbol for oxygen is O. We write water as H_2O; this tell us it has two hydrogen atoms joined to one oxygen.

Activity 1

Now find your periodic table and use it to help you complete this table of elements and compounds.

Chemical compound	Formula	Names of chemical elements in the compound
Calcium oxide		
	H_2S	
Sulphur dioxide		

In chemical reactions chemicals change; new substances are formed. We call the starting materials the **reactants**. We call the materials at the end, the **products**. In the chemical reaction the atoms are rearranged but we can’t make new atoms. For example, when the fuel, methane gas, is burned in air, methane and oxygen from the air become carbon dioxide and water. We can write this as a word **equation**:

$$\text{methane} + \text{oxygen} \rightarrow \text{water} + \text{carbon dioxide}$$

This equation shows us that methane and oxygen react together to give water and carbon dioxide. The plus sign (+) tells us that methane and oxygen react with one another. On the other side of the arrow the plus sign tells us that both water and carbon dioxide are made. The arrow tells us the ‘direction’ in which the reaction goes, i.e. from reactants to products.

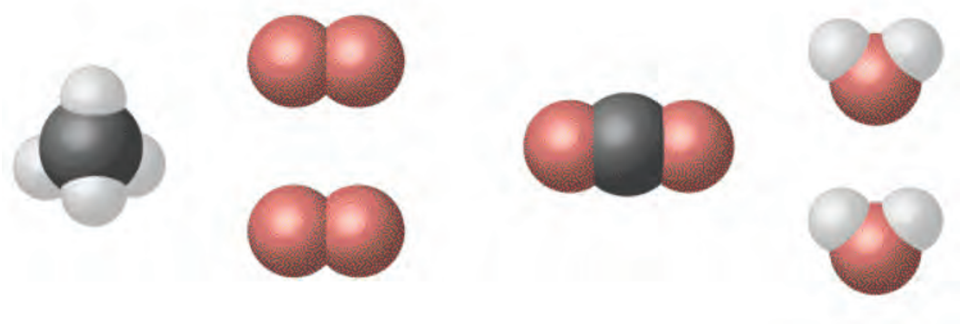
But a word equation tells us nothing about how much methane reacts with how much oxygen. To show this information we need to write a **symbol equation**. This equation shows all the atoms. It is important to remember that the atoms of each element are rearranged in a reaction – they cannot be lost or made. Oxygen is a gas with the formula O_2. (Remember most gases exist as molecules in which a number of atoms are bonded together.) Methane is made up of a carbon atom joined to 4 hydrogen atoms – we write this CH_4.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

This tells us that 1 methane molecule reacts with 2 oxygen molecules (the large number 2 in front of O_2 means that 2 of this molecule are used).

On the other side of the arrow are the products. Here we make 1 molecule of carbon dioxide and 2 molecules of water. The equation tells us also that each of the reactants are gases (g) and that carbon dioxide is also a gas and water is formed as a liquid (l).

Figure 1 demonstrates another way of showing the reaction:



CH_4	+	$2O_2$	$\longrightarrow$	CO_2	+	$2H_2O$
1 C 4 H		(4 O)		1 C 2 O		2 O 2 H

Figure 1: Methane + oxygen

Activity 2

Propane is another gas that is often used as a fuel. It reacts with oxygen in a similar way to methane and produces the same products. Write a word equation to summarize the reaction between propane and oxygen – remember to include the arrow and the '+' signs.

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Balancing equations

In a chemical reaction the number of atoms of each element must stay the same. If you have 4 atoms of oxygen at the start, you will have 4 atoms of oxygen at the end. In the chemical reaction the number of atoms on either side of the arrow is equal; for this reason it is called a **balanced equation**. This illustrates a very important fundamental principle: when chemical reactions occur matter is conserved, i.e. nothing is lost! The atoms are simply *rearranged*. The following table summarises the information in Figure 1:

Number of atoms of each element in the reactants		Number of atoms of each element in the products	
$CH_4(g) + 2O_2(g)$		$CO_2(g) + 2H_2O(l)$	
Carbon	One (in methane)	Carbon	One (in carbon dioxide)
Hydrogen	Four (in methane)	Hydrogen	Four (two in each water molecule)
Oxygen	Four (two in each oxygen molecule)	Oxygen	Four (two in carbon dioxide and one in each water molecule)

Activity 3

This equation shows what happens when we heat magnesium in air.

magnesium + oxygen → magnesium oxide

We can write the formula equation as

$$2Mg + O_2 \rightarrow 2MgO$$

Complete the diagram to show what happens to the atoms here.

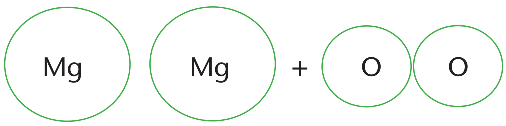


Figure 2: The synthesis of magnesium oxide (MgO) from magnesium and oxygen

Activity 4

This equation shows what happens when we heat iron and sulphur together:

iron + sulphur → iron sulphide

Now write this as a formula equation using your periodic table

....

....

and try to draw a diagram to show what is happening here:

Concentration

Many chemical reactions take place in water: that includes most of those that occur in us! When reactions happen in water they are said to take place in **aqueous solution**.

Solubility tells us how much of the substance will dissolve in a fixed amount of water. Substances which dissolve are called **soluble**. Which of the following substances do you think is most soluble in water?

Sand, sugar, flour, soap, nail varnish

Yes, you're right it is sugar. Sugar is very soluble in water; when you shake or stir sugar in water it dissolves. This creates a **solution**.

Water is called the 'solvent' and the thing that is dissolving is called the solute. So

$$\text{solvent} + \text{solute} \rightarrow \text{solution}$$

We can measure how much solute dissolves – this is the strength or concentration of the solution. A very soluble substance will make a very concentrated solution when it dissolves in a fixed amount of water. We usually measure the concentration in grammes per fixed volume of water. The fixed volume of water is one litre (this is the same as one cubic decimetre). If there is 50 g of sugar in one litre of water, the concentration is 50g/l or 50g/dm^3.

We use the equation

concentration (c) = mass in grams (m)/volume (v)

Example: 2.925 g of salt is weighed accurately and added to a glass containing 0.5 l of water at 25° C. What is the concentration of the resulting solution?

Step 1 Convert the volume into litres.

The volume = 0.5 l

= **0.5 l or dm^3**

Step 2 Calculate the concentration

concentration (c) = mass in grams (m)/volume (v)

Therefore, the concentration of the salt solution at 25° C = 2.95 g / 0.5 dm^3

= **5.9 g dm^{-3}**

It is of vital importance to state the temperature, because the solubility of most substances changes with temperature – you know that sugar dissolves more easily in hot tea than in cold tea. The solubility of substances does change with pressure but in everyday circumstances this is so slight that we can usually ignore any change.

Activity 5

Can you think of any more examples from your own experience of how temperature makes a difference to solubility? See if you can write down two examples.

1. ....

   ....

2. ....

   ....

Share your answers with your fellow Scholars.

Chemical reactions and energy

In all chemical reactions there will be an exchange of energy with the surroundings. If energy is given out, the temperature around the reaction will go up. Can you think of reactions which give out energy?

The obvious example is burning fuel. This gives out energy that we use to cook our food. In science, chemical reactions that give out energy are called **exothermic** reactions.

But some chemical reactions take in energy. The surroundings get colder and the temperature drops. We don't see many examples of this in our everyday life. One example is photosynthesis. This is the chemical reaction in plants, which uses energy from the sun to change carbon dioxide and water into the food that the plant needs to survive and oxygen. We, and other animals, use this food and oxygen so that we too can survive. (We can't make our own food.) The equation for this reaction is:

carbon dioxide + water + energy → sugar + oxygen.

Photosynthesis is an endothermic reaction because it will not happen without an external source of energy – sunlight.

Those reactions in which energy is absorbed or taken in are known as **endothermic** reactions.

In exothermic reactions, the final products have a lower energy than the reactants because energy has been given out. We can show this on an energy level diagram:

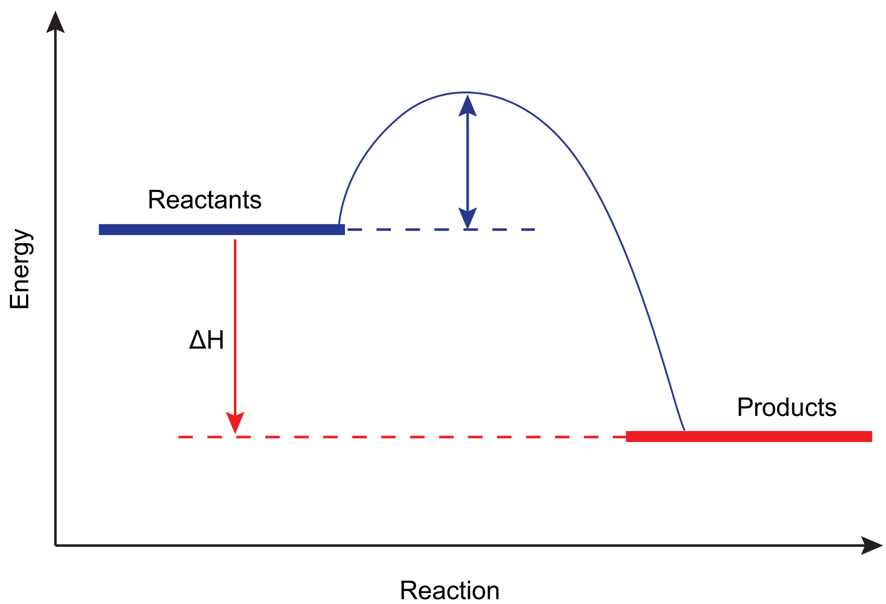


Figure 3: Energy level diagram

The difference in energy (E) between the reactants and the products is known as the heat of the reaction. It is represented by the symbol ΔH. Here energy is released – the energy of the products is lower than the energy of the reactants. ΔH is negative for an exothermic reaction – energy is released. This energy is released as heat and light – the temperature of the surroundings goes up.

Activity 6

Now try to draw an energy level diagram for an **endothermic reaction**.

Earlier in this unit we looked at the burning of one fuel – methane.

$$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (l)$$

We saw that we had to rearrange the atoms in this burning reaction. Let us look at what happens in detail.

Methane has the formula CH_4 – one carbon atom joined to four hydrogen atoms. In the products the carbon atom is joined to oxygen atoms. So in the reaction the bonds between the carbon and hydrogen have to be broken. **This process needs energy**.

But when the carbon joins to the oxygen atoms in the product (carbon dioxide) energy is released.

> Breaking bonds needs energy.
>
> Making bonds releases energy.

Overall a reaction will be exothermic (give out energy) if more energy is released in making bonds in the products than was required to break bonds in the reactant molecules.

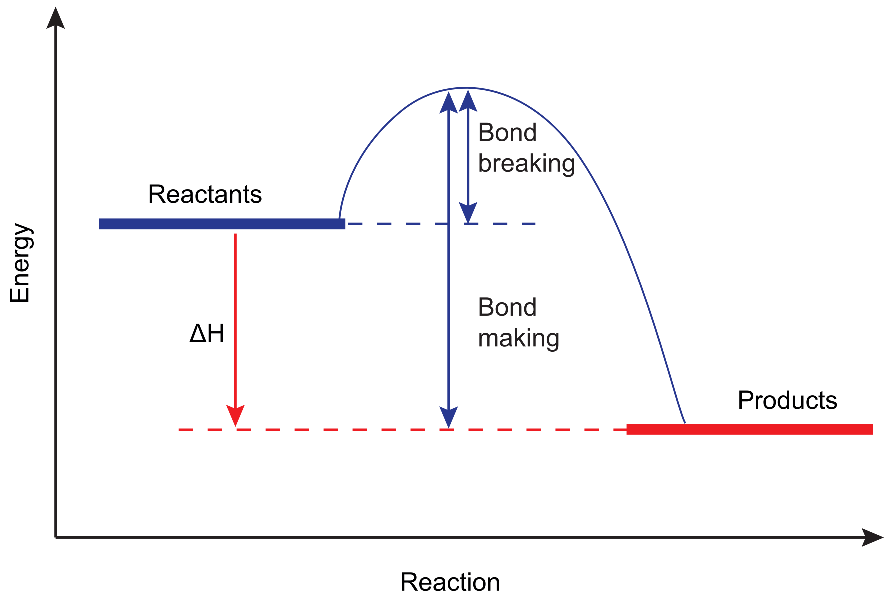


Figure 4: Making and breaking bonds

And if more energy is needed to break the bonds than is given out in making new bonds, then the reaction is endothermic.

Activity 7

Go back to your energy level diagram for an endothermic reaction. Mark on the energy to break the bonds and the energy released when bonds are made. (Remember bond breaking needs energy so the energy of the reactants goes up. When energy is released the energy level of the chemicals comes down.)

Practice questions

1. Which of these involves a chemical reaction?

    1 Baking bread

    2 Boiling water

    3 Corroding metals

    Choose one answer:

    A All of them

    B 1 and 3

    C 2 and 3

    D 1 and 2

2. The chemical change when a fuel burns can be described as:

    A A precipitation

    B A reversible reaction

    C An exothermic reaction

    D An endothermic reaction

3. Which of these involves a chemical reaction?

    A Boiling water

    B Ice melting

    C Apples decaying

    D Magnet attracting iron

4. Equal amounts of four different substances (A–D) were added separately to an equal amount of an acid and a thermometer placed in the mixture. For which substance, A, B, C or D is the reaction the most exothermic?

    A Temperature fell by 5 degrees

    B Temperature falls by 3 degrees

    C Temperature rises by 5 degrees

    D Temperature rises by 3 degrees

5. Which of these statements is correct?

    A Exothermic reactions take in energy from the surroundings

    B Endothermic reactions take in energy from the surroundings

    C Endothermic reactions release energy to the surroundings

    D Neither type of reaction releases energy to the surroundings

6. Which of these processes is always **endothermic**?

   A Condensation

   B Freezing

   C Evaporation

   D Burning

7. (a) Draw an energy level diagram for the following chemical reaction:

   $$H_2(g) + I_2(g) \rightarrow 2HI(g) \qquad \Delta H = +50 \text{ KJ / mol}$$

   (b) Is this reaction endothermic or exothermic? Give a reason for your answer.

8. A form one student gives 200 ml of salt solution to a form four student. Describe how you would determine the concentration of the salt by an evaporation method.

How am I doing?

	☺ **Easy** (Tick this box if you feel confident that you **understand this section well**)	**Fine** (Tick this box if you still **need a little work** on this section)	☹ **Difficult** (Tick this box if you still **need a lot of work** on this section)
Chemical reactions – what are they?			
Writing word equations			
Balancing equations			
Understanding concentration			
Chemical reactions and energy changes – exothermic and endothermic			

Notes on what to do next:

Signed (by Scholar): .... Date:..................

Signed (by Tutor): .... Date:..................

Answers

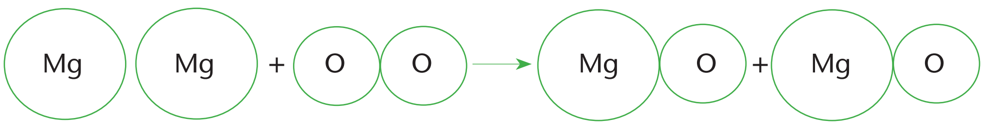
Activity 1

Chemical compound	Formula	Names of chemical elements in the compound
Calcium oxide	CaO	Calcium, oxygen
Hydrogen sulphide	H_2S	Hydrogen, sulphur
Sulphur dioxide	SO_2	Sulphur, oxygen

Activity 2

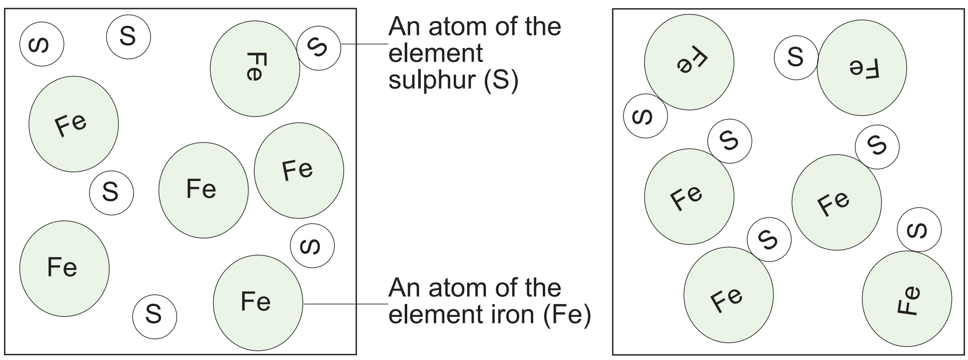
Propane + oxygen → carbon dioxide + water

Activity 3



Activity 4

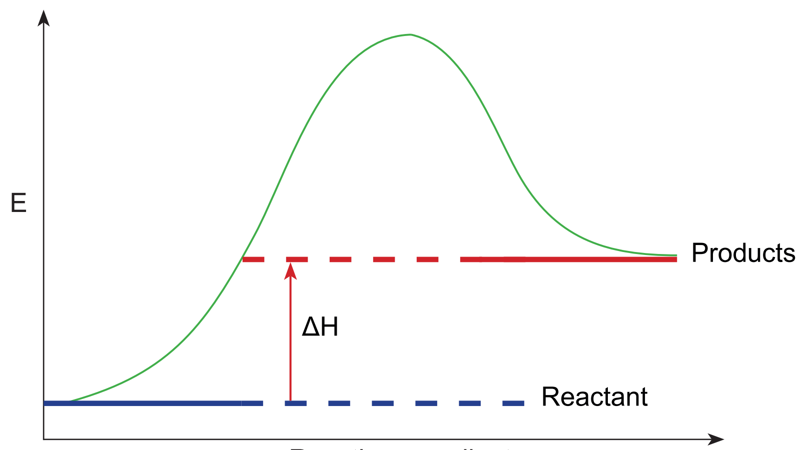
Fe + S→ FeS



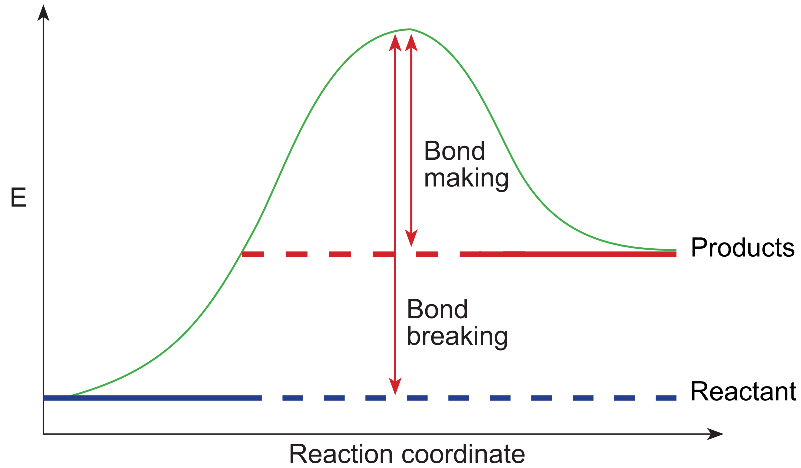
A mixture of iron and sulphur

The compound iron sulphide (FeS)

Activity 6

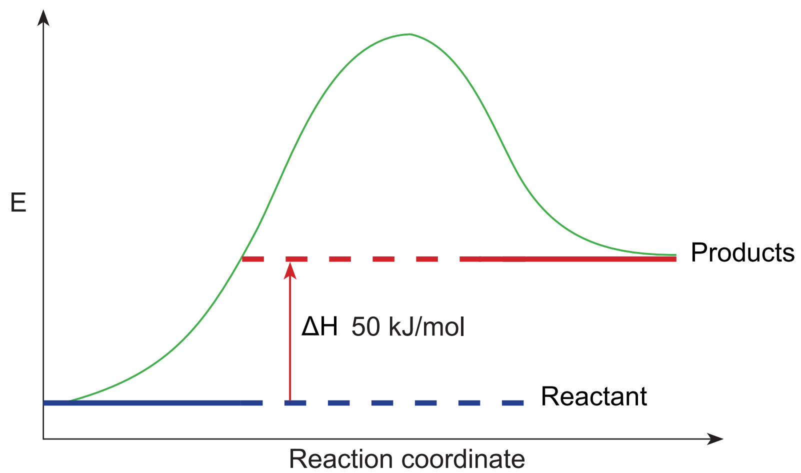


Activity 7



Answers to practice questions

1. B 1 and 3
2. C an exothermic reaction
3. C apples decaying
4. C temperature rises by 5 degrees
5. B Endothermic reactions take in energy from the surroundings
6. C evaporation
7.



This reaction is endothermic since energy is taken in from the surroundings and the products are at a higher energy level than the reactants.

8.

- Weigh an empty evaporating basin.
- Pour 100 ml of the solution into the evaporating basin.
- Gently heat the solution until all of the water has evaporated.
- When completely dry, reweigh the evaporating basin.
- Subtract the weight of the empty evaporating basin from the weight established in step 4. Multiply the result by 2. This is the mass of salt in the original solution.
- Use the mass of salt from step 5 and the volume to work out the concentration using the formula

concentration (c) = mass in grams (m)/volume (v)

where the volume is 200 ml.

Glossary

Aqueous solution	A substance dissolved in water.
Balanced equation	As a symbol equation where the total number of atoms of any reactants are equal to the total number of atoms of any products.
Chemical reaction	A reaction between chemicals which gives rise to new products.
Compound	A substance made up of two or more elements that are combined chemically.
Concentration	A measure of the amount of substance present in a unit amount of mixture.
Element	An element is a pure substance that can't be decomposed chemically and where all the atoms are identical to each other.
Endothermic reaction	A chemical reaction which requires energy.
Exothermic reaction	A chemical reaction which releases energy, usually in the form of heat.
Periodic table	An arrangement of the elements according to increasing atomic number, which shows relationships between element properties.
Product	The chemicals that are produced from a chemical reaction.
Reactant	The chemicals that react in a chemical reaction.
Solute	The substance which dissolves in a solvent to make a solution.
Solution	A solution is made up of a solute and solvent.
Solvent	The liquid in which a substance dissolves to make a solution.
Symbol equation	As a word equation but with chemical symbols.
Word equation	A chemical reaction represented in words with an arrow showing the direction.

Matter and electricity

What you are studying and why

Subject: Physical Science Unit S4

At the end of this unit you should be able to:

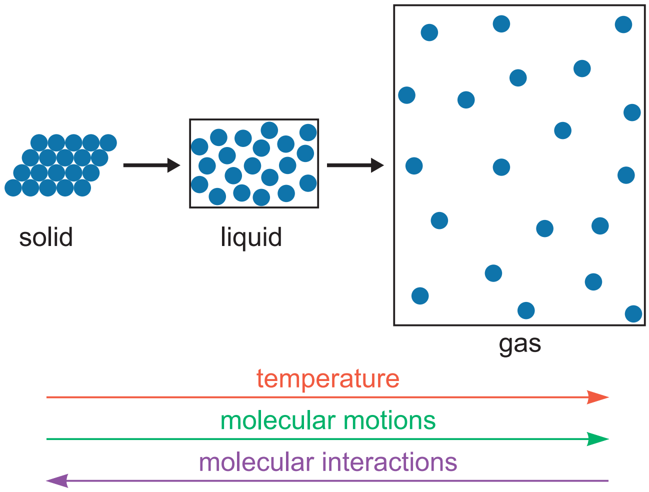
1. describe the kinetic theory model of solids, liquids and gases and use it to explain various effects such as diffusion and pressure.
2. Understand the difference between voltage, current and resistance, and series and parallel circuits
3. carry out calculations to work out the running costs of different electrical devices
4. know about transformers and a few uses of electromagnetism.

Matter

Matter is stuff – the stuff around us, solids, liquids and gases. The Kinetic Theory of Matter is a complicated way of describing a model for what is happening inside all this stuff. It is an idea that people have developed over many years. There are a few key ideas in this theory:

- Matter is made up of particles that are constantly moving.
- All particles have energy, but the energy varies depending on whether the substance is a solid, liquid or gas. Solid particles have the least energy and gas particles have the most amount of energy.
- The temperature of a substance is a measure of the average movement (kinetic) energy of the particles.
- There are spaces between the particles of matter.
- There are attractive forces between particles and these become stronger as the particles move closer together.

The diagram below summarizes these ideas.



You can see from the diagram that the particles in a solid are arranged in a very orderly way: when we increase the temperature of the solid, the particles in the solid acquire more energy and they begin to vibrate more strongly. They stay in their fixed arrangements but move backwards and forwards more quickly (imagine children sitting on the floor but all waving their arms and legs). This normally causes the solid to **expand** very slightly because the same number of particles takes up more space. The more the temperature of the solid is increased the greater the energy transferred and the particles begin to move even more. The structure becomes less and less ordered until eventually, at the melting temperature, it changes into a liquid.

In a liquid the particles are still in contact but able to move from their previously fixed positions. (Imagine the children now moving slowly round the room – they constantly bump into each other.) Adding even more heat causes the particles to move faster and faster until they completely separate and the liquid becomes a gas.

In a gas the particles are very spread out – they hardly ever touch each other, and they move very fast. (Imagine now the children running round outside in a very large area.)

Activity 1

Solids, liquids and gases have very different properties. Complete the following table of properties for solids, liquids and gases (if it helps,think of water as ice,water and steam).

	solid	**liquid**	**gas**
hardness and density		dense	
shape	fixed		
volume		fixed	
compressible?			yes

Talk to your tutor about your ideas for this activity.

Diffusion

Why is it that we can often smell food cooking from outside the kitchen?

Just like the dust particles referred to above, some of the molecules of food float free from its surface as it cooks and collide with molecules of air. After millions of such collisions some find their way into our nostrils and we smell the food! This can happen, of course, even when food is not being cooked: an orange being peeled, for example, produces a strong aroma in the air. The process responsible for the movement was mentioned in the answer to Activity 3 and its effect is **diffusion**, the movement of particles from one area to another.

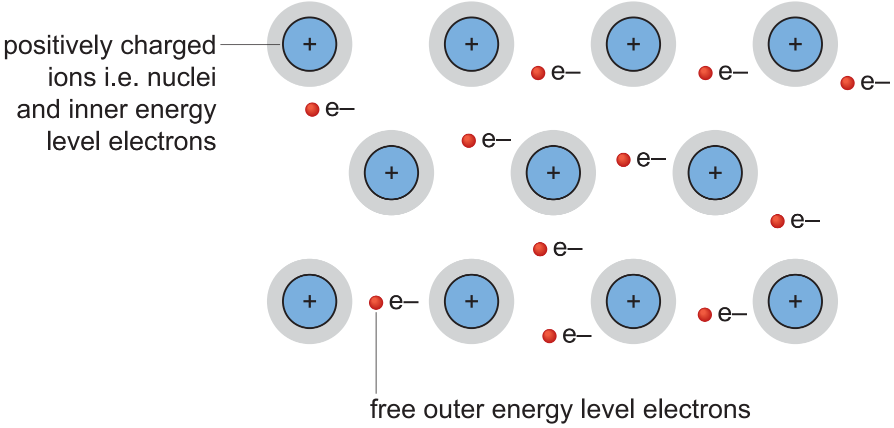
Pressure

When a gas is trapped inside a container the gas particles move in straight lines in random directions until they collide with other gas particles or the walls of the container. If the container is heated up from the outside some of the heat energy is transferred to the particles inside and they move faster (we say they have more kinetic energy). They collide more frequently with each other and the walls of their container. This is what is meant by **pressure**. The higher the temperature of a gas the higher its pressure.

Electricity

Electrical current

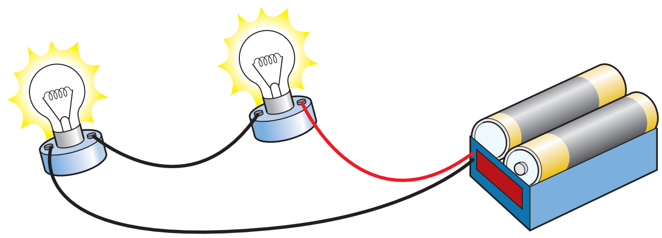
Electrical conductors allow electrons to flow through them easily. Metals are excellent conductors of electricity. The electrons in the outer shells of their atoms are only weakly held by their positively charged nuclei. This means that they have a tendency to 'wander off'. We call these 'free' electrons.

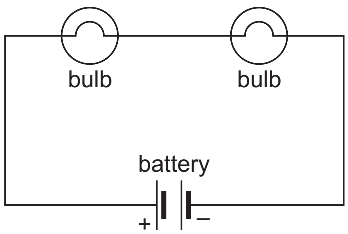


The free electrons move randomly in all directions through the three-dimensional network of metal nuclei, which are 'fixed' in their positions. However, if the piece of metal is, say, a copper wire and we make one end of the wire positive relative to the other end by connecting it, in a circuit, to a battery, the electrons no longer move at random but now all in the same direction because they are all attracted towards the positive terminal of the battery. We call this movement of electrons an **electric current**. The magnitude, or size, of a current is measured in **amperes** or simply **amps** (A).

Series circuits

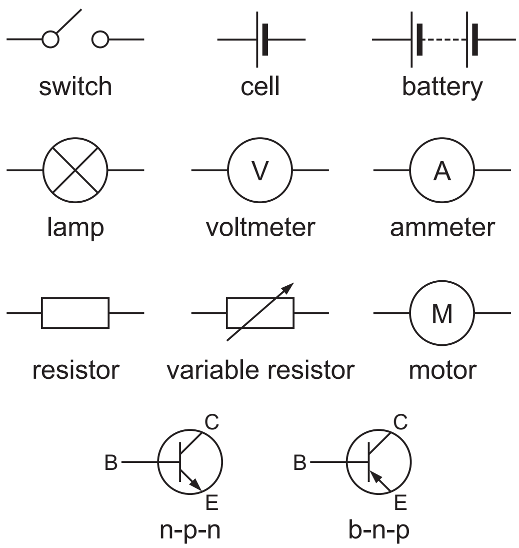
Electric circuits in which the components follow one another in the same piece of conducting wire are known as series circuits. They can contain lamps, buzzers, voltmeters etc.





series circuit

The circuit shown in the top diagram shows two batteries and two lamps wired in series. (Note that lamps are often referred to as bulbs.) The diagram below shows the same circuit diagrammatically – this is called a circuit **diagram**. Here we use symbols to represent the components. Some common circuit symbols are illustrated below.



symbols for transistors


symbol for a diode

In a series circuit the current is the same all round the circuit. (Imagine the current is like water flowing through pipes; if there is no leak the water flow is the same at the end as it is at the beginning.) The lamps are like barriers in the flow of electrons. They use the energy of the current.

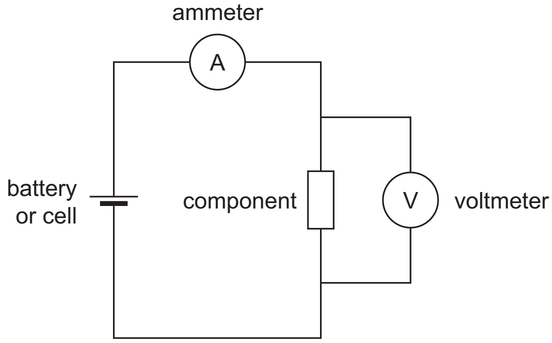
Now imagine the circuit above with only one lamp instead of two. What would happen to the brightness of the lamp?

Yes, that's correct. It would be twice as bright. Now all the energy of the current can be used by this one lamp. What would happen if you put three lamps in the circuit? And what would happen if you have three batteries instead of two?

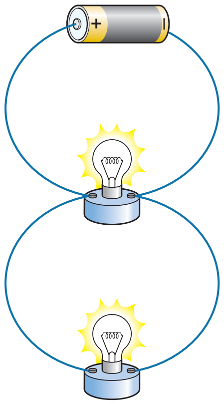
When a current flows through the lamps the electrical energy in the wire is converted into heat and light energy in the lamps. We measure current with an **ammeter** which we connect into the circuit.

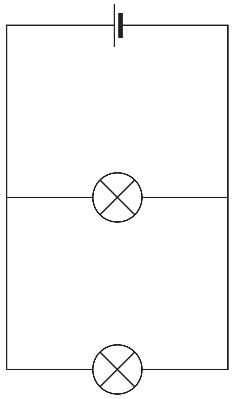
The energy for the electrons is provided by the battery. The **voltage** of the battery can be thought of as 'pushing' the electrons through the wire and around the circuit and through the lamps.

Voltage is measured in volts and the instrument used for measuring it is known as a **voltmeter**. A voltmeter has to be wired in parallel so that it measures the voltage before the current passes through the lamp and after it has passed through in order to compare the difference. It is this difference that is displayed by the voltmeter reading. Parallel circuits are where the current has a choice of paths around the circuit.

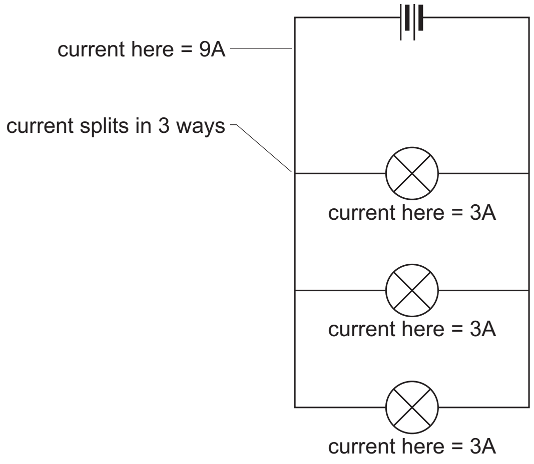


Parallel circuits





In this circuit if either one of the lamps breaks the other will remain shining. This is because the current leaving the cell splits into two and travels through each branch before resuming the same path back to the cell. Also, both lamps shine just as brightly as either would on their own because the current flowing through each branch of the circuit carries the same voltage, or energy. The current in the main circuit is the sum of the currents in the separate branches. This is illustrated in the diagram below.



We can summarize this as an equation where we use the symbol *I* for the current and *I*

$$I_{total} = I_1 + I_2 + I_3$$

The current in each of the three branches is 3 A, so that in the main circuit it must be 9 A.

Resistance

Let us think about the very thin wire that makes up the filament in a lamp. This wire is very thin and when the current flows through it it becomes very hot, so hot it gives out light. Because it is very thin, it is difficult for the current to flow through it, it **resists** the current. We say that the wire has a certain **resistance** to the current. (Imagine that you are pushing water through a very narrow pipe – this is what is happening when the current goes through the filament.) The greater this resistance is, the greater the voltage has to be to push the same amount of current through the wire. The lamp is an example of a resistor. This resistor does an obvious job; i.e. providing light!

Resistors are useful in electrical circuits; they are commonly used to reduce the current. The picture below shows what these resistors look like. The unit of resistance is called the **Ohm** (Ω).

The coloured bands indicate the value of the resistor according to a universally accepted code.

Rheostats or **variable resistors** enable the current to be varied across a range. The picture below illustrates a typical rheostat. The sliding contact enables the length of wire that the current has to pass through to vary thus varying the resistance to its flow.

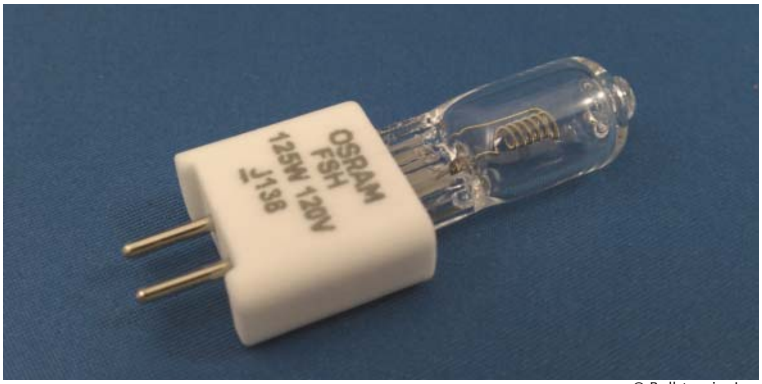
You will find out more about the relationship between current, voltage and resistance in a later unit.

There are four main factors that affect resistance:

1. Cross-sectional area (csa). The smaller the csa the greater the resistance.
2. Length of resistor (e.g. wire). The longer the wire the greater the resistance. As we saw earlier, this fact is made use of in rheostats.
3. Type of material. Different substances have different resistances. Gold is an excellent conductor because it has a low electrical resistance. However, it is very expensive. Copper is not quite as good a conductor but a lot less expensive.
4. Temperature. As the temperature of the wire increases so does its resistance.

Electrical power

Power is a measure of how quickly one form of energy is converted into another. For example with a light bulb, the power is the rate at which electrical energy is transferred by a current into another form of energy – light. If you look carefully at an electric light bulb you will see numbers written on it somewhere.



This bulb has 125 W and 120 V written on its base. The first number, the **power rating**, indicates how quickly this bulb converts electrical energy into heat and light energy.   Power has units of **watts (W)**.

A different bulb with a power rating of, say, 160 W, will be brighter because it is converting electrical energy into heat and light energy more rapidly.

Power ratings of typical electrical appliances are shown in the table below.

Appliance	Power rating (W)
Electric kettle	2000
Electric iron	500
Fan	1500
One bar electric fire	1000
Washing machine	1000
Colour television	650

Paying for electricity

When we pay for electricity we have to pay for the amount of electrical energy that we have converted into other forms of energy. The units that we use are the **kilowatt-hour** (kWh)

Energy transferred = power (kW) × time switched on (h)

This is simply the number of kilowatts of electrical power x the number of hours. There is a cost for each Kilowatt-hour or unit of electricity. Electricity meters measure the number of units of electricity used in a building. The more units used, the greater the cost. The cost of the electricity used is calculated using this equation:

total cost = number of units × cost per unit

Example 2:

What is the cost of running the fire in the table above for 3 hours if each unit (kilowatt hour) of electricity costs 25 kwacha.

Answer 2:

Units used = 1 kW × 3 hours

Cost = 3 units × 25 MWK

= 75 MWK

Activity 2

How much does it cost per year to have two showers a week if heating the water for the shower means that the water heater has to be switched on for one and a half hours at a time and each unit (kilowatt hour) of electricity costs 25 kwacha?

....

....

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Electromagnetism

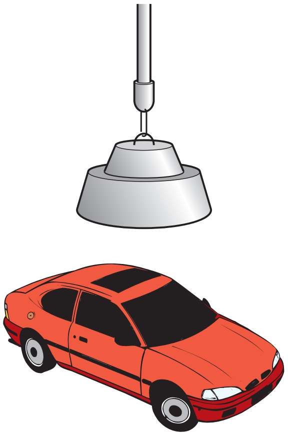
A wire carrying an electric current also has an associated magnetic field around it. If a wire is twisted into a coil and a current passed through the wire, the coil behaves like a bar magnet and has the same shaped magnetic field. This is called an **electromagnet**. We can make the electromagnet stronger by:

1. increasing the current flowing through the wire
2. using more turns of wire on the coil
3. using a 'soft' iron core inside the coil.

Using electromagnets

Electromagnets are very useful. We can change the strength of the magnet by changing the size of the electric current. And we can switch the electromagnet on and off. A permanent magnet, like an iron magnet, is always a magnet. .

This makes electromagnets useful in a variety of applications such as in electric bells, electric door locks, in hospitals to extract tiny iron or steel splinters from wounds and in scrap metal yards. In this last application the electromagnets are so powerful they are able to pick up whole cars and put them down in other places!



Transformers

Transformers are devices that are used either to increase or decrease the voltage in circuits with alternating current (AC) (AC is current from a generator or from a power station). Direct current (DC) is from a battery. If you have electricity supplied from a power station or from a generator it is usually around 240 V. But a mobile phone only needs a voltage of 5 V. So we need to use a mobile phone charger which reduces the voltage. Transformers that reduce the voltage are known as **step-down transformers**, those that increase it are know as **step-up transformers**.

Transformers are often not very efficient. They lose energy as heat energy – you can feel the heat from a transformer.

Transformers have two coils to change the voltage. The relative number of turns in each coil will determine how much the transformer steps up or steps down the voltage.

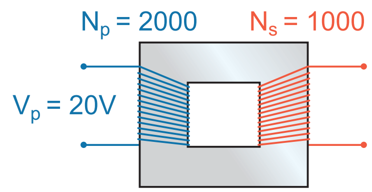
This is summarised as follows:

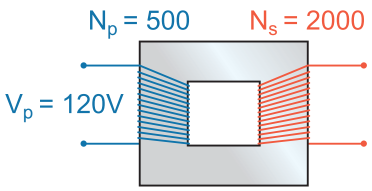
secondary voltage/primary voltage = number of turns in secondary coil/number of turns in primary coil or,

$$V_s/V_p = N_s/N_p$$

Where primary means the starting voltage and secondary is the output voltage.

Transformer calculations:





Example 3:

Consider the top diagram.

(a) What will be the voltage in the secondary coil?

(b) Is this transformer step-up or step-down?

Answer

(a)

$$\text{If } V_s/V_p = N_s/N_p$$

$$\text{Then, } V_s = (V_p N_s)/N_p$$

$$= (20\ V \times 1000)/2000$$

$$= \underline{10\ \text{V}}$$

(b) The voltage in the secondary coil is lower than that in the primary. Therefore this must be a step-down transformer.

Practice questions

1. Refer to the table below which gives the melting and boiling points of a number of elements, and then answer the questions that follow. (Data from http://www.chemicalelements.com.)

Element	Melting point (°C)	Boiling point (°C)
Copper	1083	2567
Magnesium	650	1107
Oxygen	–218.4	–183
Carbon	3500	4827
Helium	–272	–268.6
Sulfur	112.8	444.6

(a) What state of matter (i.e. solid, liquid or gas) will each of these elements be in at room temperature?

(b) Which of these elements has the strongest forces between its atoms? Give a reason for your answer.

(c) Which of these elements has the weakest forces between its atoms? Give a reason for your answer.

2. What is the approximate voltage produced by power stations?
   - 230 V
   - 25,000 V
   - 400,000 V

3. A transformer produces 100 V from an input of 50 V. What does this tell you?
   - It is very efficient.
   - It is a step-up transformer.
   - It is a step-down transformer.

4. A 250 W computer is switched on for 4 hours. How many units of electricity does it use?
   - 1000
   - 62.5
   - 1

5. A 2 kW electric fan is switched on for 30 minutes. How many units of electricity does it use?
   - 1
   - 15
   - 60

How am I doing?

	☹ **Difficult** (Tick this box if you still **need a lot of work on** this section)	**Fine** (Tick this box if you still **need a little work** on this section)	☺ **Easy** (Tick this box if you feel confident that you **understand this section well**)
The main ideas of kinetic theory			
Use kinetic theory to explain diffusion and pressure			
Know the circuit symbols and be able to draw series and parallel circuits			
Understand the differences between voltage, current and resistance			
Calculate the cost of running electrical devices			
Be familiar with an electromagnet and transformers			

Notes on what to do next:

Signed (by Scholar): .... Date:..................

Signed (by Tutor): .... Date:..................

Answers to activities

Activity 1

You could have suggested those summarised in the table below.

	solid	liquid	gas
hardness & density	hard and dense	dense	
shape	fixed	fixed	not fixed
volume	fixed	fixed	not fixed
compressible	no	no	yes

Activity 2

Cost of each shower = 1.5 hours × 3 kW × 25 Kwacha

= 112.5 Kwacha

Cost per week = 2 × 112.5 Kwacha

= 225 Kwacha

Cost per year = 225 Kwacha × 52 weeks

= 11700 Kwacha

Answers to practice questions

1. (a) copper solid

magnesium solid

oxygen – gas

carbon – solid

helium – gas

sulfur – solid

(b) carbon – because it has the highest melting temperature.

(c) helium – because it has the lowest melting temperature.

2. 25,000 V
3. It is a step-up transformer.
4. 1000.
5. 1.

Glossary

Ammeter	The device we measure current with in a circuit. An ammeter must be connected in series in a circuit.
Amperes (Amps, A)	The SI unit of electricity. The greater the size of the current, the bigger the number of amps (A).
Diffusion	This is the process in gases and liquids responsible for the movement of particles from one area to another.
Electric current or electricity	This is the overall movement of electrons when a voltage is applied across the ends of a conductor. Current is given the symbol 'I' in equations.
Electrical conductors	Electrical conductors allow electrons to flow through them easily. They are said to have high electrical conductivity and, almost always, good electrical conductors are good thermal conductors. The opposite of a conductor is an insulator.
Electrical power	Power is a measure of how quickly electrical energy is converted into another form. The unit of electrical power is a watt.
Electromagnet	This is a magnet that is created by passing an electrical current through a coil of wire. The strength of the electromagnet can be increased by increasing the current flowing through the wire, using more turns of wire on the coil and using a 'soft' iron core inside the coil.
Free electrons	The electrons in the outer shells of their atoms are only weakly held by their positively charged nuclei. This means that they have a tendency to 'wander off' or migrate through the material. When a voltage is applied, all the charges move in one direction and it is this effect that constitutes the electrical current we call electricity.
Kilowatt-hour (kWh)	This is a standard measure of the total units of electricity used by an appliance. It is calculated using the equation: Energy transferred = power (kW) × time switched on (h)
Kinetic theory of matter	This is a scientific model to explain how matter behaves and also to predict its future behaviour.
Matter	Matter is made up of particles that are constantly moving.
Ohms (Ω)	The SI unit of resistance is the ohm.
Parallel circuit	A circuit where the components are connected across each other in branches. Although they are more complicated, their advantage over series circuits is that even when one component fails, the whole circuit will continue to work normally.
Power	Power is a measure of how quickly one form of energy is converted into another form. It is a measurement of rate, i.e. the conversion per second. The unit of power is a watt.
Pressure	In terms of gas and liquid particles, pressure is what is caused by the collisions they have on the container walls. The more particles there are, or the more energy they each have, the greater the pressure. This is why the higher the temperature of a gas the higher its pressure.
Resistance	This is a measure of how much a conductor or component resists the flow of electrons. The higher the resistance, the harder it is for the electrons to flow and therefore the lower the current. Resistance can be affected by four factors: length, cross-sectional area, material and temperature.

Rheostats or variable resistors	These enable the current to be varied across a range. They usually have a sliding contact which enables the length of wire that the current has to pass through to vary, thus varying the resistance to its flow. A dimmer switch to control the brightness of a light is an example of a variable resistor.
Series circuit	A circuit where the components are connected in a continuous electrical loop. Although they are simple, the disadvantage of series circuits is that when one component fails, the whole circuit ceases working.
Step-down transformer	A transformer that increases the input voltage.
Step-up transformer	A transformer that decreases the input voltage.
Temperature	The temperature of a substance is a measure of the average kinetic energy of the particles. In the SI system, the units of temperature are degrees Celsius (°C).
Transformers	Transformers are devices that are used either to increase or decrease the voltage in circuits with alternating current (AC). (AC is current usually from a generator or a power station, and direct current (DC) is from a battery.)
Voltage	This is a measure of the electrical push all the electrons are given in a circuit.
Voltmeter	The device we measure voltage with in a circuit. A voltmeter must be connected across or in parallel with the component.
Volts (V)	The SI unit of voltage.
Watts (W)	The SI unit of power. One watt means that one joule of energy is being covered every second.

MSCE S5
Organic chemistry

What you are studying and why

Subject: Physical Science Unit S5

This is the fifth science unit for your MSCE revision.

At the end of this unit you should be able to:

1. explain the difference between an alkane and an alkene
2. name, draw and represent the molecular structure of the first ten primary alkanols
3. define isomerism and give some examples of isomers
4. name, draw and represent the molecular structure of simple carboxylic acids

Hydrocarbons – the basics that you need to know

Organic chemistry is based on **hydrocarbons**. Hydrocarbons are made up from the elements carbon and hydrogen **only**. These are very important chemicals to us as they form the basis of fuels and many other useful substances. Before we can go on, we really need to know about alkanes, so this first section will take you through some basic knowledge that will support your understanding as we develop our ideas about other types of hydrocarbon-based substances.

Counting the carbon atoms

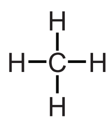
Even before we can talk about the very simplest of hydrocarbons – alkanes – we need to know what the word stems are for each carbon chain. The table overleaf gives you the prefixes that you will need to learn and use in organic chemistry.

Prefix	Number of carbons
Meth	1
Eth	2
Prop	3
But	4
Pent	5
Hex	6
Hept	7
Oct	8
Non	9
Dec	10

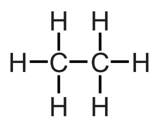
Tip: Think of these as codes and learn them carefully. You will need them when we are 'code-breaking' the names of organic compounds.

Alkanes

Alkanes are the simplest hydrocarbons as they only contain single, covalent carbon-to-carbon bonds. The two simplest ones, methane and ethane, are shown below.



Methane



Ethane

Stop and check!

Are you happy with the representations above? 'H' = one hydrogen atom, 'C' = one carbon atom, '–' is one single covalent bond and '=' is one double covalent bond.

Adding carbons and hydrogens to these simple alkanes just gives us longer molecules and bigger alkanes. So, how can we work out the formula of an alkane when we add more carbons and hydrogens? The easiest way is to use the general formula, which says that for every carbon atom there are twice the number of hydrogen atoms plus two extra hydrogen atoms; or in terms of symbols, C_nH_{2n+2} where n stands for the number of carbons.

Therefore, for **methane** we have one carbon, so n = 1 and the structural formula is $C_1H_{(2x1)+2}$, which equals C_1H_4.

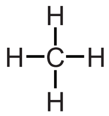
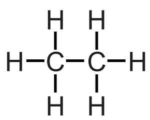
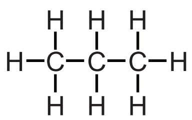
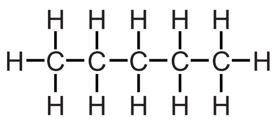
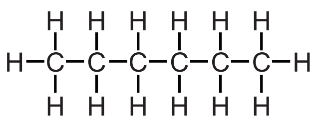
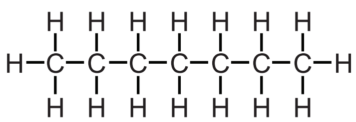
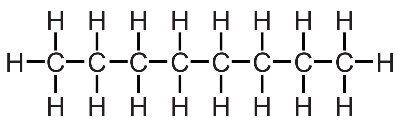
Following the same rules for **ethane**, we have two carbons, so n = 2 and the structural formula is $C_2H_{(2x2)+2}$, which equals C_2H_6.

Stop and check!

You need to know about the first ten alkanes so if you are happy with what you have done so far, go on to the next section. If not, then discuss this section with your fellow scholars or tutor.

Activity 1

The details of the first ten alkanes are shown in the table below. Using the completed examples of the first three (methane, ethane and propane) as a guide, see if you can fill in the boxes that have been left empty to show how well you understand what we have done so far.

Alkane	Molecular formula	Structural formula	Condensed structural formula
Methane	CH_4		CH_4
Ethane	C_2H_6		CH_3CH_3
Propane	C_3H_8		$CH_3CH_2CH_3$
Butane	C_4H_{10}		$CH_3CH_2CH_2CH_3$
Pentane	C_5H_{12}		
Hexane			$CH_3CH_2CH_2CH_2CH_2CH_3$
	C_7H_{16}		$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane			
Nonane	C_9H_{20}		
Decane	$C_{10}H_{22}$		

As you will hopefully see, once you have the basic idea it's just a question of learning the prefix names – meth, eth, and prop, etc. through to dec – and adding the suffix **ane** to name each of the alkanes. Using the general molecular formula, C_nH_{2n+2} gets you to the molecular formula and then drawing the molecular structure to show the bonds gives you the structural formula.

Stop and check!

If you have got less than half of these answers right then go back and reread the section, or discuss it with your tutors or fellow scholars. If you have more than half correct, well done and continue!

Alkenes

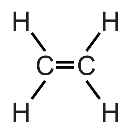
While they are still relatively simple hydrocarbons, **alkenes** are slightly more complicated than alkanes because they contain **at least** one double covalent carbon-to-carbon bond (C=C).

Code-breaking

See if you can name and draw the first alkene below:

....

Well done if you answered ethene, which looks like this:



To work out the formula of other alkenes we need to use their general formula; for every carbon atom there are double the number of hydrogen atoms, or in terms of symbols, C_nH_{2n} where n stands for the number of carbons.

For **ethene** we have two carbons, so n = 2 and the structural formula is $C_2H_{(2x2)}$, which equals C_2H_4 .

For **propene** we have three carbons, so n = 3 and the structural formula is $C_3H_{(2x3)}$, which equals C_3H_6 .

Caution: You can't automatically assume that a compound is an alkene just because it has a molecular formula that matches the general formula, C_nH_{2n}, as other hydrocarbons also fit this general formula.

Like alkanes, alkenes are named by using the prefix representing the longest carbon chain that contains the C=C bond, and adding the suffix **ene**. The chain is numbered in such a way as to give the carbon atoms of the C=C bond the lowest numbers, indicating where the double bond originates (you will cover this method of numbering more fully with alkanols later on).

Remember the code:

ane means carbon-to-carbon single bond or C–C

ene means carbon-to-carbon double bond or C=C

Applying this knowledge to alkanols

Elements like oxygen can be added to hydrocarbons to make other organic substances, like **alcohols** and **carboxylic acids**. We are going to look at unbranched alcohols (alkanols) next in this unit. There will be more about branching later on.

You might already be familiar with the term 'alcohol' in everyday language. Some alcohols can be consumed, some are used in medicine, some for basic fuels and many others are used as raw materials.

However, in organic chemistry, an alcohol is a compound that contains one or more OH groups. An OH functional group is also called a **hydroxyl group** and, as its name suggests, it only contains an oxygen and hydrogen atom bonded directly together.

What type of bond is this? ....

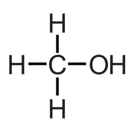
Tip: This type of bond isn't ionic.

Well done if you said 'covalent'!

More specifically, an alkanol has the same structure as an alkane except that one (and only one) of the hydrogen atoms is replaced with a hydroxyl group.

Just as we have learned that there is a general formula for alkanes, there is also a general formula for alkanols. It is C_nH_{2n+1} OH.

Methanol is the first and most simple alkanol. Its expanded molecular formula is C_1H_3OH but when 'tidied up' it has a final molecular formula of CH_4O. Its structure is shown below:



Methanol

To name the rest of the first ten alkanols, we need to use the prefixes used for the first ten alkanes as a name stem and then add a number – it's a two part process. For the first part we add 'anol' to the prefix and, for the second part, we use a number to say which carbon the hydroxyl group is bonded to on the carbon chain. The chain is always numbered so as to give the OH group the lowest possible number – we will come to this part in a moment. So the name has a word part and a number part.

For the word part, let's use ethanol as an example. Ethanol, the second alkanol, has two carbon atoms and therefore the prefix 'eth'. It is named adding 'anol' to this prefix:

Eth + anol $\rightarrow$ Ethanol

Activity 2

Now it's your turn. See if you can use the naming rule above to work out the word part of the names for the remaining eight alkanols.

....

....

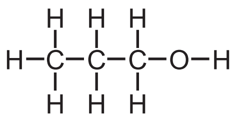
....

....

Check your answers with those at the end of the unit. You should have been able to get all the alkanols correctly named in terms of the word part.

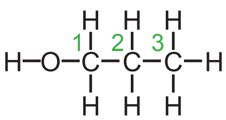
For the number part, we have to add a number after the alkane stem of the word part to show which carbon in the chain has the OH group attached.

For example, for the third alkanol, propanol (shown below), the OH group is on the end so we would call this propan-1-ol (or 1 propanol). This is because the OH group is attached to the first carbon.



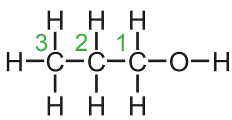
What about if the OH is attached to the last carbon?

If the OH was attached to the last carbon, it would still be called propan-1-ol, as the carbon chain is always numbered to give the lowest value, so the numbering would just begin at the opposite end, as shown below. These are both the same compound!



Propan-1-ol (or 1 propanol)

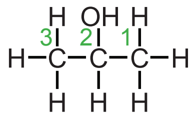
Molecular formula: C_3H_8O



Propan-1-ol (or 1 propanol)

Molecular formula: C_3H_8O

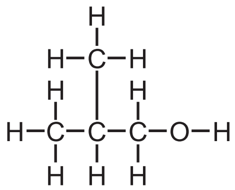
If the OH group is attached to the middle carbon, as it is in the diagram below, then we would name this 2 propanol (or propan-2-ol), as the OH group is attached to the second carbon.



Propan-2-ol (or 2 propanol)

Molecular formula: C_3H_8O

So far we have only looked at **unbranched** carbon chains. This means that all the carbons are arranged in one long chain and that only the extra functional groups branch off it. For example, the molecule (2-methylpropan-2-ol or 2-methyl-2-propanol) below is a branched chain, because there is a CH_3 attached to the middle carbon atom.

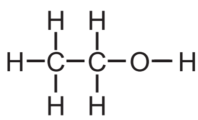


What is its molecular formula? ....

If you said $C_4H_{10}O$ then well done!

Activity 3

In the table below, which starts with ethanol and only goes as far as hexan-1-ol, complete the gaps to show the molecular formulae and expanded structural formulae.

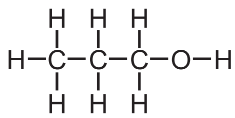
IUPAC name	**Molecular formula**	**Expanded structural formula**	**Condensed structural formula**
Ethanol	C_2H_6O		CH_3CH_2OH
Propan-1-ol (1-propanol)	C_3H_8O		$CH_3CH_2CH_2OH$
Butan-1-ol (1-butanol)	$C_4H_{10}O$		$CH_3CH_2CH_2CH_2OH$
Pentan-1-ol (1-pentanol)			$CH_3CH_2CH_2CH_2CH_2OH$
Hexan-1-ol (1-hexanol)			$CH_3CH_2CH_2CH_2CH_2CH_2OH$

> **Extra activity:**
>
> If you have time or you want to double-check your understanding, complete the table with the details of the last four alkan-1-ols. Compare your answers with those of your fellow scholars.

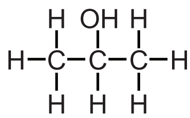
Isomers

Going back to the example of propanol, you will probably have noticed that propan-1-ol and propan-2-ol have the same molecular formula: C_3H_8O.

We call these two versions of the same compound **isomers**. The only difference between the two versions is where the OH group is attached on the carbon chain. We say that each isomer has a different structural formula. See the diagrams below and check that you are happy with this idea.



Propan-1-ol: C_3H_8O



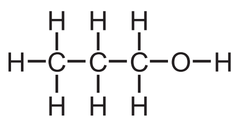
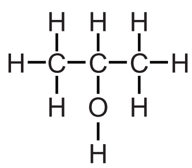
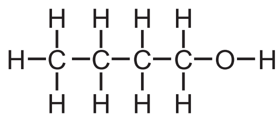
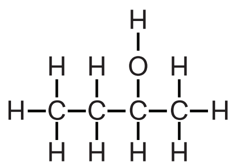
Propan-2-ol: C_3H_8O

What do you think happens when we increase the number of carbon atoms?

....

We have already shown that 'prop' compounds have only two possible isomers but as you increase the number of carbons in the chain, you begin to increase the number of possible isomers. Butanol, with four carbons, still only has two isomers but pentanol, with five carbons, has three isomers. By the time you get to decanol there are many possible isomers!

Some examples of isomers are shown below:

IUPAC Name	Molecular formula	Expanded structural formula	Condensed structural formula
Propan-1-ol (1-propanol)	C_3H_8O		$CH_3CH_2CH_2OH$
Propan-2-ol (2-propanol)	C_3H_8O		OH | CH_3CHCH_3
Butan-1-ol (1-butanol)	$C_4H_{10}O$		$CH_3CH_2CH_2CH_2OH$`
Butan-2-ol (2-butanol)	$C_4H_{10}O$		OH | $CH_3CH_2CHCH_3$

Activity 4

To check your understanding, see if you can draw all the simple unbranched structural isomers for the alkanols mentioned below.

Tip: Follow the pattern in the table above, remembering to add the correct number of carbons in the chain for the main branch.

Alkanol isomers	Expanded structural formula
Pentanol	
Octanol	
Nonanol	

Remember: The definition of an isomer is that the compounds have the same molecular formula but different structural formulae.

Practice questions

1. An isomer is a compound with the same structural and molecular formula. True or false?
2. $CH_2{=}CHCH_3$ is the structural formula of an organic compound.
   (a) To which family does it belong, alkanes or alkenes? Explain your answer.
   (b) What is its molecular formula?
   (c) Draw its expanded structural formula.
3. Give both the molecular formula and expanded structural formula of butane.
4. How many more carbon atoms will decanol have than ethanol?

How am I doing?

	☺ **Easy** (Tick this box if you feel confident that you **understand this section well**)	**Fine** (Tick this box if you still **need a little work** on this section)	☹ **Difficult** (Tick this box if you still **need a lot of work** on this section)
Explain the difference between an alkane and an alkene			
Name, draw and represent the molecular structure of the first ten alkanols			
Define isomerism and give some examples of isomers			
Name, draw and represent the molecular structure of simple carboxylic acids			

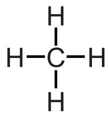
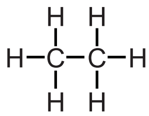
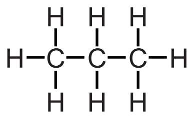
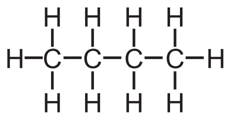
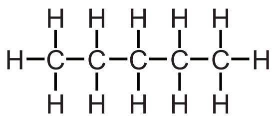
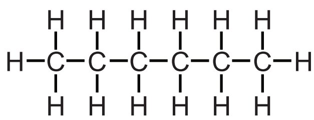
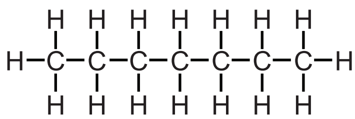
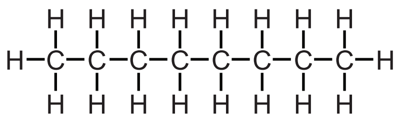
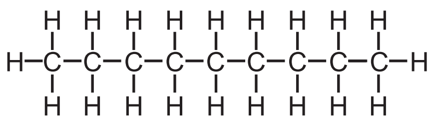
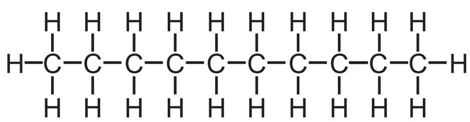
Notes on what to do next:

Signed (by Scholar): .... Date:..................

Signed (by Tutor): .... Date:..................

Answers

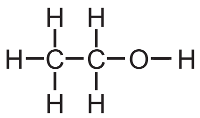
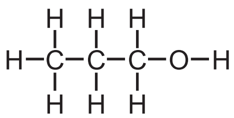
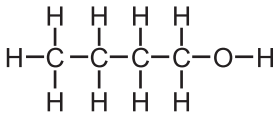
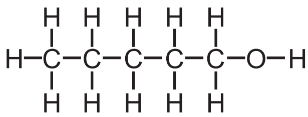
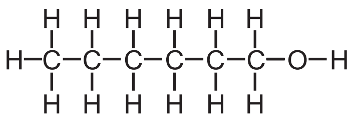
Activity 1

Alkane	Molecular formula	Structural formula	Condensed structural formula
Methane	CH_4		CH_4
Ethane	C_2H_6		CH_3CH_3
Propane	C_3H_8		$CH_3CH_2CH_3$
Butane	C_4H_{10}		$CH_3CH_2CH_2CH_3$
Pentane	C_5H_{12}		$CH_3CH_2CH_2CH_2CH_3$
Hexane	C_6H_{14}		$CH_3CH_2CH_2CH_2CH_2CH_3$
Heptane	C_7H_{16}		$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane	C_8H_{18}		$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
Nonane	C_9H_{20}		$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
Decane	$C_{10}H_{22}$		$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

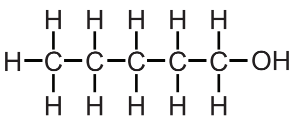
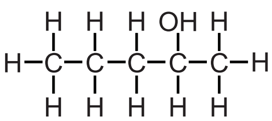
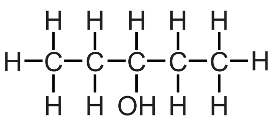
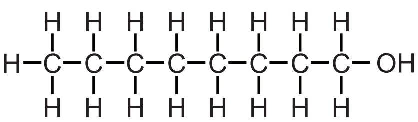
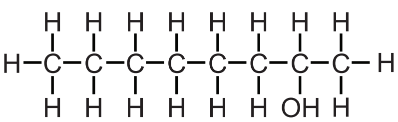
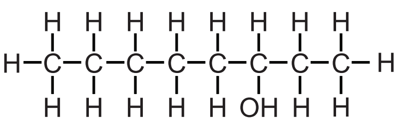
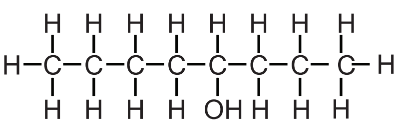
Activity 2

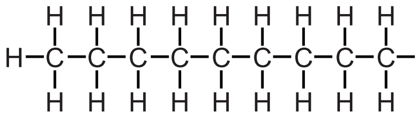
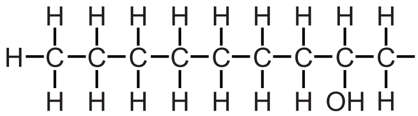
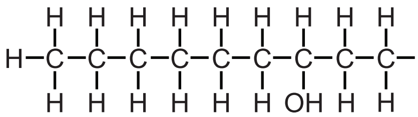
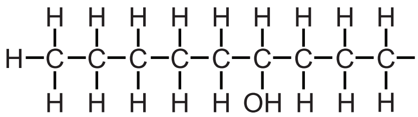
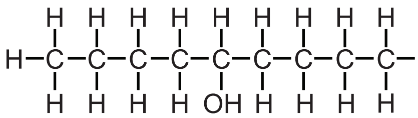
Propanol, butanol, pentanol, hexanol, heptanol, octanol, nonanol and decanol.

Activity 3

IUPAC Name	Molecular formula	Expanded structural formula	Condensed structural formula
Ethanol	C_2H_6O		CH_3CH_2OH
Propan-1-ol (1-propanol)	C_3H_8O		$CH_3CH_2CH_2OH$
Butan-1-ol (1-butanol)	$C_4H_{10}O$		$CH_3CH_2CH_2CH_2OH$
Pentan-1-ol (1-pentanol)	$C_5H_{12}O$		$CH_3CH_2CH_2CH_2CH_2OH$
Hexan-1-ol (1-hexanol)	$C_6H_{14}O$		$CH_3CH_2CH_2CH_2CH_2OH$

Activity 4

Alkanol isomers	Expanded structural formula
Pentanol	
1. Pentan-1-ol →	
2. Pentan-2-ol →	
3. Pentan-3-ol →	
Octanol	
1. Octan-1-ol →	
2. Octan-2-ol →	
3. Octan-3-ol →	
4. Octan-4-ol →	

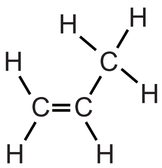
Alkanol isomers	Expanded structural formula
Nonanol	
1. Nonan-1-ol →	
2. Nonan-2-ol →	
3. Nonan-3-ol →	
4. Nonan-4-ol →	
5. Nonan-5-ol →	

Answers to practice questions

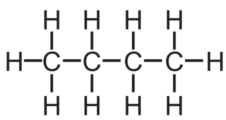
1. False. An isomer is a compound with different structural formulae but the same molecular formula.

2. (a) Alkenes because it has a double C to C bond (C=C).

   (b) C_3H_6

   (c) 

3. The molecular formula is C_4H_{10}.

   The expanded structural formula is: 

4. 8

MSCE S6:
Electricity and magnetism

What you are studying and why

Subject: Physical Science Unit S6

This is the sixth science unit for your MSCE revision.

At the end of this unit you should be able to:

1. describe the role of electrostatics in everyday life
2. calculate resistance in series and parallel circuits
3. explain the meaning of semiconductors.

Electrostatics

Not all electricity needs wires, plugs, cables, batteries or generators! Try this small experiment to prove it.

Activity 1

Rub a plastic comb against your sleeve and then try to pick up some light pieces of (tissue) paper, feathers or even hair. What happens? **Why** do you think this happens? Write down both a description and an explanation, trying to include a reference to **forces** if you can. If you can include how charges are involved that's even better.

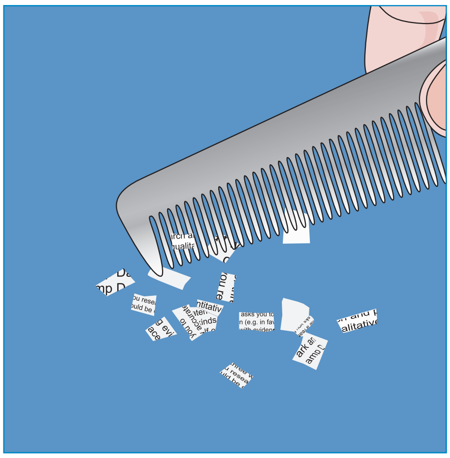


Figure 1

Description – what happens?

....

Explanation – why this happens.

....

....

....

....

....

You have just made some static electricity.

Static electricity is also called electrostatics and there is a big clue in both names about the nature and properties of it. If you guessed that it's to do with the idea of electricity staying still – or being static – you were right. We are more used to the idea of electricity being something that moves through wires and conductors, however, there are, in fact, two types of electricity: static and moving. The difference is a result of whether the charged particles are moving or not.

To put it very simply, static electricity is created by rubbing two materials together. To put it more scientifically, it's created by the frictional force acting on the subatomic particles of two materials which are brought into physical contact with each other. Friction causes electrons to be pulled off the atoms of one of the materials and deposited onto the surface of the other material, i.e. separated.

Remember, an electron is basically just a negative charge, therefore, it only has an extremely small mass. Static electricity is just a collection of charged particles that gather on the outside of objects or materials. These charges can induce or temporarily create other charges in objects that they are close to. This leads to small forces of attraction or repulsion which are responsible for all sorts of physical effects.

Stop and check!

Do you remember what an atom is?

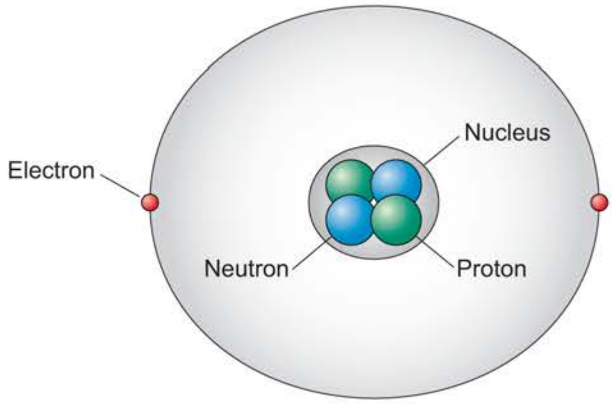


Figure 2

If the figure above doesn't refresh your memory then speak to your tutor about it before continuing.

Can you remember what the charges are on a proton and a neutron?

Well done if you said that the charge on a proton is +1 and a neutron has no charge, i.e. it is electrically neutral.

Activity 2

As you already know, electrons have a negative charge. You should be able to work out that there are two types of static electricity: positive and negative. Can you complete the table below, explaining whether electrons are added or removed to create each type?

Type of static electricity created	What happens to the electrons?
Negative, or -	Electrons ....
Positive, or +	Electrons ....

Electrostatic induction

Now, revisit your last answer to Activity 1 and consider any improvements you might want to make following what we have just discussed about electrostatic charges and forces. Then have a look at the model answer below and see how close you were. Underline any aspects of the answer you aren't sure about and discuss these with your tutor or other scholars.

Model answer for Activity 1

Description – what happens?
The small pieces of tissue move towards and then stick to the comb.

Explanation – why this happens.
This is because there is a small force of attraction between the tissue paper and the comb. The force is an electrostatic one created by the charges on the comb. Rubbing the comb has caused some electrons to be transferred.

The comb has an overall charge (we do not know if it is positive or negative – this depends on the type of plastic it is) but the paper is uncharged or neutral to begin with. The charge on the comb **induces** or creates a **temporary** and **opposite** charge in the paper, as the paper's electrons move around a tiny bit. These two sets of unlike charges – one on the paper and one on the comb – are attracted to each other, because **unlike charges attract**. The oppositely charged paper is lighter than the plastic comb, so it 'electrostatically' sticks to the comb.

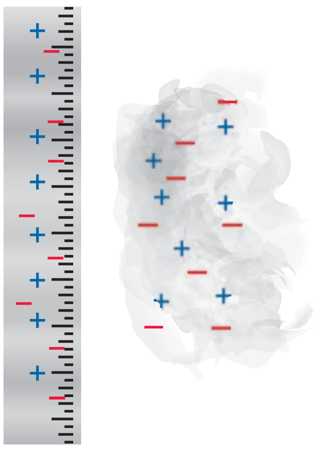


Figure 3

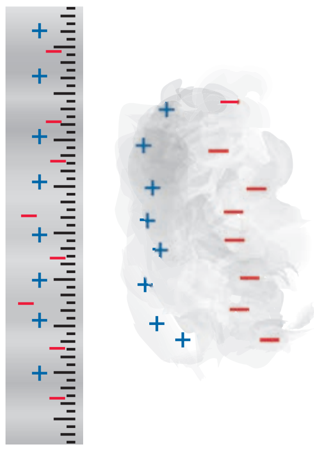


Figure 4

The figures on the previous page show how electrostatic induction would work if a ruler was negatively charged after it had been rubbed. Figure 3 is the charged ruler next to the neutral paper. Figure 4 shows how the negative charges or electrons have been repelled away from the surface of the tissue paper to leave an overall positive charge on the surface – now the tissue will be attracted to the ruler. How would you adjust the diagrams if the ruler was positively charged?

....

....

Remember: Unlike charges (or poles) ATTRACT and like charges (or poles) REPEL. This is the golden rule of electrostatics (and magnets)!

These principles of electrostatic attraction and repulsion are applied to useful effect in many ways. Photocopiers and paint sprayers are just two of the ways in which electrostatic forces are used, deliberately making paint or ink particles stick to objects. Electrostatic charges are also used in crop sprayers, capacitors and particle precipitators in power stations.

Activity 3

Match up the beginnings of these sentences about the application of electrostatics with the correct endings. The first one has been done for you.

People often become charged by walking on nylon or wool carpets but discharge themselves	create charged dust particles, which are then collected on the earthed plates.
In an electrostatic precipitator, strongly charged wires between the earthed plates	when they touch a metal handrail. Sometimes this process involves getting a small shock.
If a car body is earthed during spraying	a pattern of charge which is exactly the same as the printing on the original page, i.e. producing an electrostatic copy of the original.
In a photocopier the drum receives	are printed onto the paper as the drum rotates and presses against the copy paper.
Fine particles of powered ink (toner) are then attracted to the charged areas of the photocopier drum and	the paint droplets will be attracted onto the metal body, giving a more even coating and ensuring that the paint reaches even the most inaccessible places.

Tip: Remember that electrostatics always relies upon either the force of repulsion between like charges or the force of attraction between unlike charges. Friction usually creates these charges as a result of a rubbing action.

Electrical circuits

Turning our attention now to moving electricity rather than static electricity, imagine an electrical circuit you have experimented with in the past. When you think of this electrical circuit what comes to mind? As well as the physical objects like voltmeters, bulbs and switches, etc. that made up the circuit, you may also be thinking about the physical quantities that existed like current, voltage and resistance. Next, we will consider the idea of resistance and look at how to calculate total resistance in both series and parallel circuits. This section overlaps with the MSCE Unit 4 on Matter and Electricity.

Resistance – the basics

Resistance is a property that all electrical components have. It is how much the component **resists** or **restricts** the flow of current through it. It is measured in ohms (Ω) and its symbol is R. The bigger the resistance, the more the current flow is resisted; the smaller the resistance, the less current is resisted.

Try this thinking experiment. Imagine two water pipes, one thick and one thin. Which one will let the water flow most easily? If you answered the thick pipe, well done! Now imagine two metal wires, one thick and one thin. Which one will resist the flow of electrons (i.e. the current) the most? The answer is the thin one – we say that it has a higher resistance than the thick wire.

Stop and check!

Make sure you are happy with this summary of current and voltage before you continue – if not, discuss it with your tutor or fellow scholars.

Current and voltage (or potential difference) are two completely different things but they are related.

Current is a flow of charge. It is measured in amps (A), by an ammeter in series in a circuit. The symbol for current is I.

Voltage is a measure of how much energy is gained or lost by each unit of charge between two points. It is measured in volts (V), by a voltmeter in parallel in a circuit. The symbol for voltage is also V. You can think of it as a measure of the **electrical push** in the circuit.

Calculating total resistance

In a simple circuit with one resistor, Ohm's law is easy to apply. With any two of the three quantities, R, V and I, the unknown third quantity can be found.

Stop and check!

What can you remember about Ohm's law?

Ohm's law explains the relationship between voltage, current and resistance in a circuit. It says that voltage is equal to the product (or multiple) of current and resistance:

voltage = current x resistance

Or using the symbols, V, I and R:

$$V = I \times R$$

However, when you have multiple resistors, the first step before being able to use Ohm's law is to calculate the **total resistance**. There are two equations to use depending on whether you have series or parallel resistors.

Multiple resistors in series

In a series circuit, the same current flows through each resistor but the voltage across each resistor varies according to the resistance of the resistor. Have a look at the figure below to see this:

$I_T = I_{TOTAL}$ going into each resistor (current)

$V_T = V_{TOTAL} = V_1 + V_2 + V_3$ (voltage)

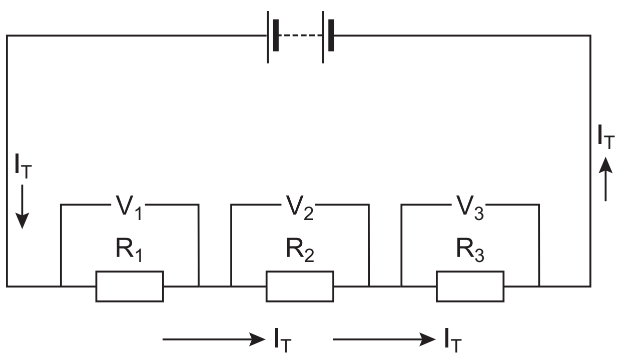


Figure 5

For **multiple series resistors** use this equation:

$$\mathbf{R_T = R_1 + R_2 + R_3 + \ldots\ldots\ldots}$$

(where R_T = total resistance in ohms, and R_1 = resistance of resistor 1, R_2 = resistance of resistor 2, R_3 = resistance of resistor 3, and so on).

Worked example

Let's try it out with an example. What is the total resistance in this simple series circuit?

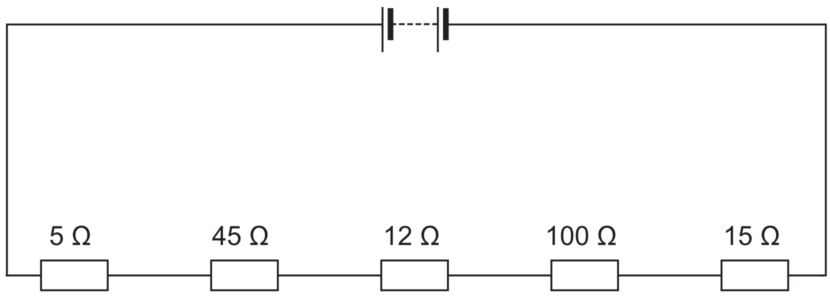


Figure 6

Looking at the circuit we can see that R1 = 5 Ω, R2 = 45 Ω, R3 = 12 Ω, R4 = 100 Ω and R5 = 15 Ω.

Substituting these values in the equation gives us:

$R_T = R_1 + R_2 + R_3 + R_4 + R_5$

$R_T = 5 + 45 + 12 + 100 + 15$

$R_T = 177\ \Omega$

Or in words, the total resistance in the circuit is 177 ohms. Looking at it another way, these three resistors could be replaced with one resistor of 177 Ω.

Multiple resistors in parallel

In a parallel circuit, the voltage across each individual resistor is the same; in fact, it is the same as the input voltage from the cell(s). What varies is the size of the current flowing through each resistor. Have a look at the figure below to see this.

I_{TOTAL} 'splits' into each resistor (current)

V_{TOTAL} is the same across each resistor (voltage)

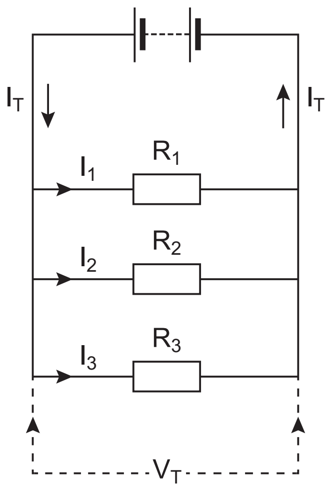


Figure 7

For **multiple parallel resistors** use the equation below. It is very similar to the equation for series resistors, except that we must add the **reciprocals** (i.e. one divided by the number) of the resistances together to give us the reciprocal of the total resistance.

$$\mathbf{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots}$$

(where, R_T = total resistance in ohms, and R_1 = resistance of resistor 1, R_2 = resistance of resistor 2, R_3 = resistance of resistor 3, and so on).

Worked example

Let's try it out with an example. What is the total resistance in this simple parallel circuit?

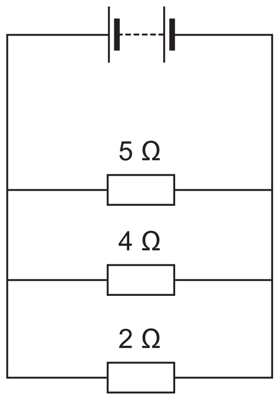


Figure 8

Looking at the circuit we can see that R1 = 5 Ω, R2 = 4 Ω, R3 = 2 Ω. Substituting these values in the equation gives us:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{5} + \frac{1}{4} + \frac{1}{2}$$

So, converting into decimals:

$\frac{1}{R_T} = 0.2 + 0.25 + 0.5$, or adding up the fractions directly: $\frac{(4 + 5 + 10)}{20}$

(if you aren't familiar with this method then speak to your tutor)

$$\frac{1}{R_T} = 0.95 \text{ (or } \frac{19}{20}\text{)}$$

$$R_T = \frac{1}{0.95} \text{ (or } \frac{20}{19}\text{)}$$

$$R_T = 1.05\ \Omega$$

Or in words, the total resistance in the circuit is 1.05 ohms. Looking at it another way, these three resistors could be replaced with one resistor of 1.05 Ω.

Go back and compare this with the total resistance in the series circuit. Even though the resistances are different in both examples, you should notice that in a series circuit the total resistance is larger because it is the **sum** of all of the separate resistors. In the parallel circuit, the total resistance is much smaller because it is the **reciprocal of the sum** of the separate individual resistors.

Semiconductors

Having considered static and conventional electricity in the last sections, we are now going to briefly conclude with a look at semiconductors.

An introduction to semiconductors

Electronic devices that use semiconductors are things like mobile phones and computers. Most semiconductors are based on the elements silicon or germanium. If you look up these elements in the periodic table (look back at MSCE Unit 1, Elements and chemical bonding,) you will see that they are in Group IV. At very low temperatures and high purities they are both insulators. By adding tiny amounts of other substances like phosphorus or boron, their conductivity can be significantly improved and this is how 'n-type' and 'p-type' semiconductors are created.

A crystal of pure silicon or germanium has a very regular structure of atoms. Every atom has four neighbours. Each atom shares its four outer electrons with its neighbours and this holds the crystals together, as shown in the figure below. At room temperature, these electrons can only move with difficulty, which explains why the conductivity is poor. Read on to find out how n-type and p-type semiconductors have improved conductivity.

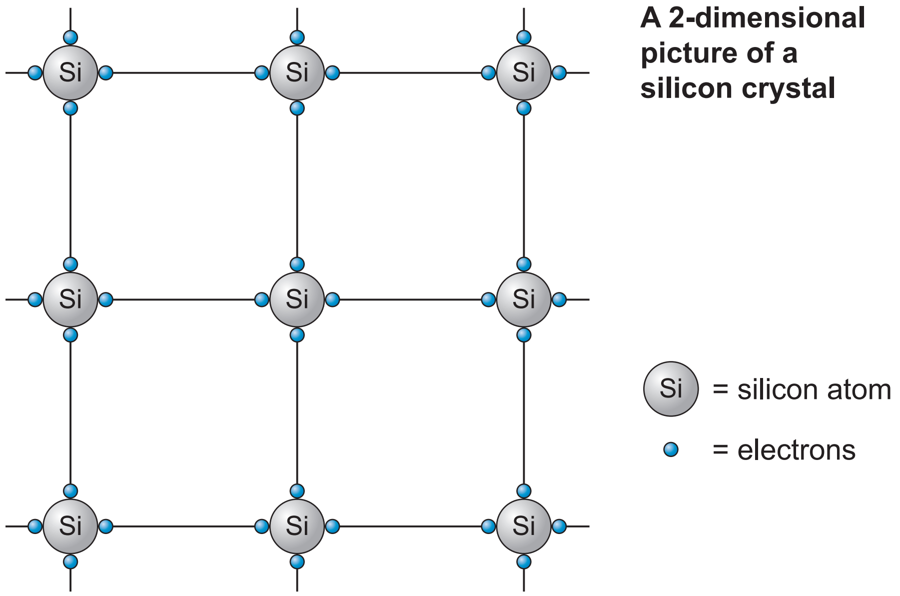


Figure 9

How do n-type semiconductors work?

A phosphorus atom has five outer electrons so one is 'spare'. By looking at Figure 10 you can see that this means for each phosphorus atom **doped** into the base semiconductor, an additional free electron is introduced, increasing the overall conductivity – more electrons, more conduction!

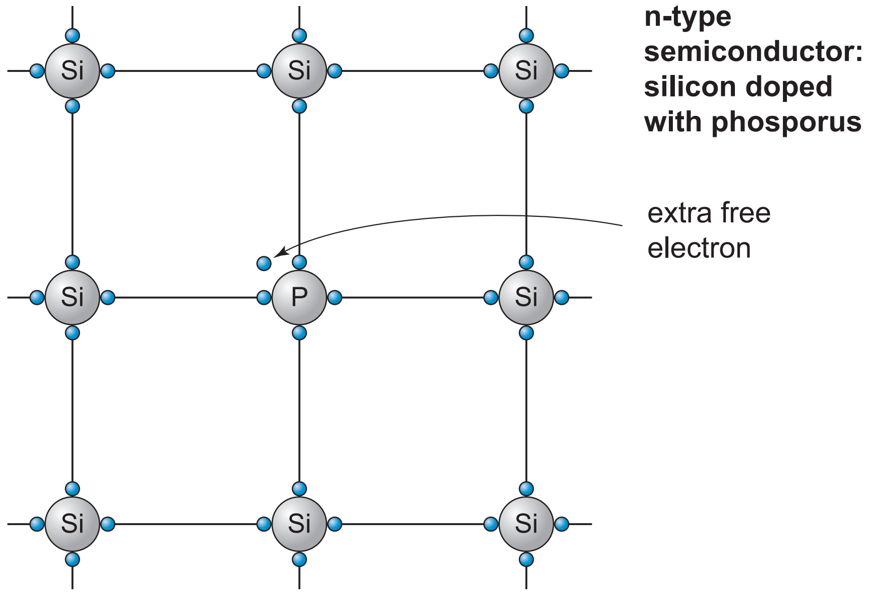


Figure 10

Important: It is called an 'n-type' because the free charge is a negative electron, not because it is negatively charged.

How do p-type semiconductors work?

By looking at the figure below you can see that for each boron atom added as an impurity to the semiconductor, a positive 'hole' is created, thereby increasing its conductivity. The positive hole arises because the boron atom has only three outer electrons. An electron from the surrounding silicon atoms moves into the gap, leaving behind another gap, and so on – the gap can 'move' through the silicon, 'conducting' as it goes.

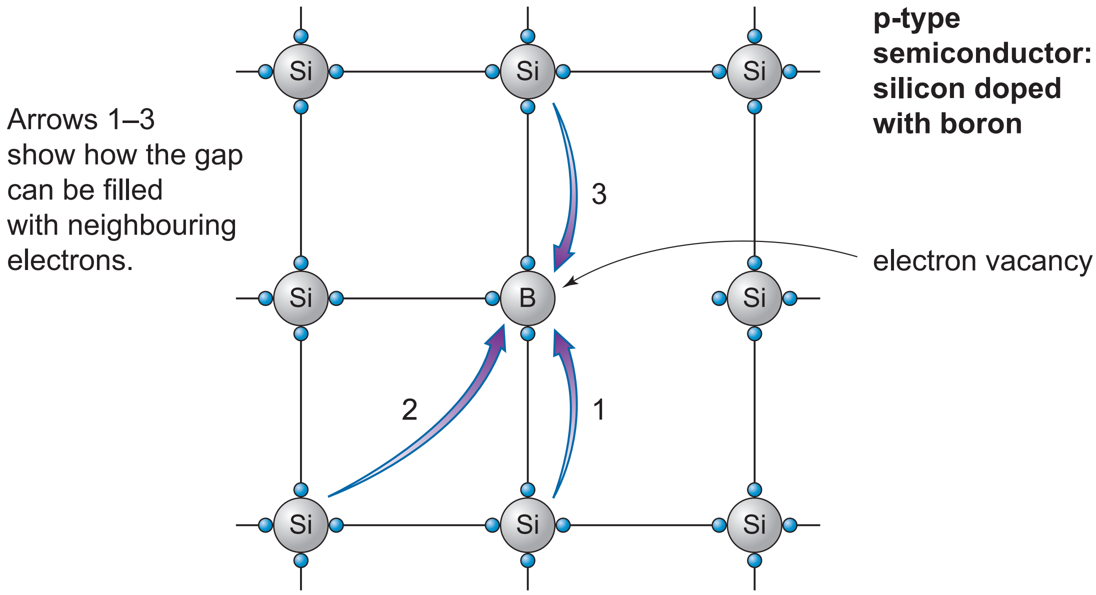


Figure 11

Important: It is called a 'p-type' because the free charge is a positive hole, not because it is positively charged.

Give yourself 30 seconds thinking time before you answer this question.

What would happen to the conductivity if the temperature of a semiconductor was increased?

If the temperature of a semiconductor was increased, ...

....

because ....

Yes, that's right, the conductivity would increase because the electrons have more kinetic energy. (This is, in fact, how thermistors work.)

Activity 4

This is a very open-ended, reflective activity. There aren't any right or wrong answers but you should discuss your final version with your tutor and fellow scholars during a suitable opportunity.

Phase 1: To get you reflecting on your learning.
Based only on what you have just read about semiconductors, list **any** plus or minus points about your learning in the relevant boxes below. Then list anything that's interesting (but not really a plus or a minus) in the final 'Interesting' box. You can also add comments about **how** you learned.

Plus	**Minus**
Interesting	

Phase 2: To link your learning back to the textbook knowledge.
Now use your textbooks (or other notes) to update the boxes with any additional information (i.e. factual knowledge) that you feel is appropriate to support your thinking, understanding and knowledge of semiconductors.

Practice questions

1. There is only one type of electrostatic charge. True or false?
2. Voltmeters measure in parallel and ammeters measure in series. True or false?
3. An n-type semiconductor is impregnated with boron. True or false?
4. A thermistor is a semiconductor whose resistance depends on the temperature. True or false?
5. A photocopier is not an example of an application of electrostatics. True or false?
6. Calculate the total resistance in the circuit below:

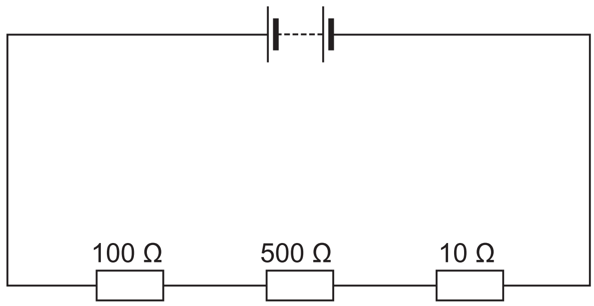


Figure 12

7. Calculate the total resistance in the circuit below:

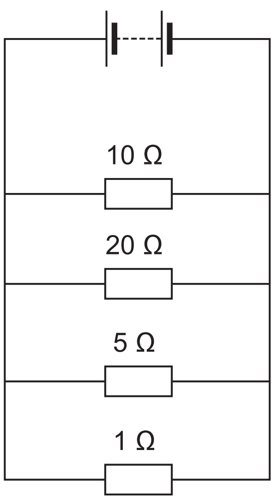


Figure 13

How am I doing?

	☺ **Easy** (Tick this box if you feel confident that you **understand this section well**)	**Fine** (Tick this box if you still **need a little work** on this section)	☹ **Difficult** (Tick this box if you still **need a lot of work** on this section)
Describing the role of electrostatics in everyday life			
Calculating resistance in series and parallel circuits			
Explaining the meaning of semiconductors			

Notes on what to do next:

Signed (by Scholar): .... Date:...................

Signed (by Tutor): .... Date:...................

Answers

Activity 1

Model answer for Activity 1 provided on page 325.

Activity 2

Negative	Electrons added
Positive	Electrons removed

Activity 3

People often become charged by walking on nylon or wool carpets but discharge themselves	create charged dust particles, which are then collected on the earthed plates.
In an electrostatic precipitator, strongly charged wires between the earthed plates	when they touch a metal handrail. Sometimes this process involves getting a small shock.
If a car body is earthed during spraying	a pattern of charge which is exactly the same as the printing on the original page, i.e. producing an electrostatic copy of the original.
In a photocopier the drum receives	are printed onto the paper as the drum rotates and presses against the copy paper.
Fine particles of powered ink (toner) are then attracted to the charged areas of the photocopier drum and	the paint droplets will be attracted onto the metal body, giving a more even coating and ensuring that the paint reaches even the most inaccessible places.

Answers to practice questions

1. False
2. True
3. False
4. True
5. False
6. 610 ohms
7. 0.74 ohms (2dp)

MSCE S7:
Waves and radiation

What you are studying and why

Subject: Physical Science Unit S7

This is the seventh science unit for your MSCE revision.

At the end of this unit you should be able to:

1. describe a wave
2. explain the characteristics of waves
3. differentiate between transverse and longitudinal waves
4. apply the wave equation in problem solving
5. distinguish between a converging and diverging lens.

Waves – the basics that you need to know

You are probably used to the term 'waves' in an everyday context, for example, sea waves, waving with your hands or perhaps even radio waves. However, in physics it has a particular meaning: a wave is a **vibration or oscillation that transfers energy from one place to another**. There are two types and you need to know about both.

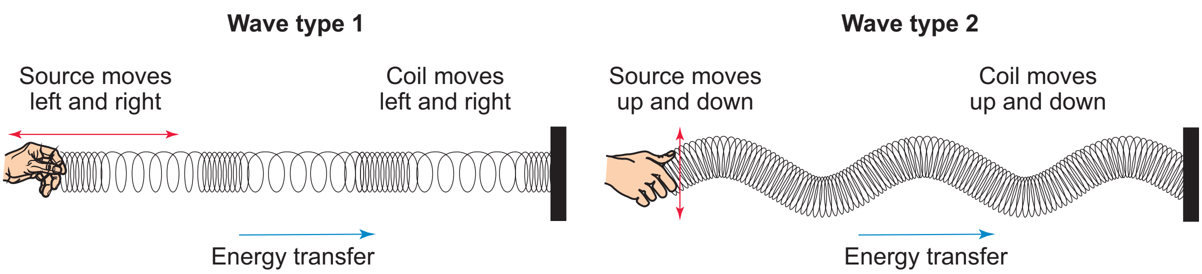
In a **longitudinal** wave the energy is transferred in the same direction as the vibration.

In a **transverse** wave the energy is transferred at right angles to the direction of the vibration.

Light, sound, radio and earthquake waves are some examples of waves in physics – what they have in common is that they all transfer some form of energy from one place to another, and are caused by vibrations or oscillations. Most waves are transverse waves – sound is the only main longitudinal wave.

Activity 1

After reading the descriptions of longitudinal and transverse waves above, see if you can correctly label each type of wave below. You'll find the answers at the end of the unit.



The subsequent direction of motion of individual particles of a medium is the same as the direction of vibration of the source of the disturbance.

Figure 1

Try this experiment. If you have a long spring, chain or rope, see if you can try to make transverse and longitudinal waves for yourself. If you put your hands at the end of the spring, for each wave, you should be able to feel the energy from the original vibration. Try it out!

Now try this thinking experiment. Imagine you are a particle in the springs in the figure above. For each type of wave, how would the energy affect you as it travels down the spring? Would you move or stay still? If you think you do move, what type of movement would you experience?

Activity 2

Give yourself 30 seconds' thinking time before you answer this question.

1. What happens to the particles in the spring as the energy is transferred through a longitudinal wave?

   In a longitudinal wave, as the energy travels through the spring, each particle vibrates:

   ....

Give yourself one minute of thinking time before you answer this second question.

2. What happens to the particles in the spring as the energy is transferred through a transverse wave?

   In a transverse wave, as the energy travels through the spring, each particle vibrates:

   ....

If you have a look at Figure 2 you can check your own answers to the questions above. Or, if you prefer, you can peer review with your fellow scholars before looking at the answers at the end of the unit.

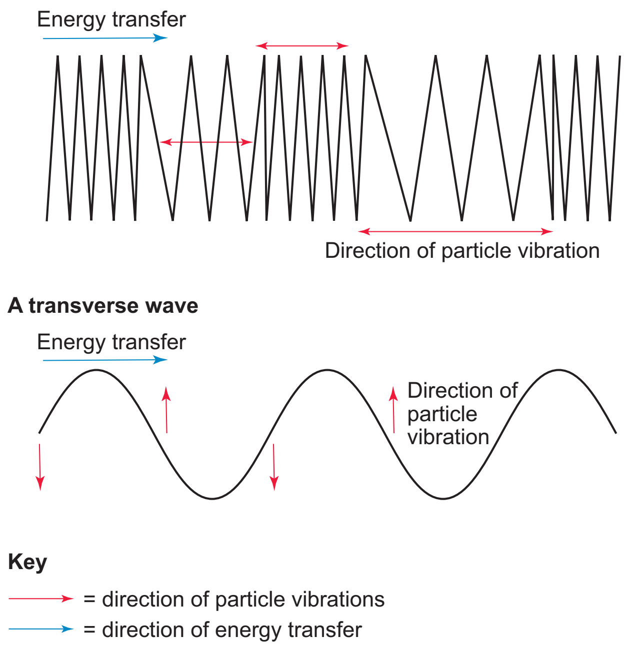


Figure 2: Energy transfer and vibration direction in longitudinal and transverse waves

Important: The particles in the rope or spring do not move through the spring or rope – they vibrate around a fixed position as the wave energy passes through them. It is the energy that is transferred, not the matter through which it travels.

How can we describe waves?

Before we can go on we need to know how to describe waves scientifically, so this next section will explain the main features of a wave. We will do this by using the diagram of a transverse wave below, as these wave types are the most common and show the features we need to know about most clearly.

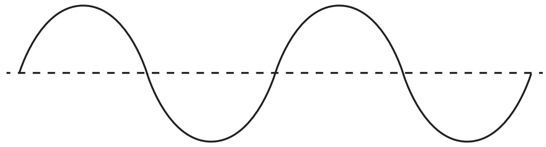


Figure 3: Simple transverse waveform

What do you notice about the wave shape? As you can see the wave is a smooth curve arranged in a repeating series of peaks (or crests) and troughs. This shape of wave is a sine wave – you might already be familiar with the term from your mathematical studies. You can have square waves, sawtooth waves or even triangular waves, but we only need to know about sine waves.

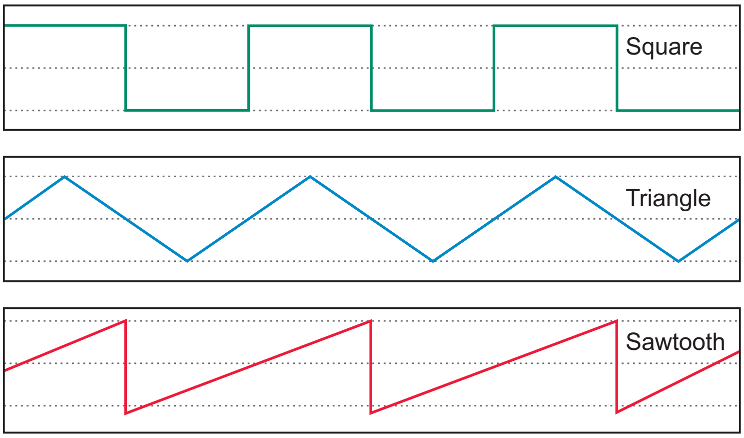


Figure 4: Other wave shapes

Imagine you had to describe the wave in Figure 3 to someone who couldn't see it. What sort of features would you need to talk about for the waveform to be fully described? You would need to talk about:

1. the height of the crests and troughs
2. the distance from one crest to the next crest (and the same for one trough to the next trough)
3. possibly, how far apart one crest and the next trough are.

Using Figure 5 below, let's consider each of these features in more detail, and define some of the terminology you will need to know and use when dealing with waves.

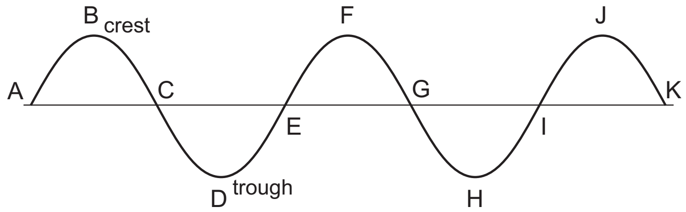


Figure 5: Features of a wave

1. As the line AK passes through the middle of the waveform, the vertical height of each crest and trough is the same. This height is called the **amplitude**. Amplitude is a scalar quantity and can be measured in mm, cm, m or km but the SI unit is metres. It is given the symbol 'a'.
2. The distance separating two consecutive crests (or troughs) is called the **wavelength**. This is the same distance as the horizontal distance from point A to point E in Figure 5. Wavelength is a scalar quantity and is measured in mm, cm, m or km but the SI unit of measurement is metres. It is given the symbol 'λ', or lambda, which is the Greek letter 'l'.
3. In fact, because the wave is a repeating series, the wavelength is the distance between any point and the next point along the wave where the pattern repeats. The horizontal distance from one peak to the next trough is half a wavelength.

Activity 3

For Figure 5, which of the following statements are true?

Statement number	Assertion	Tick if true
1	The horizontal distance A–C–E is equal to the amplitude of the wave.	
2	The vertical distance J–K is equal to the wavelength of the wave.	
3	The vertical distance B–C–D is twice the amplitude of the wave.	
4	The horizontal distance E–G–I is equal to the wavelength of the wave.	

To summarise and secure your understanding so far, see Figure 6 on the next page. This shows amplitude as either the vertical distance from point J (crest) to line AK, which we will call J–K, or the vertical distance from point H (trough) to line AK, which we will call H–I. The wavelength is represented by either the horizontal distance A–E or F–J.

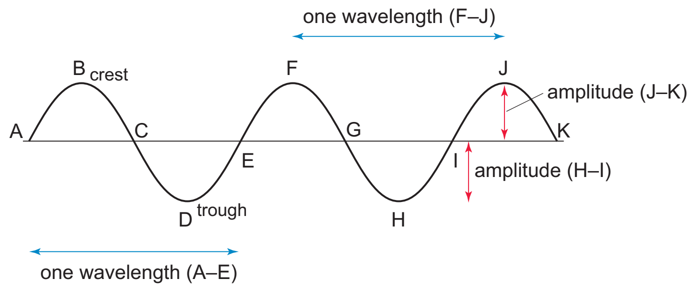


Figure 6: Features of a wave

Considering another characteristic of waves: frequency

The number of complete waves or oscillations produced each second is called the **frequency** of the wave and it is given the symbol 'f'. The SI unit of frequency is hertz (Hz). Let's think this idea through:

Consider a vibration or oscillation that occurs 50 times every second. The wave produced would have a frequency of 50 Hz.

If the number of vibrations increased to 150 times every second, then the wave would have a frequency of 150 Hz.

Say the number of vibrations decreased and only one oscillation was produced in one second, then the frequency would be 1 Hz.

Higher frequencies are measured in multiples of hertz, usually using the prefixes of 'kilo' or 'mega' to create units of kilohertz (kHz) or megahertz (MHz). As a quick check, can you work out how many hertz there are in:

1. 1 kHz
2. 1 MHz?

Hopefully you worked out that 1 kHz = 1000 Hz (or 10^3 Hz) and 1MHz = 1,000,000 Hz (or 10^6 Hz).

Stop and check!

If you struggled with this quick-check question, it may mean you do not remember your standard prefixes for units. If this is the case, ask you tutor to explain these to you.

Link back to prior knowledge

Although the prefixes in organic chemistry (see MSCE Unit 5, Organic chemistry, page 268) are individually different, the idea behind their use is similar to the use of prefixes in physics.

The wave equation

Waves take time to travel. The equation that allows us to calculate the speed of a wave is:

$$\text{speed (m/s)} = \frac{\text{distance the wave travels (m)}}{\text{time taken (s)}}$$

Or in symbols, where v = speed:

$$v = \frac{d}{t}$$

> **Link back to prior knowledge**
>
> You have used this equation in MSCE Unit 2, Forces and Motion, page 67.

There is another equation that links the speed of a wave, its frequency and its wavelength. Let's work it out by thinking about an example.

Imagine that a wave is travelling at 5 m/s and has a frequency of 5 Hz. In one second the wave would have travelled 5 m. In this same time, one second, five wavelengths would have been produced. So the total distance for five wavelengths is 5 m. This means that the distance for one wavelength would be 5/5, i.e. 1 m. In other words, the wavelength would be 1 m.

If the wave's frequency changed to 50 Hz, at the same speed, in one second 50 wavelengths would be produced and the total distance covered would be 5 m. So for 50 wavelengths to measure 5 m, one wavelength would have to measure 5/50, or 0.1 m.

If the wave's frequency changed to 10 Hz and had a speed of 5 m/s, in one second ten wavelengths would be produced and the total distance covered would be 5 m. So for ten wavelengths to measure 5 m, one wavelength would have to measure 5/10, or 0.5 m.

As you should be able to see, the wavelength depends on frequency and speed. In other words, the wavelength is equal to the speed of the wave divided by the frequency of the wave. This relationship is known as the wave equation:

wavelength = speed/frequency

Or mathematically:

$$\lambda = \frac{v}{f}$$

The equation is usually re-arranged to this:

$$v = f\,\lambda$$

Tip: Learn this formula!

Activity 4

1. If sound waves have a wavelength of 200 m at a frequency of 75 Hz, what is their speed?
2. If radio waves have a wavelength of 1000 m and travel at a speed of 3×10^8 m/s, what is their frequency?
3. Calculate the wavelength of microwaves travelling at 3×10^8 m/s with a frequency of 3×10^9 Hz.

Light

Light is most certainly something you are very familiar with already! But what do you know about it in a scientific sense? This next section will introduce you to some of the scientific ideas about light that you need to be aware of.

Light is an electromagnetic wave. It is the visible part of the electromagnetic spectrum and like all other electromagnetic waves it has the following properties:

- it is a transverse wave
- it has a speed of 3×10^8 m/s*
- it travels in straight lines
- it can travel through a vacuum.

(*This is the **speed of light in air or through a vacuum**. Nothing in the known universe travels faster than the speed of light.)

As an aside, can you think of any other electromagnetic waves? If not, Figure 7 should help refresh your memory.

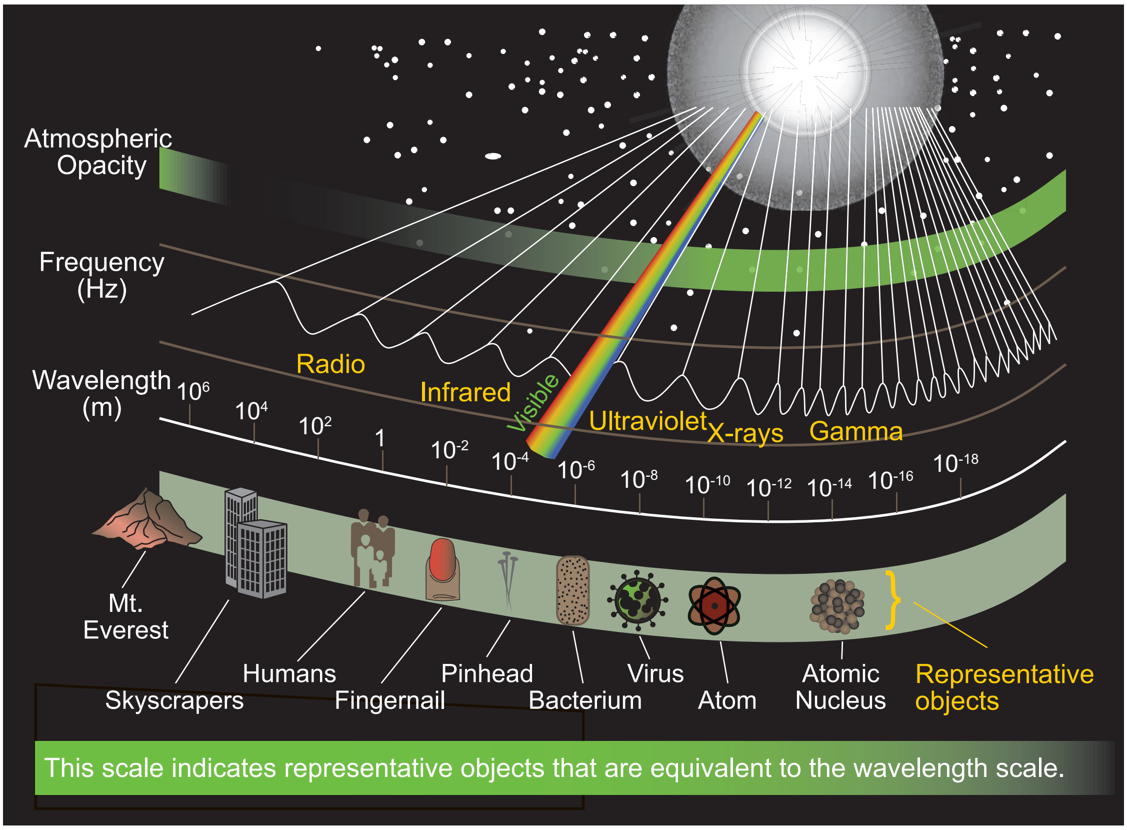


Figure 7: The electromagnetic spectrum

Lenses

Magnifying glasses or lenses have been used for centuries – they were even well known to the ancient Greeks. Anyone who wears spectacles is using lenses to see in comfort. Lenses are also used in cameras, projectors, microscopes and telescopes.

Although there are many different types, we are only going to look very briefly at the two main types of lenses – converging and diverging lenses.

Converging lenses

Converging lenses are also known as **convex** lenses. Convex lenses are used to magnify an image. Figure 8 shows how a convex lens refracts light rays.

Diverging lenses

Diverging lenses are also known as **concave** lenses. Concave lenses are used to give a diminished image. Figure 8 shows how a convex lens refracts light rays.

As you will be able to see from Figure 8 below, converging lenses essentially focus rays from infinity so that they intersect at a common point. A diverging lens bends rays from infinity so that it seems that they originate from the same point. In either case, we refer to the point of convergence or divergence as the focus of the lens, or the focal point (F).

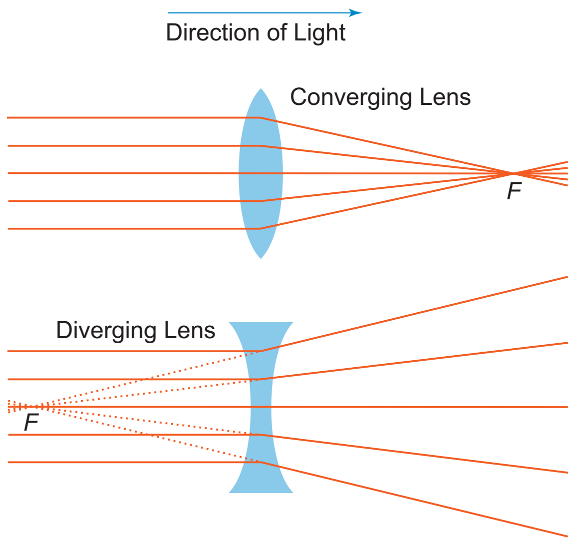


Figure 8: Converging and diverging lenses

Practice questions

1. A student moves the end of a spring from side to side 15 times per second. The wavelength of the wave is 4 m. With what speed do the waves move along the spring?
2. If sound waves have a wavelength of 12 m and a speed of 300 m/s, calculate their frequency.
3. A large weight is dropped into a tank of water. The water waves created travel at a speed of 3 m/s and have a frequency of 12 Hz. What will their wavelength be?
4. A converging lens reflects the light into a magnified image. True or false?
5. Light can travel at different speeds. True or false?

How am I doing?

	☺ Easy (Tick this box if you feel confident that you **understand this section well**)	Fine (Tick this box if you still **need a little work** on this section)	☹ Difficult (Tick this box if you still **need a lot of work** on this section)
Describing a wave			
Explaining the characteristics of waves			
Differentiating between transverse and longitudinal waves			
Applying the wave equation in problem solving			
Distinguishing between a converging and diverging lens			

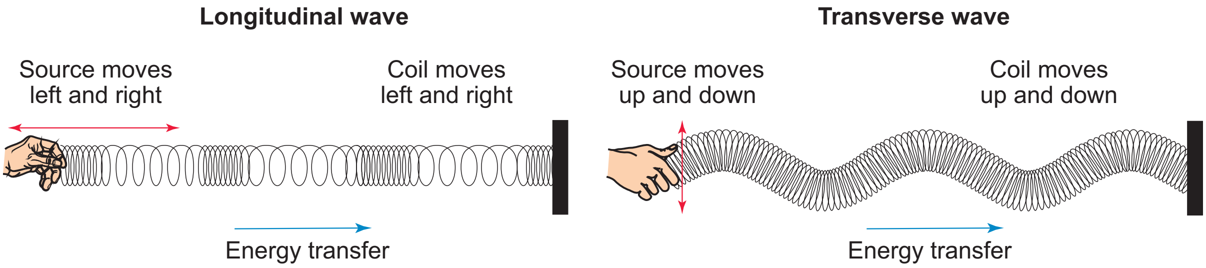
Notes on what to do next:

Signed (by Scholar): .... Date:..................

Signed (by Tutor): .... Date:..................

Answers

Activity 1



The subsequent direction of motion of individual particles of a medium is the same as the direction of vibration of the source of the disturbance.

Activity 2

1. In a longitudinal wave, as the energy travels through the spring, each particle vibrates around a fixed point in the direction of the energy transfer.
2. In a transverse wave, as the energy travels through the spring, each particle vibrates around a fixed point at right angles to the direction of the energy transfer.

Activity 3

Statement Number	Assertion	Tick if true
1	The horizontal distance A–C–E is equal to the amplitude of the wave	X
2	The vertical distance J–K is equal to the wavelength of the wave	X
3	The vertical distance B–C–D is twice the amplitude of the wave	√
4	The horizontal distance E–G–I is equal to the wavelength of the wave	√

Activity 4

1. 15×10^3 m/s (or 15,000 m/s)
2. 3×10^5 Hz (or 300,000 Hz)
3. 0.1 m

Answers to practice questions

1. 60 m/s
2. 25 Hz
3. 0.25 m
4. False – a converging lens **refracts** the light into a magnified image.
5. False.

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