Module 4

UNDERSTANDING ELECTRICITY AND MAGNETISM

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Introduction

What is electricity?

In today's world we grow up in an environment where electrical power is everywhere around us and we sometimes accept this unquestioningly ... we take it for granted.

6 a.m. Another weekday. The clock-radio blares, but you lie in bed a few minutes longer, listening to the news and weather and gathering energy to face the day. Turn on the light, start the coffee, wake the children, shower and dress. Eat a piece of toast, maybe some cereal. Brush your teeth, feed the cat, turn on the answering machine, and out the door to work. By 7 a.m. you're on your way to another busy day.

We are comfortable with the fact that when we flick the switch on the wall the light in the room comes on, or when we turn the key in the car ignition switch the motor turns over and bursts into life. So many things around us today use this form of energy from torches to stereo hi-fi systems, from microwave ovens to computers, from lighting and heating to telephone and radio communications; the list is almost endless. We have also felt the uncomfortable sensation of getting out of a car on a cold (dry) day where we get zapped as we reach to close the door, or heard the crackle as we take off an article of clothing (particularly jumpers) that contain synthetic fibres (possibly even seen the sparkler effect it sometimes produces if the lights are off in a dark room when this is done). This is in fact the discharge of charges due to a path of low resistance being provided between two charged bodies at different potentials. These terms and the process will be explained now in more detail.

Let us then explore the phenomena related to electrical energy with the various characteristics, and applications.

4.1 Static electricity – electricity at rest

From your study of module 2 you will be very familiar with the force of gravity, but this is not the only force we experience. We have all experienced synthetic clothes clinging to us; our hair standing on end on a dry day; a magnet clinging to your refrigerator door, easily overcoming the gravitational force that the entire earth, pulling down, exerts on it. These natural forces of attraction or repulsion have nothing to do with gravity; these are electrical phenomena.

The Ancient Greeks observed that when 'elektron' (amber) was rubbed with fur, the amber could attract light objects such as dust particles, cork and straw. The amber is said to be **'electrified'**, with electric charge. The electric charge is carried by subatomic particles.

Two types of electrification, or electric charge, exist. Some simple experiments show that there are, in fact, two kinds of electrical charge. If you run two plastic combs through your hair, the force between them will be repulsive: they will be pushed apart. If you take one of those combs and bring it near a piece of glass that has been rubbed with fur, the objects experience an attractive force: they will be pulled together. Benjamin Franklin in the eighteenth century, named the different types of charges, positive (+) and negative (–).

Part 3 of the course video *Everyday Matters – Preparatory Physics* shows a demonstration of some of the classical early experiments with electricity.

4.1.1 Electric charge

We have already seen in module 3 that fundamental particles which make up atoms, carry these charges. To explain further in the most simple model of the atom (refer to module 3) we have a positively charged nucleus surrounded by negatively charged electrons. An object is said to be electrically charged if electrons are added to or removed from it. So an object is said to be positively charged when electrons are removed from it and negatively charge when they are added. Charged atoms are called ions.

The SI unit of charge is the Coulomb (C). A proton possesses a charge of $+1.6 \times 10^{-19}$ C. An electron possesses a charge of -1.6×10^{-19} C.

In 'normal' atoms, the number of negative charges (electrons) is equal to the number of positive charges (protons). These charges cancel and the atom as a whole is electrically neutral. If an electron is removed from a normal atom, a surplus of positive charge results and the atom becomes positively charged. If an electron is added to a normal atom, a surplus of negative charge results, and the atom becomes negatively charged.

Different types of atoms and molecules have different affinities for electrons. If we bring two different atoms or molecules together, electrons from one can move to the other, producing two charged 'ions'. This is the process responsible for the charge produced on amber when it is rubbed with fur. This can be demonstrated using a plastic comb, rubbed with a cloth containing synthetic fibres. The comb can attract to it the small paper waste circles emptied from a paper punch. (Notice also how a nylon brush will attract strands of your hair after brushing a short while.)

Home experiment: charge and carry

Introduction

Are you tired of electrostatic experiments that just won't work? This experiment will produce a spark that you can feel, see, and hear. You rub a styrofoam plate with wool to make a large electric charge. Then you use the charged styrofoam to charge a metal pie pan. After charging the styrofoam once, you can charge the metal pie pan several times. The charge on the pie pan is portable, and can be used for many electrostatic experiments. The entire apparatus for charging the aluminium plate is called an electrophorus, which is Greek for charge carrier.

Materials

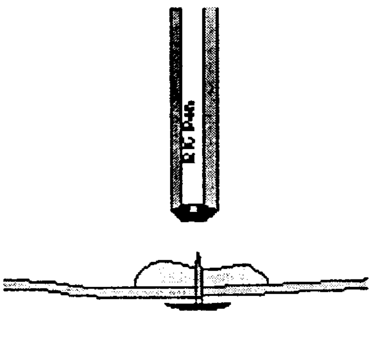
For the electrophorus, you will need:

- Styrofoam dinner plates (acrylic plastic sheets also work well, as will old LP records)
- Wool rag (other fabrics may work, but wool will definitely work)
- Disposable aluminium pie plates
- Plastic ballpoint pen (or equivalent)
- Pair of pliers
- Thumbtacks
- Hot glue gun or a pencil with an eraser.

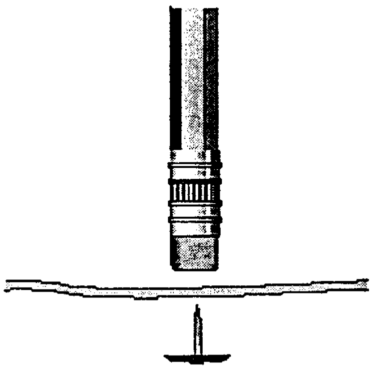
Assembly

Electrophorus

Make an insulating handle for the pie pan. Use the pliers to remove the pen point and ink supply from the pen. Hold the pen body so that the pen would stick up through the centre of the pie, if the pie pan were filled with pie. Attach the pen body to the aluminium pie pan with the thumbtack and hot melt glue. Push the thumbtack up through the centre of the pan then coat it with hot glue and jam the pen body down on top of it (diagram follows).



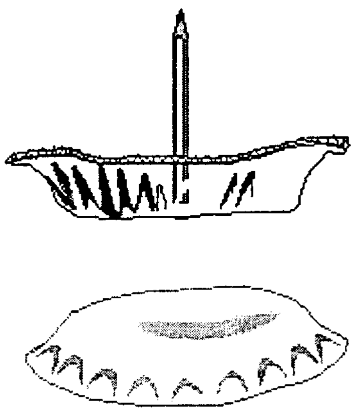
Insulating handle using a Bic pen



Insulating handle using a pencil

As a fast alternative to hot glue and a pen body, you can push a thumbtack through the bottom of the pie pan and into the eraser of a pencil (diagram above right). Try to avoid hitting the graphite in the centre of the pencil with the metal of the thumbtack.

Place the pie pan on top of an upside down styrofoam plate (or a piece of acrylic plastic.)



To do and notice

Rub the styrofoam plate with the wool rag. If this is the first time you are using the styrofoam in an electrostatic experiment rub it for a full minute.

To charge the pie pan follow the next steps exactly:

- Place the metal pie pan on top of the charged styrofoam plate.
- Briefly touch the metal pie pan with your finger. You may hear a snap and feel a shock.
- Remove the metal pie pan using only the insulating handle.

The pan is now charged.

Discharge the pan by touching it with your finger. You will hear a snap, feel a shock, and, if the room is dark, see a spark. You can also discharge the pie pan through a neon glowtube. Hold one of the two metal leads of the tube in your fingers and touch the other lead to the pie pan. The electric spark will go through the neon and make a flash that is easily visible.

- What would you expect the result to be?

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  ____

  ____

- Detail accurately what methods you used.

  ____

  ____

- Record your observations:
  - ______________________________________

    ____
  - ______________________________________

    ____

- How could the experiment be improved?

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  ____

  ____

- Explain the (charge and discharge) process involved:

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- Is there a limit to the amount of charge that can be stored?

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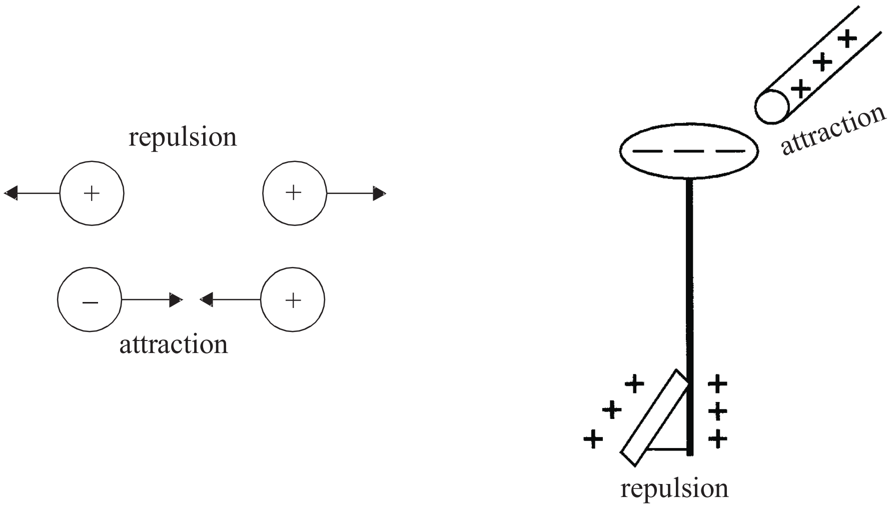
If we have a charged object, we find that it can produce forces of attraction or repulsion on other charged objects. The French physicist Charles Coulomb (1736–1806) first wrote down the law that describes forces between electric charges:

'Like' charges repel each other, 'unlike' charges attract.

Figure 4.1



(see example in video)

Thus, two positive charges repel each other and two negative charges repel each other but, a positive charge and a negative charge attract each other. This can be seen when combing or brushing your hair on a dry day. The action of the teeth or bristles rubbing through the hair causes an exchange of electrons resulting in the comb and the hair being oppositely charged. So the hair tends to be attracted to the comb or brush. Also note that as the hair strands are similarly charged they tend to repel one another and thus stand apart which is the same as occurs in an Electroscope. This is depicted clearly in the video, where you can see the gold leaf rising away from the vertical electrode because the gold leaf is charged positively compared with the positively charged electrode.

4.1.2 Forces between charges – Coulomb's Law

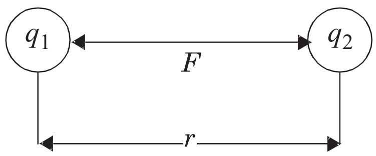
How do we quantify the force between charges and how is its value dependent on the amount of the charges, etc.? Coulomb investigated just these questions, he described his result in words and then transformed it into a formula.

Coulomb stated ...

Between any two charged objects is a force proportional to the size of the two charges, divided by the square of the distance between them.

This is called Coulomb's Law.

Figure 4.2



F positive = repulsion

F negative = attraction

In order to develop the formula, suppose that two point charges, q_1 and q_2, are a distance r apart in vacuum. If q_1 and q_2 have the same sign, the two charges repel each other; if they have opposite signs, then they attract each other. The force experienced by one charge due to the other is called a Coulomb force and is given by Coulomb's law,

$$F = k\frac{q_1\, q_2}{r^2}$$

The constant k here has an approximate value of 9.00×10^9 $\mathrm{Nm^2C^{-2}}$.

As always in the SI system, distances are measured in meters, and forces in newtons. The SI unit for charge q is the coulomb (C).

Note the similarity of the above formula with that for the force of gravitation discussed previously in module 2 (see the example problem later). In this instance, however, it is possible to have a repulsive force.

Coulomb's Law describes the force between electrical charges that do not move – static electricity. Electrostatic forces dominate the world as we know it. Plus attracts minus in chemical bonds, and thus holds materials together. Every object you see is made from atoms, themselves collections of negative electrons attracted to positive nuclei. Just as the gravitational force keeps the earth and planets in orbit around the sun, an electrostatic force keeps negative electrons in orbit around the positive nucleus of an atom.

The repulsion of electrons by electrons, on the other hand, keeps on object from passing through another. You can't put your hand through this book, for example, because electrons in atoms in your hand are repelled by electrons in atoms in the book. You don't fall through the floor, because electrons in your shoes repel electrons in the floor. Everytime you touch or feel something, you are making use of the electrostatic force. These forces between charges can act even across empty space, which can be confusing, i.e. we generally consider that if we want to move something, we have to go across and make 'contact' with it and push or pull it. (This force appears very similar to that experienced with magnets which will be discussed in a later section.)

Now consider the following example problems:

Example 1:

If two equal charges of 1C each were separated in air by a distance of 1 km, what would be the force between them, given that the constant k for air is approx. 9×10^9 Nm^2 C^{-2}?

Solution:

By substituting the given values into the formula $F = \frac{kq_1 q_2}{r^2}$ gives ...

$$F = \frac{9 \times 10^9 \times 1 \times 1}{1000^2}$$
$$= 9000 \text{ N}$$

Would this force be one of attraction or repulsion?

This force would be a repulsive force because like changes repel, therefore the resultant force has a positive sign.

Example 2:

Find the ratio of the Coulomb electric force F_e and the Gravitational force F_g between two protons in a vacuum. Assume their charge to be 1.6×10^{-19} C and their mass to be 1.67×10^{-27} kg. ($k = 9.0 \times 10^9$Nm^2/C^2).

Solution:

From Coulomb's law and Newton's law of gravitation,

$$F_e = \frac{kq_1 q_2}{r^2} \quad \text{and} \quad F_g = \frac{Gm_1 m_2}{r^2}.$$

Now, since the two masses are the same we can write $m_1 = m_2 = m$. Similarly, since the two charges are the same we can write $q_1 = q_2 = q$.

Since we require the ratio of the two forces we need to divide the two formulae above and then substitute into this expression. This gives:

$$\begin{aligned}\frac{F_e}{F_g} &= \frac{kq^2}{r^2} \div \frac{Gm^2}{r^2}\\ &= \frac{kq^2}{r^2} \times \frac{r^2}{Gm^2}\\ &= \frac{kq^2}{Gm^2}\\ &= \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2}\\ &= 1.24 \times 10^{36}\end{aligned}$$

As you can see because the ratio is much greater than 1, then the electric force is much higher than the gravitational force.

Activity 4.1

Question 1: Why does the hair on your head tend to want to stand up after brushing with a nylon bristled brush on a dry day? Explain the process.

Question 2: Gravitational forces depend on the property called mass. What comparable property underlies electrical forces?

Question 3: When Darren takes his jumper off, it becomes negatively charged as it rubs against his shirt. This is because the jumper has

(a) lost electrons

(b) gained electrons

(c) lost protons

(d) gained protons.

Question 4: The SI unit of mass is the kilogram. What is the SI unit of charge and what is the charge of one electron?

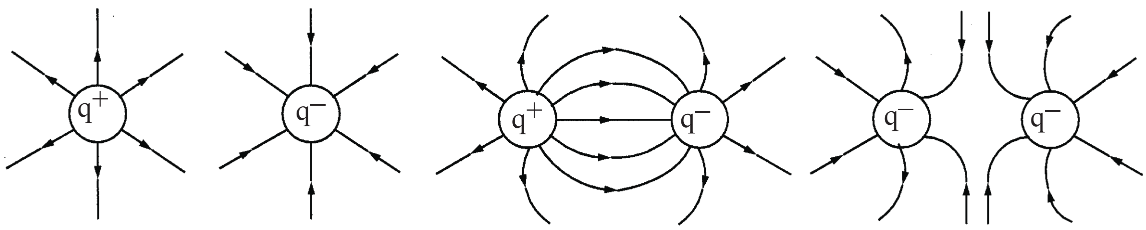
Question 5: The proportionality constant ***k*** in Coulomb's law is huge compared to the proportionality constant *G* in Newton's law of gravitation. What does this mean in terms of the relative strengths of these two forces?

4.1.3 Electrical energy characteristics

Electric fields

Previously we posed the question 'How can a charge act over an empty space?' The way physicists solve this problem is to assume the existence of electric fields which surround electric charges. We can draw diagrams representing these electric fields. We say that these electric fields can push and pull on electric charges. If we introduce one charge near another, then the forces that act can be though of in terms of a field-charge interaction rather than a charge-charge interaction. The lines we draw representing electric fields, indicate the direction a positive charge would move, if we introduced a charge into the electric field region. The closer the lines, the 'stronger' the electric field.

Figure 4.3



Electric field lines isolated point change

Electric field lines between unlike charges

Electric field lines between like charges

The strength of an electric field, E, at a particular point is defined as the force per unit positive test charge placed in the field. So if a charge of 1C were placed in the field in order to test its strength we would just need to calculate how much force was applied to that charge. If we had instead used a test charge of 2C, then we would have to halve the force in order to obtain the force per unit charge. In general the electric field strength is the force divided by the size of the test charge used. That is:

$$E = \frac{F}{q}$$

Consequently the unit of electric field strength is the Newton/Coulomb.

Example: What is the strength of the electric field 25mm from a fixed charge of $3\mu C$?

Solution: We need to calculate the force on a test charge placed 25mm from the fixed $3\mu C$ charge. The size of the test charge is arbitrary so we shall use one of 1C.

$$F = \frac{kq_1\, q_2}{r^2} \qquad \text{(Coloumb's law)}$$

$$= \frac{9 \times 10^9 \times 3 \times 10^{-6} \times 1}{(2.5 \times 10^{-2})^2} \qquad \text{(substituting 1 for the test change)}$$

$$= 4.32 \times 10^7 \text{ N}$$

So the electric field strength will be $4.32 \times 10^7\ \text{NC}^{-1}$.

If we had used a test charge of 2C, then the force would have been twice as large, however we would have had to halve the result to obtain the force per unit charge. In other words the result would have been the same.

In general we can calculate the electric field strength E using the following formula:

$$E = \frac{kq}{r^2}$$

(This formula is Coulomb's force equation with one of the charges set to 1.)

Electric potential

Now there is a good parallel between electric fields and gravitational fields. If we lift an object above the ground it gains gravitational potential energy similarly when we move a charge away from a fixed charge to which it is attracted, the moved charge gains electrical 'potential'. Whenever a charge is in an electric field we say it has electric potential, when it moves to a point with lower potential it can gain kinetic energy (just as an object which loses gravitational potential energy can gain kinetic energy). The difference in potential between two points in an electrical field is called the 'potential difference'. The unit of electrical potential is the Joule/Coulomb, however since this is such a common unit it is also called the Volt (V). In a 6V battery, the potential difference between the two terminals is 6 Volts. This means that it would take 6 Joules of energy to move a positive charge of 1 Coulomb from the negative terminal along a connecting wire to the positive terminal (or alternatively 6 Joules of energy would be released if the charge moved from the positive terminal to the negative terminal).

Example: How much work would be done in order to move a positive charge of $3\mu C$ from the negative terminal to the positive terminal in a 12V battery?

Solution: The work done depends on the change in electric potential, in this case 12V. This means that 1 Coulomb would need 12 Joules of work, 2 Coulombs would need $2 \times 12 = 24$ Joules, but what about $3\mu C$?

A much smaller charge would require a lot less energy, we need to multiply the potential difference by the size of the charge, that is:

$$\begin{aligned} W &= Vq \\ &= 12\ \text{JC}^{-1} \times 3 \times 10^{-6}\ \text{C} \\ &= 3.6 \times 10^{-5}\ \text{J} \end{aligned}$$

The change in potential between two parallel plates

The strength of an electric field is constant between two parallel charged plates. That means, if a charge is placed anywhere between the two plates it will experience the same force. Calculation of the potential difference between any two points in the electric field between two parallel charged plates is therefore relatively straightforward.

The electrical potential between the plates is the amount of work done in moving a charge across the plates divided by the size of the charge, that is:

$$V = \frac{W}{q},$$

The work done in moving the charge will depend on both the force acting on the charge and the distance covered. Assuming that the electric field strength is a constant E, the force on the charge will be $F = Eq$. If a distance of d separates the plates, then the work done in moving the charge will be:

$$\begin{aligned} W &= Fs \\ &= Fd \\ &= Eqd \end{aligned}$$

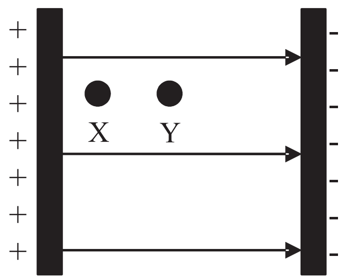
Therefore the difference in potential across the plates will be:

$$V = \frac{W}{q} = \frac{Eqd}{q} = Ed.$$

Consider the following example.

Example: Two parallel charged plates are placed 25mm apart. If the potential difference across the plates is 12V, what is the difference in potential between two points X and Y in this field, if they are 5mm and 10mm respectively from the positive plate (distances are measured perpendicular to the plate).

Figure 4.4:



Solution: Since the force is constant in the field the electric field strength can be calculated:

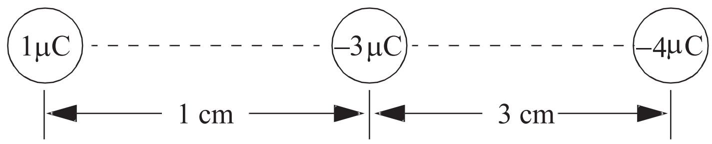
$$\begin{aligned} E &= \frac{V}{d} \\ &= \frac{12}{2.5 \times 10^{-2}} \\ &= 480 \text{ Vm}^{-1} \end{aligned}$$

For every metre that a charge moves in this field, its potential will change by 480V. Consequently the change in potential between two points separated by only 5mm will be $480 \times 0.005 = 2.4 \text{ V}$.

Activity 4.2

Question 1: In the case of electrostatic voltage build-up in a car, this is alleviated by having a chain or semi-conductive strap dragging below the car. How does this work?

Question 2: If three point charges are placed in a line as shown below, what would be the net force experienced by the $-3\mu C$ charge due to the two other charges?



Question 3: A Helium nucleus has a charge of +2*e*, and an oxygen nucleus +8*e*, where *e* is the charge of one electron, 1.6×10^{-19}C. Find the force of repulsion exerted on one by the other when separated by 5 nm (nanometres) (1 nm $=$ 1×10^{-9} m). Assume them to be in a vacuum.

Question 4: How much energy is released by a charge of 5C if it passes through a potential difference of 24V?

Question 5: Two parallel plates are separated by a distance of 5mm and have a total potential difference of 6V. Calculate the magnitude of the force experienced by a charge of $6\mu C$ which is placed between the two plates. Assume that a vacuum exists between the plates.

Question 6: A potential difference of 22 kV maintains a downward-directed electric field between two horizontal parallel plates separated by 2.0 cm. Find the charge on an oil droplet of mass 2.2×10^{-13} kg that remains stationary in the field between the plates.

4.2 Direct current (DC) concepts – electricity in motion

In this module we are going to consider direct currents (DC). We will study alternating currents (AC) and voltages later. AC electricity is what is used in the home mains supply, and DC is what you would get from a battery (also known as a dry cell) say in a torch or car.

4.2.1 Currents, voltages and resistance – Ohms Law

Current

With direct current, the charge carriers (electrons) always move in the one direction. Although we now know that it is electrons (negative charges) that move in metal conductors, when the theory was being established it was thought that it was positive charges that moved. We still use this convention, and assume that electric current is a movement of positive charges. We call this, the conventional current, or simply, the current.

The movement of charges through conductors is hindered by vibrations of the atoms in the conductor and by impurity atoms, imperfections in the crystal structure, etc. Electrons move through metal conductors at a relatively slow speed (only millimetres per second). This movement of charges is called an electric current (I) and current is a fundamental SI quantity with units of ampere (A). The ampere is defined in terms of forces between two parallel conductors.

We know that the unit of charge is the coulomb (C). It is defined as the charge which passes a given point if one ampere flows for one second. This can be represented as

$$I = \frac{q}{t} \quad \left(\text{Amperes} \ = \frac{\text{Coloumb}}{\text{Second}}\right)$$

Example: Calculate the amount of charge that flows in a wire when a steady current of 2 A flows for 5 seconds.

Solution: Using the above definition of current:

$$I = \frac{q}{t}$$

$$2 = \frac{q}{5}$$

$$q = 10 \ C$$

So a total amount of 10 Coulombs of charge will move in the wire during this period.

Voltages

As charges move, they lose energy as heat. The system that provides energy to the charges in the first place is called a **source** of electromotive force (emf). The emf is defined as the energy given to the charges as one coulomb of charges passes. The emf (E) has units of volt – the same as potential difference.

A traditionally used analogy is that of water flowing from a tank providing a head of pressure (see module 3). The head can be likened to the potential difference, and the rate of flow likened to the current (flowing water = moving charges).

The potential difference (V) between two points in a circuit is associated with the energy lost by, or supplied to charges which move between the two points. If there are no energy losses in the source of emf itself, then we would have

$$E = V$$

A potential difference (potential drop, voltage drop) exists between two points in an electric field. If a charge, q, moves between two points and loses energy, W, the potential difference is

$$V = \frac{W}{q} \qquad \text{(Volts = Joule/Coulomb)}$$

At the simplest level, the potential difference in a DC circuit can be produced by a single electrical 'cell'. An electrical cell is a pair of parallel plates in a chemical solution that causes them to produce different charge so that one becomes positively charged and the other negatively charged. Consequently a potential difference exists between the two plates. In circuit diagrams, two parallel lines of differing length represent a cell. The longer line is the positive plate and the shorter the negative plate (see below):

A battery often has a number of cells connected in such a way as to combine their total potential difference. For example a 12 V battery might consist of 6 cells each of 2V. The symbol for a battery is shown below.

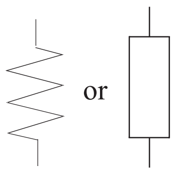
Resistance – Ohms Law

If we take different sizes, shapes, types of conductors and apply the same emf we find that different currents flow. We say that these different conductors have different electrical resistance and define the static resistance, *R*, for a conductor, by:

$$R = \frac{V}{I}$$

where *R* is the resistance in ohms (Ω), *V* is the voltage in volts, and *I* is the current in amperes.

This is termed Ohms Law. In circuit diagrams resistances are represented by the symbols:



This does not mean that the current is 'used up'; rather it means that the amount of current able to flow around the circuit is affected by the total resistance in that circuit. So for example, if a circuit consisted of a battery and one globe and then a second globe was connected (in series), the resistance would be doubled and the current halved. Returning to the water analogy; resistance could be likened to the cross-sectional area of the pipe which will affect the flow rate.

Resistivity

The resistance of a conductor, *R*, is found to be proportional to the length *l* and inversely proportional to the cross-sectional area *A*, i.e.

$$R \propto \frac{l}{A}$$

Introducing a constant of proportionality gives the following formula for the resistance of a conductor:

$$R = \rho\frac{l}{A}$$

where the constant of proportionality ρ depends on the particular material. This constant is called the resistivity, with SI units of ohm-metre. The resistivity depends on the atomic structure of the conductor, and varies with temperature.

Here are some resistivity values in ohm.m at 20°C

Silver	1.6×10^{-8}	Nichrome	100×10^{-8}
Copper	1.7×10^{-8}	Carbon	$3\,500 \times 10^{-8}$
Aluminium	2.8×10^{-8}	Glass	10^{+11}
Iron	10×10^{-8}	Quartz	10^{+16}
Tungsten	5.6×10^{-8}		

Example:

A resistance of 2.5 ohm is required for a particular piece of equipment and has to be made from a length of tungsten wire of diameter 0.2 mm, what length will be required?

Solution:

We firstly need to calculate the cross-sectional area of a wire with radius 0.1 mm.

$$\begin{aligned} A &= \pi r^2 \\ &= 3.14 \times (1 \times 10^{-4})^2 \\ &= 3.14 \times 10^{-8}\ \text{m}^2 \end{aligned}$$

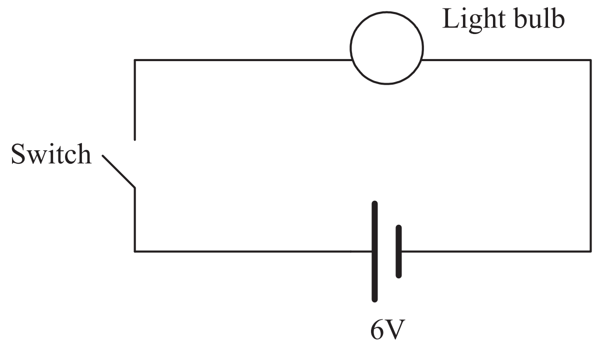
Then using the formula for resistance above with $R = 2.5\Omega$, $\rho = 5.6 \times 10^{-8}$ and $A = 3.14 \times 10^{-8}$ we obtain:

$$\begin{aligned} R &= \rho\frac{l}{A} \\ 2.5 &= 5.6 \times 10^{-8} \times \frac{l}{3.14 \times 10^{-8}} \\ l &= 1.4\ \text{m} \end{aligned}$$

Circuit diagrams

Consider a simple battery operated torch. The electrical circuit in the torch could be represented by the following circuit diagram:

Figure 4.5



Once the switch is closed current will flow from the positive terminal of the cell (longest line) to the negative terminal. The resistor in the light bulb will slow down the current and in doing so should glow sufficiently to produce light.

Suppose the total resistance in the above circuit was 3000Ω, we should be able to calculate the current flow using Ohm's law.

$$V = IR$$
$$6 = I \times 3000$$
$$I = 6 \div 3000$$
$$= 2 \times 10^{-3} \text{ A}$$
$$= 2 \text{ mA}$$

Often circuits can be quite complex and calculating the current flowing in different branches of the circuit involves us being able to determine the resistance offered in each of these branches. Resistors can be placed in many combinations in a circuit. We shall deal with some of these now.

Combinations of resistances

Have you ever noticed that when a light bulb blows in the home the other lights in the house stay on? Have you also noticed that the lights on the Christmas tree will only work if every bulb is OK, i.e. if one blows they all go out? The difference in these two examples is the way the bulbs are connected in the circuit. The Christmas tree lights are connected in series so if one blows, the circuit connecting the current to the other bulbs is broken, whereas in the case of the house lighting the globes are connected in parallel so if one blows it does not break the current path to the others.

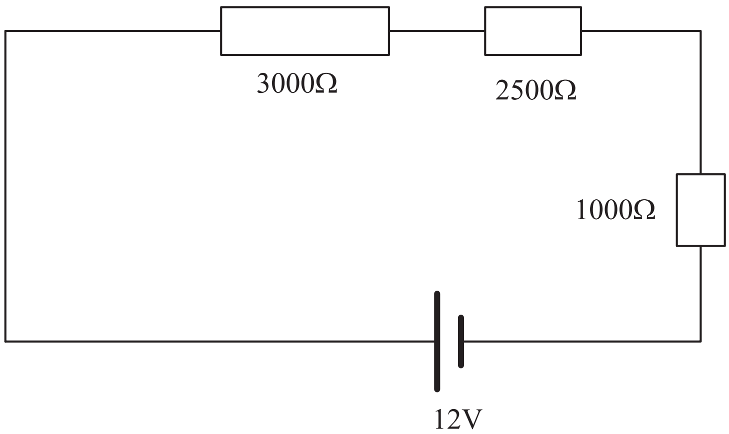
When a number of resistances are connected together in some arrangement or pattern it is advantageous to know what the collective resistance would be. Experimentally this is done easily: we can connect a voltage source to the circuit, measure the voltage of this supply and the current that is delivered into the resistance combination, and then use Ohms Law to calculate the total resistance. Measuring the total resistance is also possible by using an ohmmeter directly across the resistance circuit. The relationship between the value of the total resistance and the individual values depends on the way they are connected. See the video for a demonstration of this.

Resistors in series

When resistors are placed one, after another, we say that they are in series. The current flowing through each of the resistors is the same. In such a situation the total resistance is just the sum of the individual resistances.

Consider the following circuit diagram.

Figure 4.6



The three resistors are placed in series and therefore the total resistance offered by the circuit is:

$$R_T = 3000 + 2500 + 1000$$
$$= 6500\Omega$$

We can then use Ohm's law to calculate the total current flowing in the circuit, that is:

$$V = IR$$
$$12 = I \times 6500$$
$$I = 12 \div 6500$$
$$= 1.846 \times 10^{-3}\ \text{A}$$
$$= 1.8\ \text{mA}$$

The current will remain steady all the way around the circuit. The potential drop across each resistor, however, will vary. For example the potential drop across the 3000Ω resistor will be:

$$V = IR$$
$$= 1.8 \times 10^{-3} \times 3000$$
$$= 5.4\ \text{V}$$

While the potential drop across the 2500Ω will be

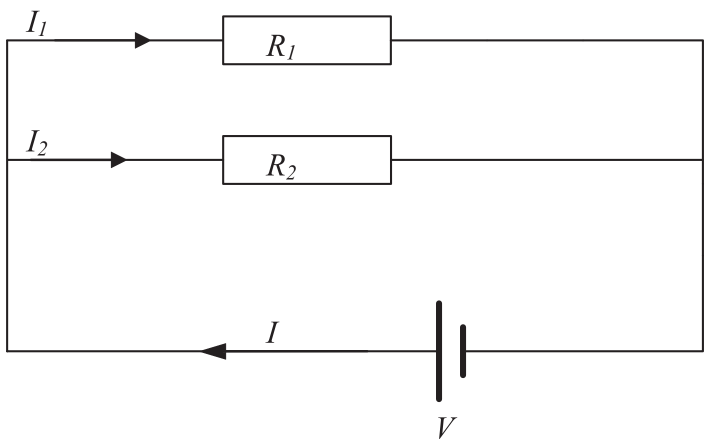
$$V = IR$$
$$= 1.8 \times 10^{-3} \times 2500$$
$$= 4.5\ \text{V}$$

Of course the potential drop across the last resistor must be $12 - (5.4 + 4.5) = 2.1$ V, as the total drop around the entire circuit has to be 12V.

Resistors in parallel

Consider the situation below where two resistors are placed in parallel:

Figure 4.7



The current flowing from the cell I will split into two paths with currents I_1 and I_2. The potential drop across each resistor is now V. Therefore:

$I = I_1 + I_2$ (since the current in the two branches must sum to the total current)

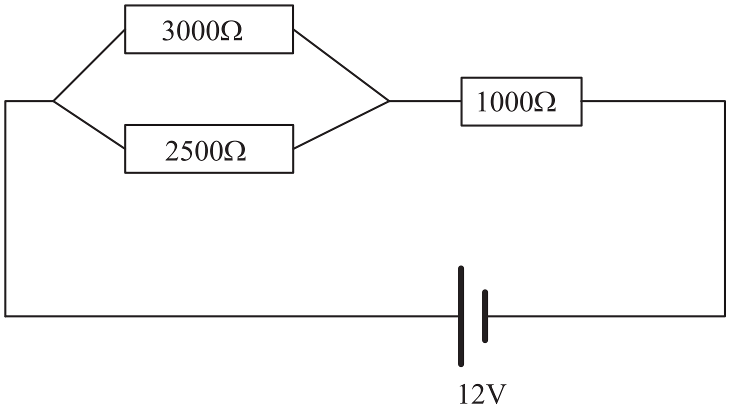
$\frac{V}{R_{total}} = \frac{V}{R_1} + \frac{V}{R_2}$ (Using Ohm's law)

$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$ (dividing both sides by V).

So the total resistance is not found by summing the two individual resistances as was the case for resistors in series, but instead by using the above relationship.

Some circuits have resistors in parallel and in series. Consider the following circuit diagram.

Figure 4.8



The 3000Ω and 2500Ω resistors are in parallel. They could be replaced by a single resistor; however we need to calculate its size.

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_{total}} = \frac{1}{3000} + \frac{1}{2500}$$

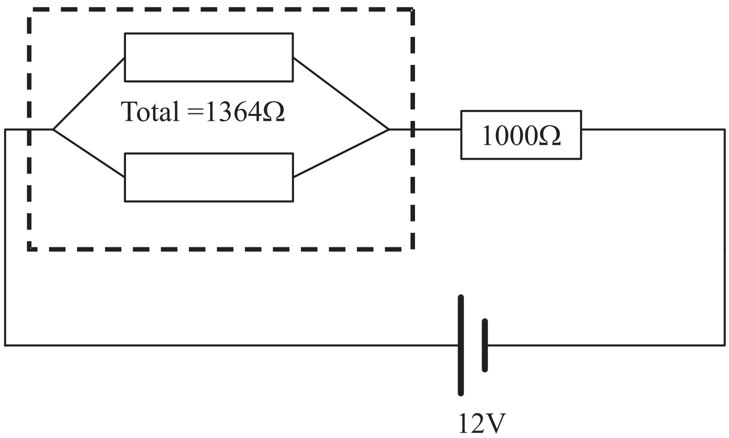
$$= \frac{2500 + 3000}{3000 \times 2500}$$

$$R_{total} = \frac{3000 \times 2500}{2500 + 3000}$$

$$= 1364\Omega$$

We could consider the original circuit as being one with only two resistors connected in series (see diagram below where the two parallel resistors are boxed by a dashed line to represent one resistor of 1364Ω).

Figure 4.9



The total resistance offered by the circuit is now 2364Ω, and therefore the current flowing from the cell will be:

$$I = \frac{V}{R_{total}}$$
$$= \frac{12}{2364}$$
$$= 5.08 \times 10^{-3} \text{ A}$$
$$= 5.08 \text{ mA}$$

Now the total potential drop of 12V is shared by the two resistors according to Ohm's law. The drop across the 1364Ω resistor will be:

$$V = IR$$
$$= 5.08 \times 10^{-3} \times 1364$$
$$= 6.93 \text{ V}$$

and therefore the drop across the 1000Ω resistor will be 5.07 V (since the total drop is 12V).

If we now return to our original circuit we know that the current flowing from the cell will be the same as the current flowing through the 1000Ω resistor; however the current flowing through each of the resistors in parallel will be different. Let's look at the current flowing through the 3000Ω resistor.

We know that the potential drop across both of the parallel resistors will be the same (6.93V), so we can use Ohm's law to calculate the current flowing through the 3000Ω resistor.

$$I = \frac{V}{R}$$
$$= \frac{6.93}{3000}$$
$$= 2.31 \text{ mA}$$

The current flowing in the other parallel resistor will be $5.08 - 2.31 = 2.77 \text{ mA}$.

In this way, we should be able to ascertain the current and voltage drop across each resistor in any circuit.

Activity 4.3

Question 1: Resistance is measured in_______________ . The resistance of a wire increases as the length ________________; and as the cross-sectional area ___________ .

Question 2: An ammeter is connected in series with an unknown resistance, and a voltmeter is connected across the terminals of the resistance. If the ammeter reads 1.5 A and the voltmeter reads 12 V, compute the value of the resistance. (Assume ideal meters; that is they do not effect the circuit in any way.)

Question 3: A copper bar carrying 1500 A has a potential drop of 1.5 mV along 20 cm of its length. What is the resistance per meter of the bar?

Question 4: What is the resistivity of the bar in question 3 if it had a cross-sectional area of 2 cm^2?

Question 5: Two resistors, 8Ω and 12Ω, are placed in parallel with a 12V battery. Draw a circuit diagram to represent this and then calculate the total current flowing out of the battery.

4.2.2 Power

Internal resistance

As we have seen in module 2, if a person pushes an object up a hill against friction, then that person has given the object a potential energy (PE) equal to *mgh*, but the work that has been done is actually the potential energy plus the work done in overcoming friction.

The potential energy is therefore not equal to the work done (energy supplied) but equals the energy supplied minus the amount of energy necessary to overcome friction.

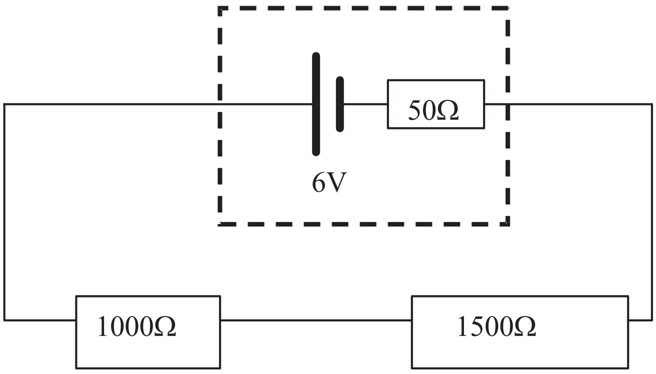
In an analogous way, when a source of emf is supplying energy to charges, there is generally some energy lost in the source itself. We say that this energy loss is associated with an internal resistance (r).

If a current I is flowing in the circuit, there is voltage drop of Ir associated with the internal resistance. The voltage that appears across the terminals of the source of emf, is then

$$V = E - Ir$$

This ‘internal resistance’ has implications when we try to calculate the current flowing in any circuit. Consider the following circuit where the internal resistance is shown adjacent to the cell.

Figure 4.10



The total resistance in the circuit is made up of the internal resistance and the external or load resistance. In this case it is $2500 + 50 = 2550\Omega$, so the current flowing in the circuit will be:

$$I = \frac{V}{R} = \frac{6}{2550} = 2.35 \text{ mA}$$

Power (DC)

As the charge flows through a circuit it loses energy. The total amount of energy it loses is the potential drop in the circuit (Volts = Joules/Coulomb) multiplied by the total charge (Coulomb). The speed at which this energy is lost is called the power (remember that power is defined as how quickly work is done).

$$P = \frac{W}{t}$$

$$= \frac{qV}{t} \quad \text{(since the work done is equal to the voltage multiplied by the charge)}$$

$$= VI \quad \text{(since current is charge divided by time)}$$

Using Ohm's law we can derive an expression for the power lost in a given resistor.

$$P = VI = (IR)I = I^2R$$

Consider the circuit shown in figure 4.10. The total current flowing in the circuit was calculated to be 2.35mA. The power lost in the cell itself is:

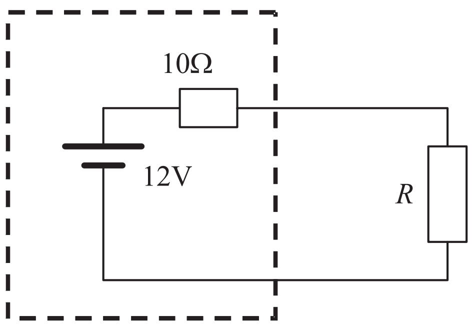
$$\begin{aligned} P &= I^2R \\ &= (2.35 \times 10^{-3})^2 \times 50 \\ &= 2.76 \times 10^{-4}\ \text{W} \\ &= 27.6\ \text{mW} \end{aligned}$$

The power lost in the external circuit is:

$$\begin{aligned} P &= I^2R \\ &= (2.35 \times 10^{-3})^2 \times 2500 \\ &= 0.138\ \text{W} \\ &= 13.8\ \text{mW} \end{aligned}$$

Activity 4.4

Question 1: Consider the circuit below which shows a 12V battery with internal resistance of 10Ω connected in series with an external and variable resistance *R*.

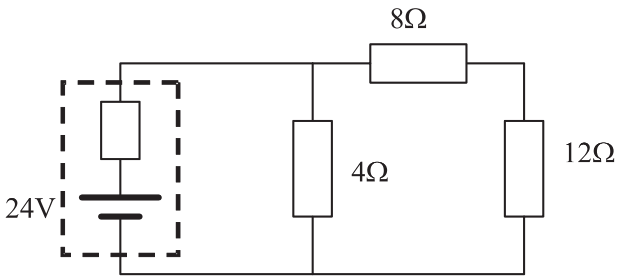


Complete the table for the power dissipated in the internal resistance P_r and the power dissipated in the load P_R for the various conditions given. We assume that the internal resistance *r* is fixed at 10Ω, while the load resistance *R* is free to alter.

r	R	I	P_r	P_R
10	5			
10	8			
10	10			
10	15			
10	20			

Maximum power transfer will occur in a circuit when the load receives maximum power. Of the situations described above which resulted in maximum power for the load? How could you generalise this result?

Question 2: In the circuit below the 24 V battery has an internal resistance of 1 ohm.



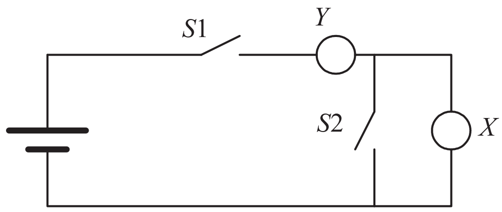
Compute

(a) the battery current

(b) the terminal voltage of the battery

(c) the current in the 4 ohm resistor

(d) the current in the 12 ohm resistor.



Question 3: Explain what happens to the identical lamps *X* and *Y* in the circuit shown above when:

(a) switch *S*1 only is closed

(b) *S*2 only is closed

(c) *S*1 and *S*2 are closed.

Question 4: Draw a circuit diagram to show how 3 lamps can be lit from a battery so that 2 lamps are controlled by the same switch while the third lamp has its own switch. (Two possibilities.)

Question 5: A DC current in a 10 ohm resistance produces heat at the rate of 360 W. Determine the values of the current and voltage applied to the resistor.

Section review

In this section we have studied the effects of electro-static forces and concepts such as potential difference, electric field, current, resistance and voltage. We have also discussed how these concepts apply to direct current (DC) circuits. You should now assess yourself as to whether you have met the module objectives.

You should now be able to:

- explain the meaning of static electricity
- describe Coulombs law and how it applies to stationary charges
- calculate the magnitude and direction of the force that exists between two stationary point charges
- calculate the magnitude and direction of the electric field near a stationary point charge
- describe what is meant by electric potential
- calculate the work done in moving a point charge through a potential difference
- recognize and describe the common DC circuit components, such as the electric cell and the resistor
- calculate the electrical resistance of a piece of wire
- calculate the equivalent resistance of parallel and series combinations of resistors
- distinguish between internal and external resistance
- calculate the power dissipated in a circuit.

In your study of this section you should have been making notes of the main points and listing those concepts that were difficult to understand.

Have you been able to revise those concepts that were difficult to understand?

Have you sought help?

Use the following post-test to see how you are going so far.

Post-test 4.1

Question 1:

Which statements are true concerning electric fields?

(a) All charges are surrounded by an electric field.

(b) Field lines are drawn as concentric circles around the charge.

(c) Electric field lines terminate at negative charges.

(d) Electric field lines originate from positive charges.

Question 2:

How many electrons are required to produce 1 C of charge? ($e = 1.6 \times 10^{-19}$ C)

(a) 1.6×10^{-19}

(b) 1

(c) 6.25×10^{18}

(d) 6.023×10^{23}

Question 3:

Calculate the electric field strength at a point 4 cm from a 2μC charge.

Question 4:

What is the force of repulsion between two argon nucleii that are spaced 2nm (2×10^{-9} m) apart? (The charge on an argon nucleus is +18 e.)

Question 5:

A flash of lightening carries 10 C of charge which flows for 0.01 s. What is the current? If the voltage is 10 MV, what is the energy?

Question 6:

Two parallel charged plates are 5mm apart and have a difference in potential of 12 volts. Calculate the force on a charge of 2μC placed between these plates.

Question 7:

What resistance needs to be placed in parallel with a 30Ω resistor to provide an equivalent resistance of 20Ω?

Question 8:

Two metal plates are attached to the two terminals of a 3.0V battery. How much work is required to carry a +5μC charge

(a) from the negative to the positive plate

(b) from the positive to the negative plate?

Question 9:

A potential difference of 9V is applied to two resistors (of 12Ω and 15Ω) connected in series. Calculate:

(a) the combined resistance

(b) the current flowing

(c) the potential difference across the 12Ω resistor.

Question 10:

A 300 Ohm resistor is placed in series with a parallel combination of two 100 Ohm resistors. These resistors are then connected to a 12V battery, with a known internal resistance of 10 Ohms.

(a) Draw a circuit diagram to represent this situation.

(b) Calculate the current flowing in the battery.

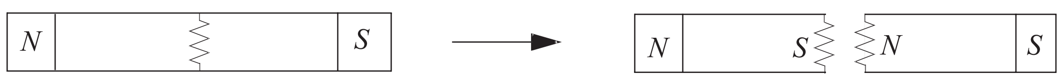
(c) Calculate the potential drop across the battery terminals.

(d) Calculate the power lost in the external circuit.

4.3 Magnetism

Magnets and magnetism have been known about for thousands of years. Naturally occurring magnets, called lodestones, were scientific curiosities in the ancient world, and slivers of lodestone that lined up in a north-south direction were the first compasses. The existence of a magnetic force can be easily verified by anyone who has used magnets to hang notes on the refrigerator.

Even though magnetism has some properties similar to electric charge, there is a basic difference: all known magnets, whether they be the size of an atom, a bar magnet, or the planet Earth, have two poles. Each pole is usually labelled north or south (depending on which end of the earth they would point to if they were allowed to act as a compass). Like charges, poles with the same character always repel, while opposite poles always attract (north attracts south, but repels north). This difference between electrical charges and magnetic poles is enshrined in Maxwell's second law. No matter how hard you try, the law says, you can never create an isolated magnetic pole. Unlike electrical charges (which can exist as independent positive or negative particles), magnetic poles always come in pairs. If you cut a 2-inch long bar magnet in half, you don't get one north end and one south end. You get two 1-inch-long bar magnets, each with its own north and south pole. Cut those pieces in half and you just get more magnets. Even the individual atoms are tiny 'dipole' (two-pole) magnets.



Thus, Maxwell's second law states:

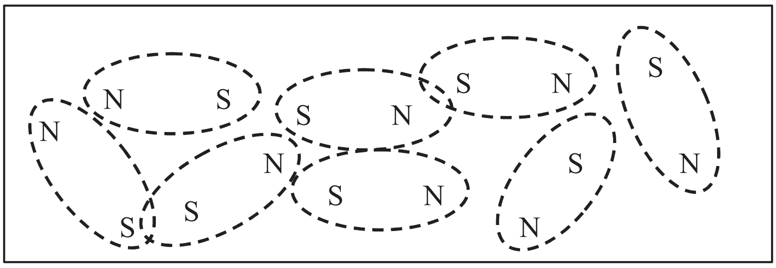
There are no isolated magnetic poles.

This statement by Maxwell says nothing about how magnetic fields come to be. In dealing with magnetic materials, the unit magnetic 'cells' (charges in electrostatics, which contain both poles) are known as 'domains'.

The domain theory of magnetism

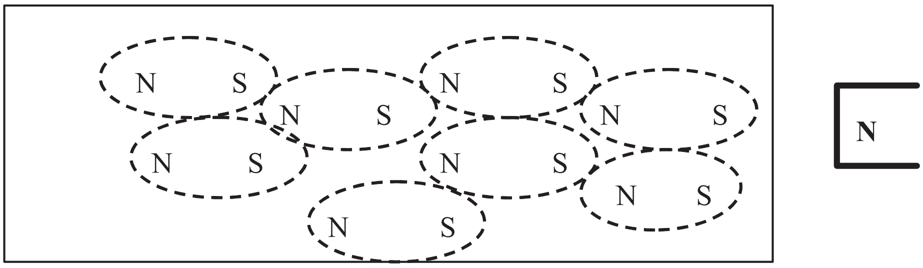
The 'domain theory' of magnetism helps us explain some of the more common phenomena associated with magnets. It is known that some materials (called ferromagnetic materials) are either naturally magnetic or can become magnetic if placed near anther magnet. We assume that within these materials there are many domains (unit magnetic cells), not necessarily aligned (see figures 4.11 and 4.12).

Figure 4.11: Ferromagnetic material with unaligned magnetic domains



If the material is placed near a strong magnet, its magnetism might cause the domains in the material to align. If this happens the material itself will become magnetic.

Figure 4.12: Ferromagnetic material after being placed near a strong magnet



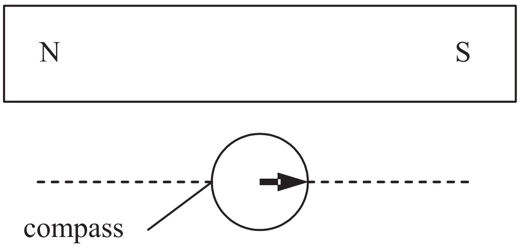
If a bar magnet is suddenly dropped, it can lose its magnetism. The force experienced by the magnet when it hits the ground can cause the domains to move out of alignment, in other words the reverse of the process described above.

4.3.1 Magnetic fields

The region where a magnet can exert a force is termed its magnetic field. Just as a charge placed in an electric field experiences a force, a magnetic substance placed in a magnetic field will also experience a force.

The direction of a magnetic field is defined as the direction that a North seeking compass would point if placed in the field. For example, if a compass was placed mid way between the North and South poles of a bar magnet, it would point towards the South Pole of the compass (see figure 4.13).

Figure 4.13: Finding the direction of magnetic field using North seeking compass



Electromagnetism

Magnetism and static electricity seem to be very different things. The nature of magnetism, and its connection with electricity, is what Maxwell's third and fourth laws deal with.

The relationship between electricity and magnetism can be stated as:

Every time an electric charge moves, a magnetic field is created; every time a magnetic field varies, an electric field is created.

Electricity and magnetism are two inseparable aspects of one phenomenon: you cannot have one without the other.

The story of the discovery of this connection is a curious one. The Danish physicist Hans Oersted (1777–1851) was giving a physics lecture when he noticed that when he flipped a switch to start the flow of an electric current a nearby compass needle began to twitch. Further experiments convinced him that a magnetic field is present whenever electrical charge flows through a wire.

If we could see or feel electric and magnetic fields, their close ties would be obvious because we would always see them together. But in day-to-day life we are generally unaware of electrical effects when we use magnets, nor do we sense magnetic fields when we use electricity. We have to use instruments to tell us about the connection between the two.

It is believed that magnetism is actually caused by the spin of electrons within the atom. In most substances magnetism from the spin of one electron will cancel out the magnetism from the spin of another. However in the ferromagnetic substances, this is not the case, and the substance will form magnetic domains (discussed earlier).

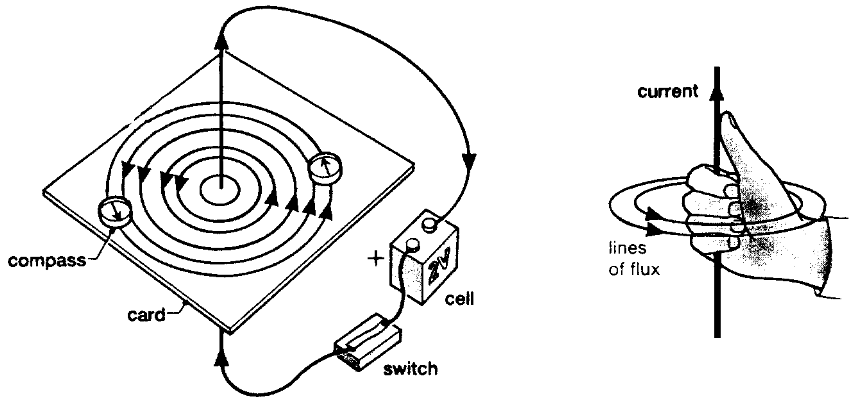
The magnetic effect of a current

In the section on electric fields we saw that a stationary charge could be pushed or pulled by an electric field in the direction of that field. If a charge is moving, then at times a sideways deflecting force acts. We say that this sideways force is due to a magnetic field.

So while stationary charges only experience electrostatic forces, a moving charge will experience both an electrostatic and a magnetic force.

As moving charges produce magnetic fields, so do electric currents which are essentially moving charges constrained to a conductor. The direction of the magnetic field produced by a current may be described by the right hand grip rule. Place your right hand with fingers curled as if to grip the wire (as in figure 4.14). If your thumb points in the direction of the current flow your fingers will give the direction of the magnetic field associated with that current. The field pattern and direction can also be found by placing a compass near the current (see also figure 4.14).

Figure 4.14: Magnetic field associated with a current



The strength of the magnetic field *B* created by a current is found to be proportional to the magnitude of the current I and inversely proportional to the distance from the wire *r*. That is:

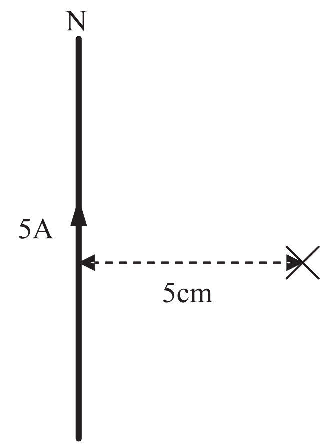
$$B \propto \frac{I}{r}$$

$$B = \frac{\mu}{2\pi}\frac{I}{r}$$

The constant μ depends on the substance surrounding the wire, for free space or air it has a value of $4\pi \times 10^{-7}$. The unit of magnetic field strength *B* is the Teslar T.

Example: A straight wire carrying a current of 5A is placed so that its length runs north/south and the current flows north. Calculate the direction and magnitude of the magnetic field produced by the current at a point 5cm east of the wire.

Solution: A diagram might assist with our solution (see below).



The current $I = 5\text{A}$, the distance $r = 5 \times 10^{-2}$ m and we will assume that it is placed in air, therefore:

$$B = \frac{\mu I}{2\pi r}$$

$$B = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 5 \times 10^{-2}}$$

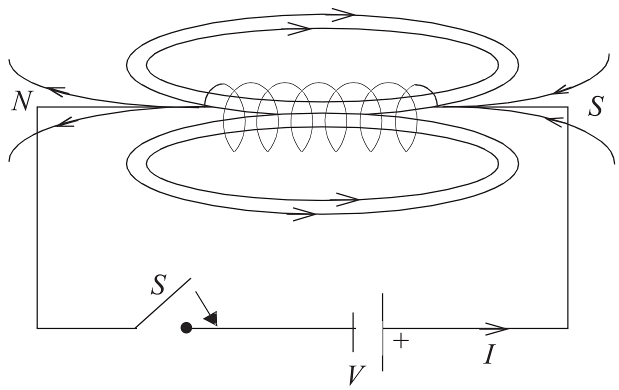
$$B = 2 \times 10^{-5}\ \text{T}$$

Using the right hand grip rule, the field should be pointing in a direction into the page.

The electromagnet

One common application of the magnetic field associated with a current is the electromagnet. When a wire is wrapped into a coil (also called a solenoid) the combined effect of the magnetic field from each loop of the coil closely resembles that of a bar-magnet (see figure 4.15).

Figure 4.15: Magnetic field associated with a solenoid



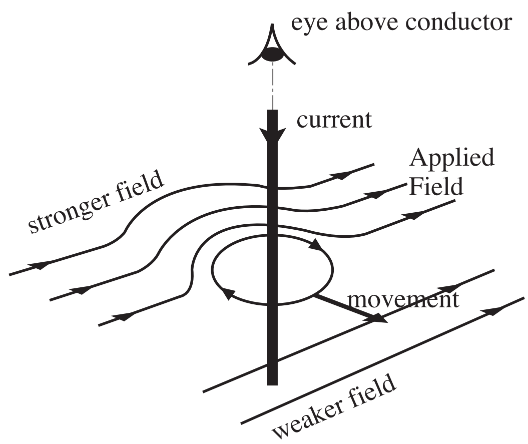
The strength of the magnetic field can be enhanced if soft iron bar is inserted into the solenoid, rather than just free space. This then forms the basis of the electromagnet. The magnet only operates when the switch is closed and current flows. Electromagnets are found in many devices and machines, from ordinary speakers to the large magnets that lift scrap iron and cars around in junkyards.

4.3.2 Forces in magnetic fields (the motor effect)

Have you ever thought what makes the car's starter motor turn or how the needle pointer in an electrical meter deflects to give a reading? These devices use the principle that if a current carrying conductor is in a magnetic field, a sideways force is exerted on the conductor.

For the conductor shown in figure 4.16, if a person looks in the direction of the current, the magnetic field due to the current in the conductor is clockwise around the conductor as confirmed by the right-hand grip rule mentioned earlier. To the left of the conductor, the magnetic field due to the current in the conductor and the applied magnetic field are in the same direction and add to give a stronger field. To the right, the fields are in opposite directions and the resultant field is weaker than to the left. The conductor experiences a force to move it from the stronger to the weaker field region. The direction of these vectors in relation to one another is easily remembered by the right hand slap rule. Open your right hand as if you are to slap something, again position it so that your thumb points in the direction of the current and the fingers in the direction of the applied magnetic field. Your open palm will point in the direction of the force i.e. if you were to then slap something the movement of your hand would be in the same direction as the movement on the conductor.

Figure 4.16: The force on a current carrying wire that is placed in a magnetic field

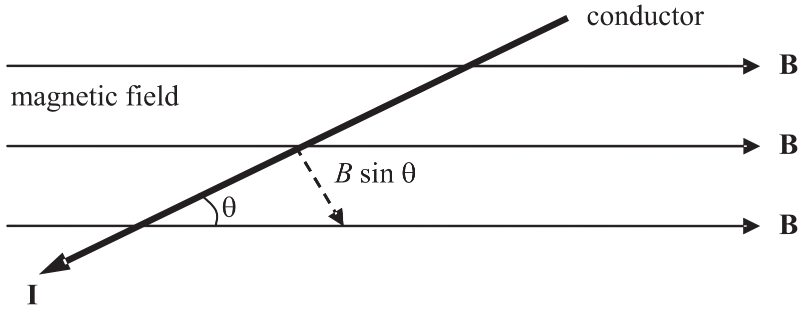


The strength of this force will depend on both the current flowing in the wire and that component of the magnetic field which is perpendicular to the wire. That is:

$$F = BIl\sin\theta$$

where B is the strength of the field, I the current flowing in the wire, l the length of the wire and θ the angle between the field direction and the current direction (see figure 4.17).

Figure 4.17: Wire placed at an angle in a magnetic field



Example: A conductor of length 50cm and carrying a current of 35mA is placed in a magnetic field of strength 0.4T. If its length is perpendicular to the direction of the magnetic field, calculate the magnitude and direction of the force experienced by the wire.

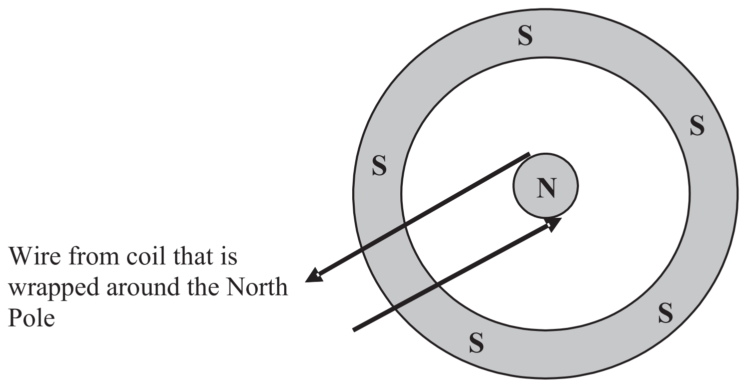
Solution: Since the wire is perpendicular to the field $\theta = 90°$ so the magnitude of the force will be:

$$\begin{aligned} F &= BIl\sin\theta \\ &= 0.4 \times 35 \times 10^{-3} \times 0.5 \times \sin 90 \\ &= 7 \times 10^{-3}\ \text{N} \end{aligned}$$

The loudspeaker

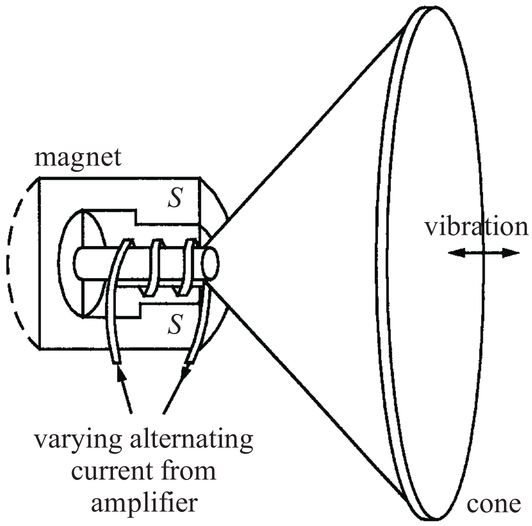
The loudspeaker is a great example of how the force experienced by a current carrying wire can be used. At the end of the loudspeaker there is a tubular magnet which produces a radial magnetic field (see figure 4.18).

Figure 4.18: End view of loudspeaker showing tubular magnet



The paper cone that vibrates in the speaker is free to move up and down over the north pole of the tubular magnet. The coil of wire is attached to the cone so that when current passes through the coil in one direction it experiences a force due to the presence of the perpendicular magnetic field. This force in turn results in the diaphragm moving in one direction (see figure 4.19). If the current changes direction the diaphragm will move in the opposite direction. Now 'sound' signals, when in an electrical form, change direction at the frequency of the sound in question. These changes in current will cause the speaker to vibrate at the same frequency as the signal current, hence producing sound waves. See the video for a demonstration.

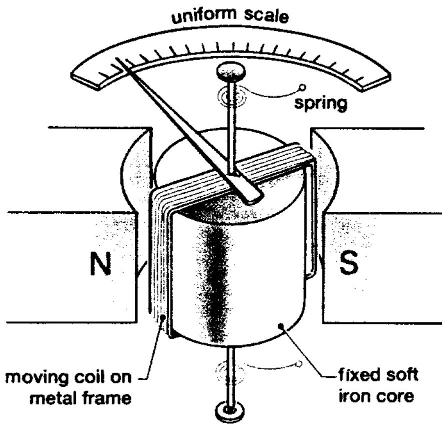
Figure 4.19 Side view of loudspeaker



The moving coil galvanometer

A moving coil galvanometer is used to measure very sensitive currents flowing in a circuit. It is another application of the force experienced by a current carrying conductor when placed in a magnetic field. The galvanometer consists of a coil of wire which is placed in a magnetic field (see figure 4.20). As current moves in the coil, those parts of the coil which are perpendicular to the magnetic field will experience a force; this force will cause the whole iron core to move, which in turn will cause the needle to move. A stronger current will result in a greater movement of the needle. Similarly, a current flowing in the opposite direction will cause the needle to change direction.

Figure 4.20 Moving coil galvonometer



The force on a moving charge

If a beam of electrons moves into a magnetic field, it will experience a force in much the same way that a current carrying conductor will when it is placed in a magnetic field. More specifically if a charge q is moving at right angles to a magnetic field of strength B it will experience a force given by:

$$F = qvB$$

where v is the velocity of the charge. As the force always acts at right angles to the direction of the current, the charge will begin to move into a circular path.

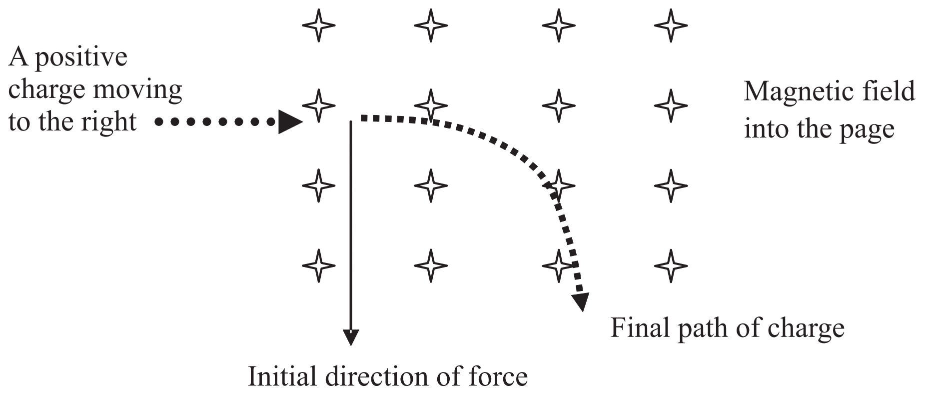
Example: An alpha particle is fired at a velocity of 2.4×10^4 ms^{-1} into a vacuum which is subject to a magnetic field of 0.23T that acts at right angles to the direction of the alpha particle. Calculate the magnitude and direction of the force on the alpha particle.

Solution: An alpha particle is a helium nucleus whose charge is $+2e = 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19}$ C. Consequently the magnitude of the force will be:

$$\begin{aligned} F &= qvB \\ &= 3.2 \times 10^{-19} \times 2.4 \times 10^4 \times 0.23 \\ &= 1.8 \times 10^{-15} \text{ N} \end{aligned}$$

Now the direction of the force will be always at right angles to the direction of the charge. Initially it will be straight down the page, however as the charge experiences this force it will change direction. When this occurs, the force on the charge will also change direction. Consequently the charge will move in a curved path (see figure 4.21).

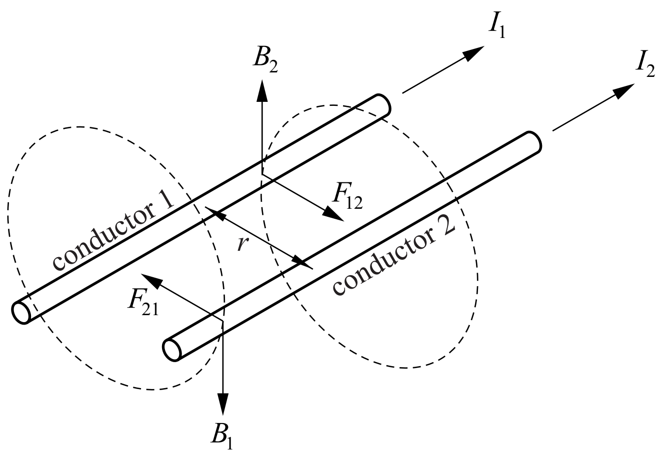
Figure 4.21: Movement of charge in a magnetic field



The force between two parallel conductors

Consider the situation shown in figure 4.22 where two wires are separated by a distance of r and carry currents of I_1 and I_2 respectively.

Figure 4.22 Force between two parallel conductors



If $I_1 = I_2$

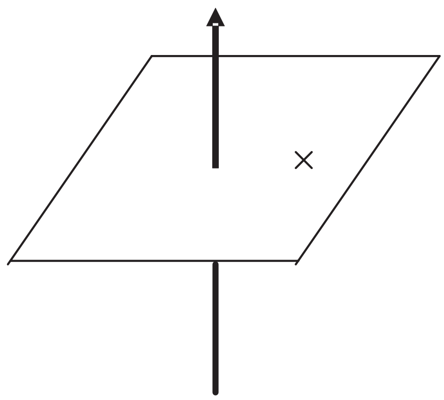
and $F_{21} = -F_{12}$ (opposite direction)

These forces are attractive when the currents are in the same direction.

The first wire is in the magnetic field created by the second wire and therefore will experience a force towards the second wire. Similarly the second wire will experience a force towards the first wire. Consequently when the two currents flow in the same direction the wires will move together and when the currents flow in opposite directions the wires will move apart.

Activity 4.5

Question 1: Sketch the shape and direction of the magnetic field shown below where the direction of the current is up the page.

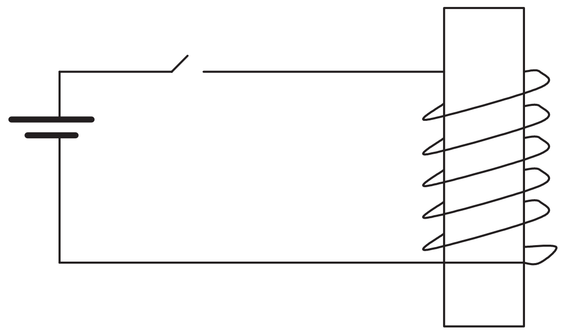


Question 2: In the previous question calculate the strength of the magnetic field at a point 2.5mm to the right of the conductor. Assume that the current flowing in the wire is 25mA.

Question 3: Draw a bar magnet and illustrate the shape and direction of the magnetic field that surrounds it.

Question 4: A current of 35mA passes through a wire of length 25cm which in turn in is moved through a uniform magnetic field of 3T. Assuming that the wire is at all time perpendicular to the magnetic field, calculate the force on the wire.

Question 5: The circuit below shows a solenoid wound around a soft iron cylinder. When the switch is closed in the circuit an electromagnet is formed. At what end of the cylinder will the North Pole of the field appear?



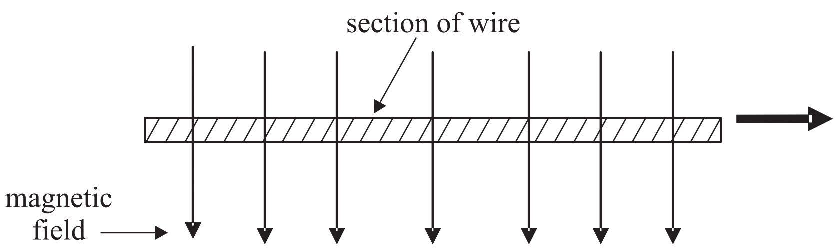
Question 6: In the previous question, how can we increase the strength of the electromagnet?

4.4 Alternating current (AC) concepts – more 'electricity in motion'

4.4.1 The generator effect (electro-magnetic induction)

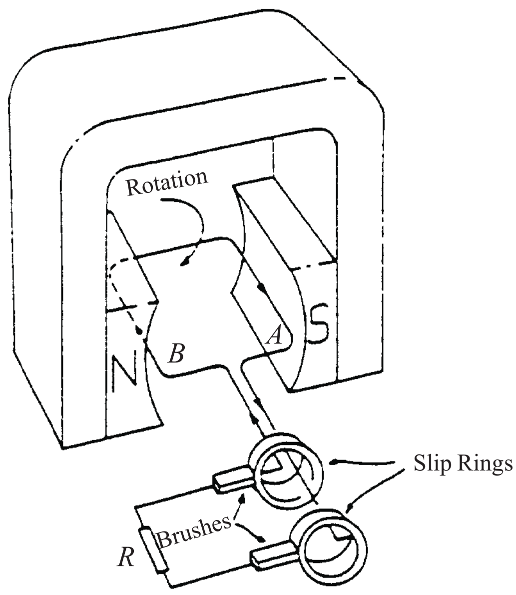
We have just seen that a current carrying conductor experiences a force on it if placed within a magnetic field (if the field lines are perpendicular to the current flow). We will now look at the inverse situation: by moving a conductor (wire) within a region of magnetic field, a current is generated. We call this current an **induced** current. This effect was discovered by Michael Faraday in 1831. In figure 4.23 if the wire were moved out of the page through the magnetic field that runs down the page, the current would continue to flow to the right. Unfortunately it is not practical to move a wire continuously in the one direction so a simpler solution to the production of electricity is to use an alternating generator.

Figure 4.23: Production of induced current



A simple alternating generator is shown in figure 4.24. In this generator there is a single coil of wire placed in a magnetic field. If we are able to rotate the coil from the other end (as shown in the diagram) current will flow briefly out of the loop at A which is connected to the slip ring furthest from the coil. Similarly the movement of the coil will induce a current to flow into the coil at *B* which is connected to the closest slip ring. As the coil rotates there is less wire actually perpendicular to the field so the current decreases until it finally ceases when the coil is upright. Further turning of the coil will then produce a current in the opposite direction. In this way an alternating current will be produced. The nature of the current produced can be varied by using more or less coils of wire, a different magnet and by altering the speed of rotation of the coil.

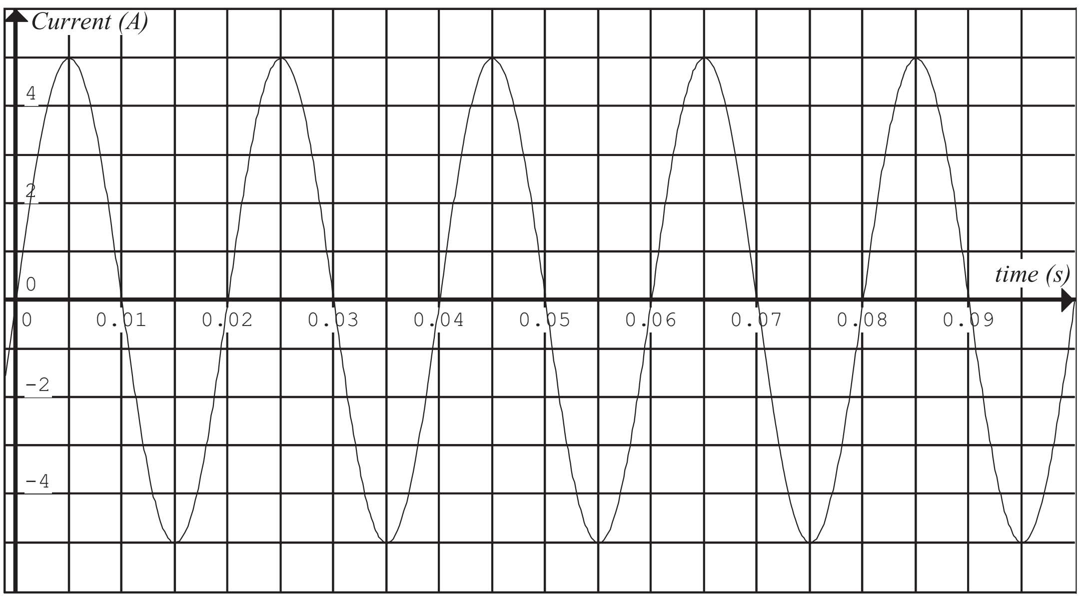
Figure 4.24: Simple alternating generator (AC Dynamo)



Simple Alternating Current Generator (AC Dynamo)

The current produced by a generator varies according to a sine relationship. The variation in current might look like that shown in figure 4.25 which shows a signal with 50 cycles per second (Hertz), the usual 240 volt frequency. You will notice that the current reaches a maximum (called peak) value of 5 amps after 0.005 seconds, this then drops to zero after 0.01 seconds and then it changes direction.

Figure 4.25: Graph of current against time for a typical AC power supply of 50Hz



One might think that having a current that changes direction all of the time is useless. As it turns out, resistors like light globes work irrespective of the direction of the current flowing. Ohm's law also applies to the voltage drop across a resistor in an alternating current (AC) circuit. As a result voltage change across a resistor will also vary according to a sine relationship.

Power in AC circuits and RMS values

As mentioned earlier, alternating current can still make a light bulb glow (in other words power is expended even if the current varies all of the time). When we calculate how much power might be used up in a light bulb (for example) we can use the same formula as used in DC circuits, that is:

$$P = I^2 R .$$

In this case I is the average current flowing in the AC circuit and R the resistance of the light bulb. This average current is more accurately termed the RMS (root mean square) value. The current shown in figure 4.25 had a peak value of 5 amps, its RMS value is:

$$\begin{aligned} I_{RMS} &= \frac{I_{Peak}}{\sqrt{2}} \\ &= \frac{5}{\sqrt{2}} \\ &= 3.5 \text{ A} \end{aligned}$$

So if that particular current was connected to a light bulb of resistance 200Ω, the power used would be:

$$\begin{aligned} P &= I^2 R \\ &= 3.5^2 \times 200 \\ &= 2450 \text{ W} \end{aligned}$$

Similarly when we refer to a power supply as being 240V we are talking about the 'average' voltage, the equivalent peak voltage would be:

$$\begin{aligned} V_{RMS} &= \frac{V_{Peak}}{\sqrt{2}} \\ 240 &= \frac{V_{Peak}}{\sqrt{2}} \\ V_{Peak} &= 240 \times \sqrt{2} = 339 \text{ V} \end{aligned}$$

Example: How much current should flow through a 60W light globe which is connected to a 240V mains power supply?

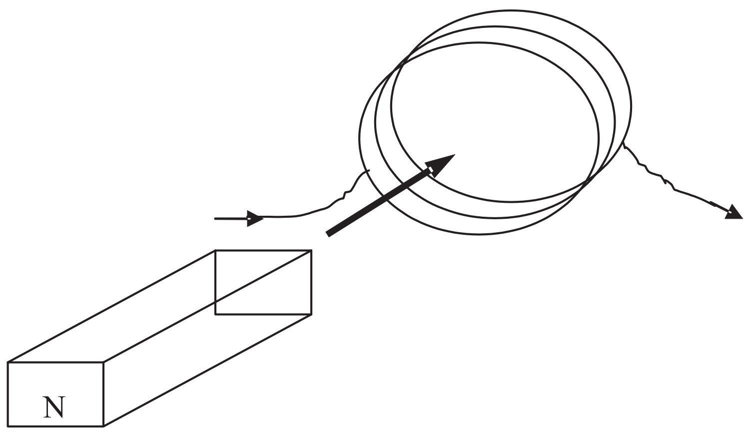
Solution: We use the RMS value of voltage in our power formula.

$$\begin{aligned} P &= VI \\ 60 &= 240I \\ I &= 60 \div 240 \\ &= 0.25\ \text{A} \end{aligned}$$

4.4.2 Transformers

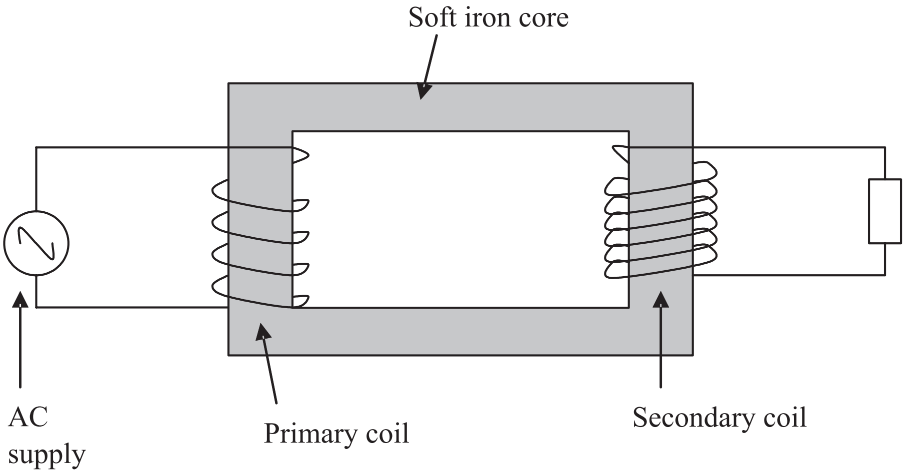
In the previous section, we discussed how AC electricity can be produced by moving a conductor in a magnetic field. It is not the movement of the conductor, as such, that produces the current, but rather the change in the magnetic field on the conductor caused by its movement. Consequently an induced current can be produced in a solenoid if a magnet is moved in and out of the solenoid. For example, in figure 4.26 moving the magnet into the coil will produce a current in the coil (provided that the coil is connected to a complete circuit!). The induced current is caused by the changing magnetic field.

Figure 4.26: Creation of an induced current in a solenoid



A changing magnetic field could also be achieved if the moving magnet in figure 4.26 was replaced by another stationary coil carrying an alternating current. We know that an electromagnet is formed when current moves through a solenoid, changing the direction of this current will therefore create a condition where the magnetic field is constantly changing. This phenomenon is the basis of the transformer which is shown in figure 4.27.

Figure 4.27: Diagram of simple transformer



The transformer consists of two coils of wire insulated from each other and wound onto a common soft iron core. One coil (the primary coil) is connected to an AC power supply. As the current begins to flow in the primary coil, a magnetic field will be set up in the iron core and consequently in the secondary coil. Every time the current changes direction in the primary coil the magnetic field in the core and therefore in the secondary coil will change direction. This changing magnetic field will induce an alternating current in the secondary coil.

The voltage on each coil is directly proportional to the number of turns on the coil, that is:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

where: V_p is the voltage in the primary coil; V_s the voltage in the secondary coil; N_p the number of turns in the primary coil; and, N_s the number of turns in the secondary coil.

This property is extremely useful, as it provides a mechanism for easily changing the voltage in an AC circuit.

Example: A 12V toy needs to be connected to a 240V mains power supply. Calculate the turns ratio in the transformer needed for this toy.

Solution: We know that the voltage in the primary coil will be $V_p = 240\text{V}$ and the voltage in the secondary coil $V_s = 12\text{V}$, therefore the turns ratio will be:

$$\frac{240}{12} = \frac{N_p}{N_s}$$

$$\frac{N_p}{N_s} = 20$$

That is, the transformer designer will need to ensure that the primary coil has 20 times more turns than the secondary coil.

If we assume that no power is lost in a transformer, then:

$$\text{Input power} = \text{Output power}$$
$$V_p I_p = V_s I_s$$
$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \left(\frac{N_p}{N_s}\right)$$

We see that the ratio of currents in the two coils is inversely proportional to the ratio of the voltages. So as we increase our voltage our current will decrease. Consider the following example.

Example: A transformer with 300 turns on the primary coil and 50 turns on the secondary coil is connected to a 240V AC supply which produces 15A of current. Calculate the current and voltage on the secondary coil.

Solution:

Calculating the voltage first we have $V_p = 240\text{V}$, $N_p = 300$ and $N_s = 50$. Therefore:

$$\frac{240}{V_s} = \frac{300}{50}$$
$$240 \times 50 = 300 \times V_s$$
$$12000 = 300V_s$$
$$V_s = 40\text{V}$$

Assuming no power is lost in the transformer, we can calculate the current.

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$
$$\frac{240}{40} = \frac{I_s}{15}$$
$$I_s = \frac{15 \times 240}{40}$$
$$= 90\text{A}$$

Notice that as the voltage is reduced the current is increased.

Power loss during transmission

We know that as electricity passes through any conductor, it will encounter some resistance and will therefore lose energy. The loss in power as a current passes through a wire of resistance R is given by:

$$P = I^2 R$$

That is, the power lost is proportional to the square of the resistance in the wire. Now the electricity generated in a power station may have to travel hundreds of kilometres along wires before it reaches the user. Even when using wires of very low resistance, the total resistance over a large distance can be quite large and consequently the power loss may be large. One way to reduce this power loss is to transmit the electricity with a lower current (as we cannot alter the resistance in the wires). Consequently the voltage is ‘stepped up’ at the power station (and the current is reduced) and then it is ‘stepped down’ at the user end of the transmission line.

Consider the following examples which show this important application of the transformer.

Example: Electricity is produced in a power station with a potential of 20000V and there is a demand for 30 Megawatts of power. We shall assume that the resistance of transmission lines is $2 \times 10^{-4} \Omega m^{-1}$ and the length of these lines is 50km. How much current will be needed and how much power will be lost in the wires?

Solution:

Using $V = 20000$ and $P = 30 \times 10^6$ we can calculate the size of the current necessary to deliver such power.

$$\begin{aligned} P &= VI \\ 30 \times 10^6 &= 20000 \times I \\ I &= 1500\text{A} \end{aligned}$$

The resistance encountered along the total length of the transmission lines will be $2 \times 10^{-4} \times 50000 = 10\Omega$, consequently the power lost will be:

$$\begin{aligned} P &= I^2R \\ &= 1500^2 \times 10 \\ &= 2.25 \times 10^7 \\ &= 22.5 \times 10^6\text{W} \end{aligned}$$

That is, even with such low resistance in the wires, 22.5 Megawatts would be lost in heat during the transmission.

If on the other hand the electricity was transmitted with a much higher voltage, then we wouldn’t need to have as much current and so power loss would be reduced.

Example: If in the above example the electricity was transmitted with a potential of 275kV instead of the original 20kV, how much current would be needed and what would be the power loss?

Solution:

A transformer would be needed to increase the potential from 20kV to 275kV, in doing so the current would be reduced. In the transformer $V_p = 20000$, $V_s = 275000$ and $I_p = 1500$. Consequently the new current can be calculated:

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$\frac{20000}{275000} = \frac{I_s}{1500}$$

$$I_s = 109$$

In order to deliver the same power a current of 109 Amps is necessary.

The power loss over the 50km of line can be calculated as:

$$\begin{aligned} P &= I^2R \\ &= 109^2 \times 10 \\ &= 118810 \\ &= 0.12 \times 10^6\text{W} \end{aligned}$$

We see that the power loss during transmission is reduced from about 22.5 Megawatts to approximately 0.12 Megawatts. In this example we assume no power is lost in the transformers. In practice this is not the case and some energy is lost in the transformer.

4.4.3 Domestic electricity

With the current awareness of effects on the environment and the daily economic pressures presently experienced, many people today are, or need to be, more conscious of the 'amount of electricity used' in the household. This is particularly the case when the bill from the electricity supply company arrives in the mail. Energy economy is also a selling point these days for many of the white goods/appliances that are available on the market, using a 'star rating' system.

As we have already seen in previous modules, power is the rate of change (or use) of energy with respect to time. Conversely, energy is the product of power and the time of application. So

$$P = Q/t \quad \text{(W)} \qquad \text{or} \qquad Q = Pt \quad \text{(J)}$$

(Where Q is the amount of energy in joules, P is the power in watts and t is the time in seconds.)

In this electrical environment the unit 'kilowatt-hour' (kWh) is used rather than joules, which means that power is measured in kilowatts and time in hours. So the conversion factor is

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

The household energy meter indicates the total accumulated kWh used. Note that some meters also indicate 0.1 kWh in the least significant digit (analog or digital readout). So to get an idea of your average daily use take note of the reading on your household meter and then one week later at the same time take another reading. By dividing the difference by seven will give you your average daily usage for that week.

To determine the amount of ‘power used’ domestically (actual energy used) by a particular appliance, just multiply the power rating in kW by the length of time it is in operation in hours. To assist you in this use the table supplied in this module, which gives approximate power ratings of a variety of domestic appliances.

Total energy consumption for domestic use,

$$Q = P \times t$$

where P is the power of the appliance in kW and t the time in hours.

Example:

What amount of energy in kWh is used by the conventional refrigerator on an average daily basis considering that the thermostatic control means that the internal motor is only on 60% of the day?

Solution:

Daily average number of hours usage $= 0.6 \times 24 = 14.4$ h

Conventional refrigerator power rating $= 150$ W $= 0.15$ kW

Average energy usage per day $= P \times t = 14.4 \times 0.15 = 2.16$ kWh

Activity 4.6

Question 1: The domestic electricity supply in the United Kingdom is nominally 230 V (RMS), what would be the peak voltage value?

Question 2: What will be the peak value of the current that flows through a 2400W heater connected to a 240V mains power supply?

Question 3: A transformer is required to reduce mains power of 240V and 10A to run a 6V appliance. Calculate the turn’s ratio for such a transformer.

Question 4: What will be the current flowing in the secondary coil of the transformer in question 3? How can we reduce the size of this current in the appliance itself?

Question 5: A 2000W electric fire is used for 10 hours. What is the cost, at 12c per kWh?

Table 4.1: Some common power ratings for appliances

Cooking Appliances	**Typical Rating (Watts)**
Crockpot	150
Frying pan	1200
Griller	1200
Vertical griller	1800
Range, stove	7000–12000
Hotplate 16cm diam.	1250
Hotplate 20.5cm diam.	2100
Grill/boiler 20.5cm × 25.5cm	2000
Grill/boiler 19cm × 38cm	2400
Grill/boiler 25.5cm × 30.5cm	2750
Ovens	1800–2500
Wall ovens	2500+
Domestic microwave oven	1300+

Note: the ratings in this table are for the appliance running on 'full' or 'high'. The use of lower settings or thermostats will reduce the power consumption.

Kitchen Appliances		
Coffee grinder		100
Coffee percolator		600
Dishwasher		2400
Food blender		450
Food mixer		110
Food warmer		400
Garbage disposal		500
Immersion heater –	large	2400
	small	1500
Jug		1800
Juice extractor		300
Kettle		1500
Toaster –	manual	600
	automatic	1500
Sandwich maker		600
Range hood		80

Lighting		
Incandescent lamps		40–1000
Fluorescent lamps –	20W–600mm (2 ft)	30
	40W–1200mm (4 ft)	50
Lighting (average home)		125 kWh per 2 months

Laundry Appliances	
Clothes dryer – cabinet type	2400
rotary plug-in	2400
rotary fixed wiring	4000
Iron – automatic or steam	1000
Washing machine – washing action	250
heating element	2400

Other Appliances	**Average Rating (Watts)**
Aquarium heater	100
Blankets – single	75
– double	120
Clock	2
Electric drill	500
Fan – 250mm (10") exhaust or circulating	50
400mm (16") circulating	70
Floor polisher	250
Hair dryer	1000
Lawn mower – 0.5kW cylindrical	500
1.5kW rotary	1500
Medical lamp infrared (heat)	250
Motors, electric – 0.25 kW	290
0.5 kW	550
Radio	100
Record player	120
Sewing machine	75–120
Swimming pool filter	300–1000
Television set	200
Vacuum cleaner	500
Video recorder	100
Water bed heaters	325

Direct Heating

Stripheaters	750–1500
Radiators	1000–2400
Skirting board heater/oil-filled heater	1000–2000
Portable fan heater	2000–2400
Fixed fan heater	3500–7000

If your heaters are thermostatically controlled your operating costs could be reduced by up to 50%.

Refrigeration

Refrigerator –	conventional	150
	two door	250
	frost free	350
Freezer –	chest type	200
	vertical	200
	frost free	250

Electric Water Heating

Persons in household	Water consumption (litres per person day)	consumption (kWh per day)
1	45–75	3.6–6.1
2	45–65	7.2–10.3
4	40–55	12.8–17.5
6	30–45	14.3–21.5
8	25–40	16.0–25.4

If your family uses off peak water heating you can expect the cost to be reduced by 50%.

(Source: Dangerfield, E 1991, *Engaging science – electricity – transformation*, Curriculum Corporation, Victoria, Australia, pp. 186–7. (Table quoted from *Your guide to operating costs of domestic electric appliances*, ACT Electricity and Water, Canberra, 1988.))

Section review

In this section we have studied magnetism and its relationship with electricity. We have also discussed concepts associated with the production and transmission of alternating current (AC) electricity. You should now assess yourself as to whether you have met the module objectives.

You should now be able to:

- explain the domain theory of magnetism
- calculate the magnitude and direction of the magnetic field near a current carrying wire
- describe how an electric motor operates
- calculate the force on a current carrying conductor placed in a magnetic field
- calculate the force on a charge moving in a magnetic field
- describe how a simple alternating generator (AC Dynamo) operates
- distinguish between peak and RMS features of an AC current
- describe the operation of a transformer
- calculate the voltage and current flowing in the secondary or primary coils of a transformer
- calculate the amount of power used by a domestic appliance.

In your study of this section you should have been making notes of the main points and listing those concepts that were difficult to understand.

Have you been able to revise those concepts that were difficult to understand?

Have you sought help?

Use the following post-test to see how you are going so far.

Post-test 4.2

Question 1:

Describe the shape of the magnetic field around a straight current carrying conductor.

Question 2:

Explain how the moving coil meter provides a deflection proportional to the current flowing through its coil.

Question 3:

An electron is accelerated from rest through a potential difference of 3000 V. It enters a region where $B = 5 \times 10^{-3}$ T perpendicular to its velocity. Calculate the force on the moving charge due to the magnetic field.

Question 4:

A copper bar 25 cm long lies perpendicular to a uniform magnetic field B of 0.75 T and carries a current of 2.5 A. Calculate the force experienced by the bar.

Question 5:

An AC current in a 10Ω resistance produces heat at the rate of 360W. Determine the effective (rms) values of the current and voltage.

Question 6:

A vacuum cleaner has a rating of 450W on the 240V mains. Which one of these fuses should be fitted in the plug: 0.5A, 1A, 2A, 5A?

Question 7:

A 'step up' transformer has 500 turns on the primary coil and 3200 on the secondary coil. If the electricity on the primary coil has a potential of 230V and a current of 9A, what will be the potential and current of the electricity on the secondary coil?

Question 8:

What is the cost of energy per week used in boiling a kettle to make a cup of tea if it takes 3 mins twice every day, and the electricity cost rate is 15 c/kWh?

Solutions to activities

Activity 4.1

Question 1:

The stroking of bristles against the hair results in charges being transferred. As all the hair strands are charged the same, forces of repulsion exist between them, causing them to tend to stand apart. The charge on the hair is different from that on the brush, so they also are attracted to the brush if it is brought close.

Question 2:

The comparable property is electric charge

$$F_{gravity} = \frac{Gm_1m_2}{r^2} \text{ and } F_{electric} = \frac{kq_1q_2}{r^2}$$

Note the similarity between these two equations.

Question 3:

Answer is (b).

(c) will also provide the resulting negative charge, however the protons are locked within the atomic/molecular structure of the jersey material.

Question 4:

Coulomb (C). One electron charge $= 1.6 \times 10^{-19}$ C.

Question 5:

Electrostatic forces are much stronger than gravitational forces. (This means we don't fall through the floor ! !)

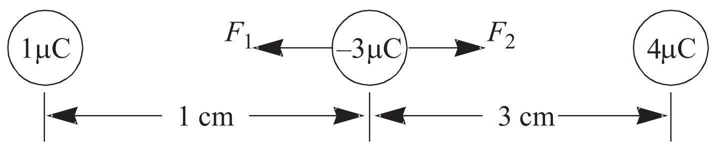
Activity 4.2

Question 1:

The chain or strap provides a conductive path for any charge imbalance to flow to/from earth. (The earth acts as a massive charge reservoir.)

Question 2:

Let us denote as F_1 the force between the $1\,\mu C$ and the $-3\,\mu C$ charges.



Similarly let F_2 be the force between the $-3\mu C$ and the $4\mu C$ charges.

Using Coulomb's law we can calculate these two forces.

$$F_1 = \frac{kq_1q_2}{r^2}$$

$$= \frac{9 \times 10^9 \times 1 \times 10^{-6} \times 3 \times 10^{-6}}{(1 \times 10^{-2})^2}$$

$$= 270 \text{ N}$$

Similarly

$$F_2 = \frac{kq_1q_2}{r^2}$$

$$= \frac{9 \times 10^9 \times 3 \times 10^{-6} \times 4 \times 10^{-6}}{(3 \times 10^{-2})^2}$$

$$= 120 \text{ N}$$

As both forces are in opposite directions, the resulting force on the $-3\mu C$ charge will be $270 - 120 = 150 \text{ N}$ towards the $1\mu C$ charge.

Question 3:

The charge on the helium nucleus is:

$$q_1 = 2e$$

$$= 2 \times 1.6 \times 10^{-19}$$

$$= 3.2 \times 10^{-19} \text{ C}$$

Similarly the charge on the oxygen nucleus is:

$$q_1 = 8e$$

$$= 8 \times 1.6 \times 10^{-19}$$

$$= 1.28 \times 10^{-18} \text{ C}$$

Therefore the force between the two ions will be:

$$F = \frac{kq_1q_2}{r^2}$$

$$= \frac{9 \times 10^9 \times 3.2 \times 10^{-19} \times 1.28 \times 10^{-18}}{(5 \times 10^{-9})^2}$$

$$= 1.47 \times 10^{-10} \text{ N}$$

Question 4:

The amount of work done is equal to the potential difference multiplied by the size of the charge:

$$\begin{aligned} W &= Vq \\ &= 24 \times 5 \\ &= 120 \text{ J} \end{aligned}$$

Consequently the amount of energy released by charge will be 120 J.

Question 5:

The field between the two plates is constant and its strength can be calculated:

$$\begin{aligned} E &= \frac{V}{d} \\ &= \frac{6}{5 \times 10^{-3}} \\ &= 1200 \text{ Vm}^{-1} \end{aligned}$$

Remember the field strength was defined as the force per unit charge, therefore:

$$\begin{aligned} E &= \frac{F}{q} \\ 1200 &= \frac{F}{6 \times 10^{-6}} \\ F &= 7.2 \times 10^{-3} \text{ N} \end{aligned}$$

Question 6:

The field between the two plates is constant and its strength can be calculated (as above):

$$\begin{aligned} E &= \frac{V}{d} \\ &= \frac{22 \times 10^{3}}{2 \times 10^{-2}} \\ &= 1.1 \times 10^{6} \text{ Vm}^{-1} \end{aligned}$$

If we let the charge on the oil droplet be q C, then the electrostatic force on it will be:

$$\begin{aligned} E &= \frac{F}{q} \\ 1.1 \times 10^{6} &= \frac{F}{q} \\ F &= 1.1 \times 10^{6} \times q \text{ N} \end{aligned}$$

This force is preventing the droplet from falling, so must equal its weight.

$$\begin{aligned} W &= mg \\ &= 2.2 \times 10^{-13} \times 9.8 \\ &= 2.156 \times 10^{-12}\ \text{N} \end{aligned}$$

Therefore:

$$\begin{aligned} F &= W \\ 1.1 \times 10^{6} \times q &= 2.156 \times 10^{-12} \\ q &= 2.156 \times 10^{-12} \div 1.1 \times 10^{6} \\ &= 1.96 \times 10^{-18}\ \text{C} \end{aligned}$$

Activity 4.3

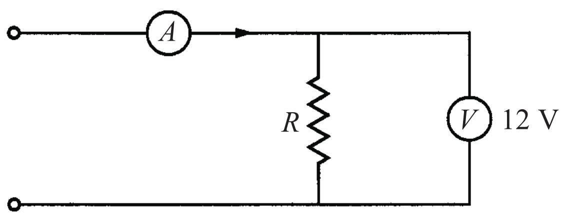
Question 1: Ohms (Ω); increases; decreases

Question 2:

$I = 1.5\text{A}$ and $V = 12\text{V}$

By Ohms Law $V = IR$

So $R = \frac{V}{I} = \frac{12}{1.5} = 8\Omega$



Question 3:

Using Ohms Law with $V = 1.5 \times 10^{-3}$ at $I = 1500$

$$R = \frac{V}{I} = \frac{1.5 \times 10^{-3}}{1500} = 1 \times 10^{-6}\ \Omega$$

Since the bar is 20 cm the resistance per meter will be:

$$\frac{1 \times 10^{-6}}{20 \times 10^{-2}} = 5 \times 10^{-6}\ \Omega\text{m}^{-1}$$

Question 4:

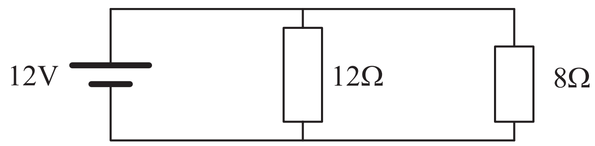
From the previous question $R = 1 \times 10^{-6}$ and $l = 20 \times 10^{-2}$. The cross sectional area is $A = 2 \times 10^{-4}\ \text{m}^2$, therefore the resistivity can be found:

$$R = \rho \frac{l}{A}$$

$$1 \times 10^{-6} = \rho \frac{20 \times 10^{-2}}{2 \times 10^{-4}}$$

$$\rho = 1 \times 10^{-9}\ \Omega\text{m}$$

Question 5:



The total resistance of the circuit can be calculated:

$$\frac{1}{R_T} = \frac{1}{8} + \frac{1}{12}$$

$$= \frac{20}{96}$$

$$R_T = \frac{96}{20} = 4.8\Omega$$

Consequently the total current flowing from the battery will be:

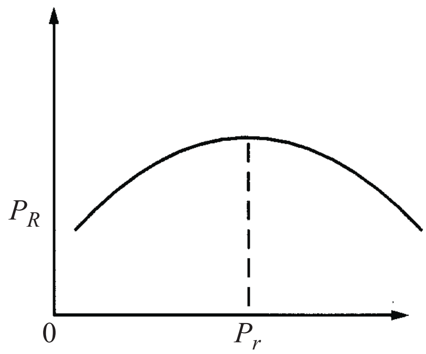
$$I = \frac{V}{R} = \frac{12}{4.8} = 2.5\ \text{A}$$

Activity 4.4

Question 1:

r	R	I	P_r	P_R
10	5	$\frac{12}{15}$	6.4	3.2
10	8	$\frac{12}{18}$	4.4	3.55
10	10	$\frac{12}{20}$	3.6	3.6
10	15	$\frac{12}{25}$	2.3	3.46
10	20	$\frac{12}{30}$	1.6	3.2

From the table it can be seen that the maximum power transfer is 3.6 watts when the internal and external resistances are each 10Ω. This can be shown in the figure below.



Question 2:

We need to firstly calculate the total external resistance. The 8Ω and the 12Ω resistors can be regarded as one resistor of 20Ω. The total external resistance is therefore:

$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{20}$$

$$= \frac{24}{80}$$

$$R_T = \frac{80}{24} = 3.3\Omega$$

Together with the internal resistance the total resistance is therefore $3.3 + 1 = 4.3\Omega$.

The current flowing in the battery will therefore be:

$$I = \frac{V}{R} = \frac{24}{4.3} = 5.58\ \text{A}$$

As this current flows in the battery (and through the internal resistance) it loses some potential. This can be calculated:

$$V = IR = 5.58 \times 1 = 5.58\ \text{V}$$

In other words the resistance in the battery accounts for almost 5.6V of lost potential. Therefore the overall voltage across the terminals will be $24 - 5.6 = 18.4$ V.

This will be the potential drop across the 4Ω resistor. So the current flowing in this resistor can be calculated:

$$I = \frac{V}{R} = \frac{18.4}{4} = 4.6\ \text{A}$$

The remaining 1 A of battery current should flow through both the 8Ω and 12Ω resistors.

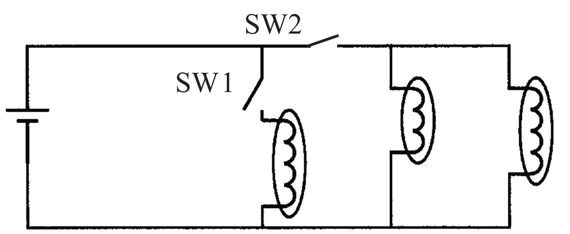
Question 3:

(a) Both lamps are lit (equally)

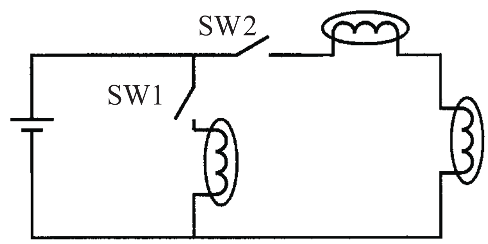
(b) Neither lamps are lit

(c) Only lamp Y is lit. (lamp X is off)

Question 4:



OR



Question 5:

Using our definition of power, we can calculate the current flowing in the circuit:

$$P = I^2R$$
$$360 = I^2 \times 10$$
$$I^2 = 36$$
$$I = 6\ \text{A}$$

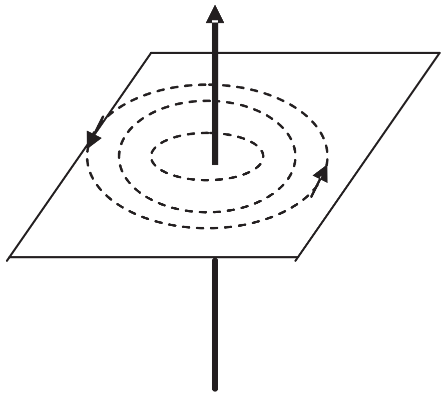
Then using Ohm's law we can calculate the voltage across the resistor.

$$V = IR = 6 \times 10 = 60\ \text{V}$$

Activity 4.5

Question 1:

The field will be circular as shown in an anti-clockwise direction.



Question 2:

Using $r = 2.5 \times 10^{-3}$ m and $I = 25 \times 10^{-3}$ A we obtain:

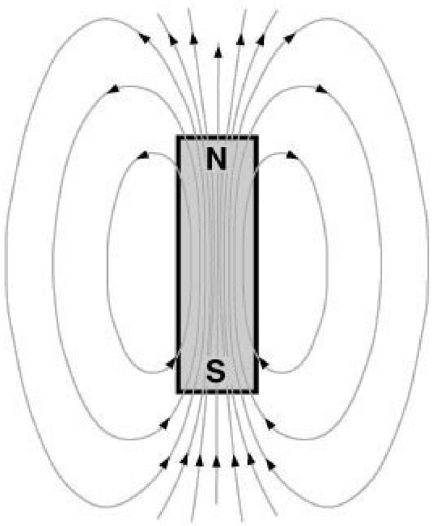
$$B = \frac{\mu I}{2\pi r}$$

$$= \frac{4\pi \times 10^{-7} \times 25 \times 10^{-3}}{2\pi \times 2.5 \times 10^{-3}}$$

$$= 2 \times 10^{-6} \text{ T}$$

Question 3:

For a bar magnet the field will resemble:



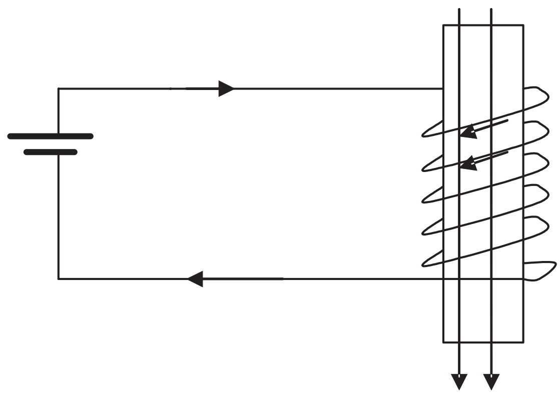
Question 4:

Using $I = 35 \times 10^{-3}$ A, $l = 0.25$ m, $B = 3$ T and $\theta = 90$ we obtain:

$$\begin{aligned} F &= BIl\sin\theta \\ &= 3 \times 35 \times 10^{-3} \times 0.25 \times \sin 90 \\ &= 0.026 \text{ N} \end{aligned}$$

Question 5:

When the switch is closed the current will flow in the direction shown below. Using the right hand grip rule, we find that the magnetic field within the solenoid will be in the downward direction. Consequently the North Pole will be on the bottom of the cylinder.



Question 6:

The strength of the magnetic field can be increased by either using a larger current or putting more coils of wire on the metal cylinder.

Activity 4.6

Question 1:

$V_{RMS} = 230$ V, therefore $V_{peak} = \sqrt{2} \times V_{RMS} = \sqrt{2} \times 230 = 325\text{V}$.

Question 2: Using the RMS value of 240V for voltage we obtain:

$$P = VI$$
$$2400 = 240I$$
$$I = 10\text{A}$$

Consequently the peak current will be:

$I_{peak} = \sqrt{2} \times I_{RMS} = \sqrt{2} \times 10 = 14.1\text{A}.$.

Question 3:

In this case $V_p = 240\text{V}$, $V_s = 6\text{V}$ and $I_p = 10\text{A}$. The turns ratio is equal to the ratio of the primary and secondary voltage, that is 240 : 6 = 40 : 1. So the primary coil will need 40 times more turns than the secondary coil.

Question 4:

The secondary current will be 40 times the primary current, that is 400A. Obviously this is a very large current and it would burn out most appliances. In order to reduce this current, a very large resistance (called a shunt resistance) can be placed in series with the appliance or alternatively a very small resistance can be placed in parallel with the appliance.

Question 5:

The amount of energy used $Q = P \times t = 2\text{kW} \times 10\text{h} = 20\text{kWh}$. Since energy costs 12c per kWh, the cost of running this appliance will be $20 \times 12 = 240\text{c}$.

Solutions to post-tests

Post-test 4.1

Question 1: a, c, d

Question 2: c (number of elections $= \dfrac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$)

Question 3:

$$E = \frac{kq}{r^2} = \frac{9 \times 10^9 \times 2 \times 10^{-6}}{(4 \times 10^{-2})^2} = 1.125 \times 10^7 \text{ NC}^{-1}$$

Question 4:

$$F = \frac{kq_1q_2}{r^2}$$

$$= \frac{9 \times 10^9 \times (18 \times 1.6 \times 10^{-19})^2}{(2 \times 10^{-9})^2}$$

$$= 1.87 \times 10^{-8} \text{ N}$$

(where $q_1 = 18 \times 1.6 \times 10^{-19} = q_2$)

Question 5:

Current is the rate of flow of charge, $I = \dfrac{q}{t} = \dfrac{10}{0.01} = 1000\text{A}$

Energy (work done) $W = qV = 10 \times 10 \times 10^6 = 10^8\text{J} = 100 \text{ MJ}$

Question 6:

The electric field between the two plates is given by

$$E = \frac{V}{d} = \frac{12}{0.005} = 2400\text{NC}^{-1}$$

The force on a charge of $2\mu C$ will be:

$$E = \frac{F}{q}$$

$$2400 = \frac{F}{2 \times 10^{-6}}$$

$$F = 4.8 \times 10^{-3} \text{ N}$$

Question 7:

For parallel resistances

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{20} = \frac{1}{30} + \frac{1}{R_2}$$

$$\frac{1}{R_2} = \frac{1}{20} - \frac{1}{30}$$

$$R_2 = 60\Omega$$

$\therefore$ Parallel resistor required $= 60\Omega$

Question 8:

The work done in moving the charge from the negative to positive plates will be $W = qV = 5 \times 10^{-6} \times 3 = 1.5 \times 10^{-5}$ J, however there will be no work necessary to move the charge the other way as a positive charge will freely move towards the negative terminal.

Question 9:

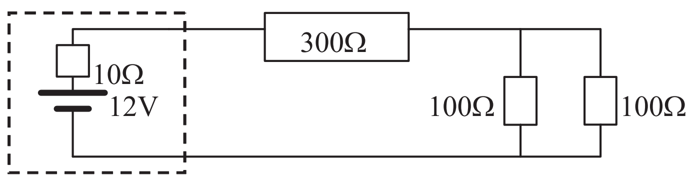
(a) Combined resistance $R = R_1 + R_2 = 12 + 15 = 27\Omega$

(b) Current flowing $I = \frac{V}{R} = \frac{9}{27} = 0.33\text{A}$

(c) Potential difference across 12 Ω resistor $V = IR = 0.33 \times 12 = 4\text{V}$.

Question 10:

(a) A possible circuit diagram is:



(b) In order to calculate the current flowing in the battery, we need to firstly determine the total resistance in the circuit.

The two 100Ω resistors in parallel are equivalent to one resistor of 50Ω. Therefore the total external resistance will be $300 + 50 = 350\Omega$ and the total resistance on the battery $350 + 10 = 360\Omega$. The current flowing in the circuit and in the battery will be:

$$I = \frac{V}{R} = \frac{12}{360} = 0.033\text{A}$$

(c) The nominal drop across the battery is 12V, however some of that is lost on the internal resistance. The potential drop across the internal resistor is:

$V = IR = 0.033 \times 10 = 0.33\text{V}$.

Therefore the drop across the terminals will be $12 - 0.33 = 11.66\text{V}$.

(d) The power lost in the external circuit will be $P = I^2R = 0.033^2 \times 350 = 0.38\ \text{W}$.

Post-test 4.2

Question 1:

The magnetic field surrounding a current carrying conductor is circular. See figure 4.14.

Question 2:

The moving coil is placed within a magnetic field. As current moves in the arms of coil, it will experience a force. This force causes the coil to turn which in turn causes the needle on the meter to turn.

Question 3:

Firstly we need to calculate the velocity of the electron as it enters the magnetic field. We know that as it passes through the potential difference it must gain energy. More specifically:

$$V = \frac{W}{q}$$

$$3000 = \frac{W}{1.6 \times 10^{-19}} \quad \text{(since the charge on an electron is } 1.6 \times 10^{-19}\text{ C)}$$

$$W = 4.8 \times 10^{-16}\text{ J}$$

If we assume that energy gained by the electron becomes kinetic, we can then calculate its velocity. Remember that the work done on an object will equal its change in kinetic energy.

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$4.8 \times 10^{-16} = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 \quad \text{(since the mass on an electron is } 9.1 \times 10^{-31}\text{ kg)}$$

$$v^2 = 1.05 \times 10^{15}$$

$$v = 3.25 \times 10^7 \text{ms}^{-1}$$

The force on the electron due to the magnetic field is:

$$F = qvB$$

$$= 1.6 \times 10^{-19} \times 1.6 \times 10^7 \times 5 \times 10^{-3}$$

$$= 2.6 \times 10^{-4}$$

Question 4:

$$l = 25 \times 10^{-2}\text{ m}, B = 0.75\text{ T and } I = 2.5\text{ A}$$

$$\text{Force } F = BIl = 0.75 \times 2.5 \times 0.25 = 0.47\text{ N}$$

Question 5:

$P = 360\text{W}$ and $R = 10\Omega$. Now $P = VI = I^2R$, so

$$\begin{aligned} P &= I^2R \\ 360 &= I^2 10 \\ 36 &= I^2 \\ I &= 6\text{A} \end{aligned}$$

Using Ohm's law we can then calculate the voltage drop

$V = IR = 6 \times 10 = 60\text{V}$

Therefore the effective (RMS) voltage is 60V and current is 6A.

Question 6:

$P = 450$ W and $V = 240$ V, so

$$\begin{aligned} P &= VI \\ 450 &= 240I \\ I &= \frac{450}{250} = 1.875\text{A} \end{aligned}$$

A 2A fuse would be necessary.

Question 7:

In this question we have $N_p = 500$, $N_s = 3200$, $V_p = 230$ and $I_p = 9$. Calculating the voltage on the secondary coil first gives:

$$\begin{aligned} \frac{V_p}{V_s} &= \frac{N_p}{N_s} \\ \frac{230}{V_s} &= \frac{500}{3200} \\ 736000 &= 500V_s \\ V_s &= 1472\text{V} \end{aligned}$$

Similarly the current on the secondary coil will be:

$$\begin{aligned} \frac{I_p}{I_s} &= \frac{N_s}{N_p} \\ \frac{9}{I_s} &= \frac{3200}{500} \\ I_s &= 1.4 \text{ A} \end{aligned}$$

Question 8:

Total time per week that the kettle is on is

$$\begin{aligned} t &= 7 \times 2 \times 3 \text{ mins} \\ &= 42 \text{ mins} \\ &= \frac{42}{60} \text{ hours} \end{aligned}$$

Kettle power rating = 1500 W (see table)

Energy used by kettle per week $Q = P \times t = 1500 \times \frac{42}{60} = 1050\,\text{Wh} = 1.05\,\text{kWh}$

Total weekly cost of running kettle = $1.05 \times 15 = 15.75\text{c} = 16\text{c}$

Appendix 1

A.2 TPP7160 – Preparatory physics

Home Experiments

(Note this experiment is detailed on the video that accompanies this unit.)

Consider the following home experiment.

What is the relationship between the angle of projection of a stream of water and the length of that projection?

In the experiment you will need a garden hose connected to a water supply, a protractor and a long measuring tape.

Hold the hose close to the ground and turn the tap on. As you change the angle of projection where does that water land? Be aware of changing weather conditions.

What do you think will happen?

The steeper the angle the closer the water will land.

Describe in detail the methods you used to perform this experiment.

- Tape measure 10m long, marked in mm.
- Standard Protractor.
- Standard garden hose fitted with nozzle.

Standing with hose vertical I decreased the angle, about 20° each time. An assistant measured the distance from the nozzle base to the first drop of water. I recorded the angle and distances in a table, using angles measured on a sheet of cardboard.

Describe what did happen.

The water always travelled in a parabolic path. At first it landed close to the nozzle as the angle increased the distance also increased until it reached a maximum then the distance started to decrease. (See attached table.)

What is your explanation of this?

Effects of gravity cause parabolic shape. At different angles of projection the force of gravity acts in the water to produce different parabolic curves.

Did you use any other resources in this experiment?

Ohanian, H.C. 1994, *Principles of Physics*, W.W. Norton & Co., New York.

Taylor, J., Grant, D. & Norman, U. 1996, Study Notes for *Preparatory Physics*, USQ.

The Home Experiment Report

Title

A report on the effect of change in angle of projection on the a stream of water.

Brief and specific.

Introduction

On Earth gravity effects motion of all types. It is known to cause any body moving through the air to move in a parabolic path. The experiment aims to investigate the effects of changing the angle of projection of a stream of water on the distance that water lands from the point of origin.

Occasionally more background information is given, but should be less than 20% of the report.

Material and Methods

The experiment was set up in a clear open space in fine weather conditions with no wind. A standard garden hose six m long, fitted with a nozzle, was used to project a stream of water into the air. Angles were measured using a piece of cardboard graduated with angles between 0 and 90° with a standard protractor. The length of stream from the nozzle was measured with a 10 m tape graduated in 5 cm units.

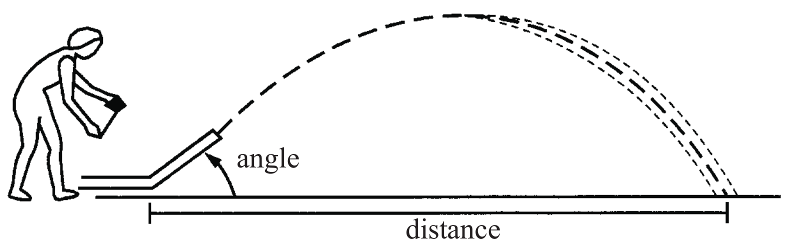
Past tense.

Third person.

Short sentences.

Initially the hose was projected horizontally and then moved up in 10° jumps. After each move an assistant measured the distance from the end of the nozzle to the landing place to the majority of the water spray (see diagram).

Include diagrams of experimental setup.



Results

Past tense.

Third person.

Short sentences.

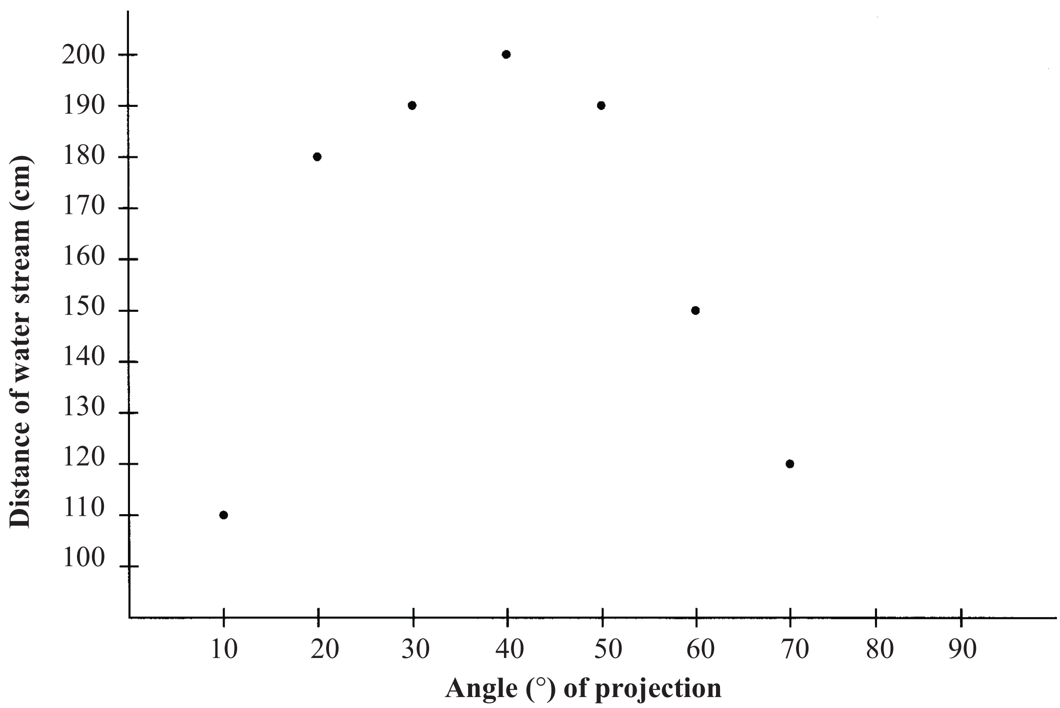
Include tables or graphs, representing data collected.

The water was seen to travel in a distinct parabolic path.
The distance of the water from the nozzle changed considerably with the changing angle of projection. The table below details these results.

Angle (°)	Distance (mm)
10	110
20	180
30	190
40	200
50	190
60	150
70	130
	not measurable

These data are represented diagrammatically in the figure below.

Distance of stream of water (cm) and angle of projection (°)



Discussion and Conclusions

It was clear from the experiment, that the water, like all bodies moving through the air, followed a parabolic path i.e. this is the classical response to the pull of gravity on the water droplets (see study notes section 2.3.1).

Past tense.

Third person.

Do not repeat results, but interpret results.

Relate results to references.

Discuss results in terms of aims and methods used.

Further the results indicate that the distance from the origin of the water is a function of the angle of projection. An angle of about 40° gives the maximum distance travelled while angles smaller or larger then this result in shorter distances. These results confirm the water pathway described in Ohanian (1994) that 'two angles that are of equal amounts above or below 45° yield equal ranges'. For example angles at 55° and 35° gave a similar range.

Results however were not exactly as predicted by Ohanian (1994) due to the effects of air resistances on varying water pressures supplied by the hose. Control of the later and removal of the experiment to an internal environment would reduce the errors due to these factors. Measurement of the angle of projection was also only an approximation because of the accuracy of the equipment available, and errors due to the reading of the results (parallax error).

References

Ohanian, H.C. 1994, *Principles of Physics*, W.W. Norton & Co., New York.

Taylor, J., Grant, D. & Norman, U. 1996, Study Notes for *Preparatory Physics*, USQ.

Appendix 2

Mathematics Concepts and Formulae: In Brief

It is expected that when you enrol in this unit that you will be proficient in the appropriate mathematics (e.g. *Level B Tertiary Preparation Mathematics* or equivalent). However to jog your memory we have included certain basic concepts crucial to your success in this physics unit. If you have difficulty with any of these concepts please consult your tutor who will be able to provide you with extra help or materials.

Powers

In module 1 of this unit, numbers expressed to a range of powers were commonly used. But what is a power.

For any number, a, the nth power of that number is the number multiplied by itself n times.

So that

$$a^1 = a$$

$$a^2 = a \times a$$

$$a^3 = a \times a \times a \qquad \text{etc.}$$

$$\vdots$$

$$a^n = \underbrace{a \times a - - - - - \times a}_{n \text{ lots of } a}$$

Powers can also be termed exponents so

a^n ← power, exponent or index

↑ base

Zero, negative and fractional powers also exist. By definition these mean.

$$a^0 = 1$$

$$a^{-n} = \frac{1}{a^n}$$

$$a^{\frac{1}{n}} = \sqrt[n]{a}$$

Example

1. $2^0 = 1, \quad 100^0 = 1$

2. $3^{-2} = \frac{1}{3^2} = \frac{1}{9}, \quad 10^{-1} = \frac{1}{10}$

3. $2^{\frac{1}{2}} = \sqrt[2]{2} \cong 1.4142$

   $2^{\frac{1}{3}} = \sqrt[3]{2} \cong 1.2599$

Powers can be combined using the following rules.

$$a^m \times a^n = a^{m+n}$$

$$a^m \div a^n = a^{m-n}$$

$$(a^m)^n = a^{mn}$$

$$a^m \times b^m = (ab)^m$$

Example

1. $2^3 \times 2^{203} = 2^{3+203} = 2^{206}$
2. $10^{67} \div 10^{23} = 10^{67-23} = 10^{44}$
3. $(7^6)^{-2} = 7^{6 \times -2} = 7^{-12}$
4. $2^7 \times (-5)^7 = (2 \times -5)^7 = (-14)^7$

Algebra

Physicists look for general rules or laws which will apply in many situations. To this end algebra is an important tool for the physicist as it is method in which a variable or a quantity, that can take on a range of values, is easily manipulated. In the language of algebra, variables are always represented by a letter and often included in mathematical equations which are the generalisations of a particular relationship or rule.

The rules of algebra instruct us now to manipulate equations so that we can obtain values of a variable or write one variable in terms of another.

Example

Change the subject of the following formula from x to y.

(i) $x = 2y - 3$

$x + 3 = 2y - 3 + 3$ Add 3 to both sides.

$x + 3 = 2y$

$$\frac{x+3}{2} = \frac{2y}{2}$$ Divide both sides by 2.

$$\frac{x+3}{2} = y$$

$$y = \frac{x+3}{2}$$ Reverse equation so that written in conventional form of $y =$

(ii) $x = 2 + \frac{1}{2}y^2$

$$x - 2 = 2 - 2 + \frac{1}{2}y^2$$ Subtract 2 from each side.

$$x - 2 = \frac{1}{2}y^2$$

$$2(x - 2) = \frac{2}{2}y^2$$ Multiply both sides by 2.

$$2(x - 2) = y^2$$

$$y^2 = 2(x - 2)$$

$$y = \pm\sqrt{2(x-2)}$$ Take square root at both sides.

(iii) $x = \frac{1}{2y} + \frac{1}{3y}$

$$x = \frac{3}{3 \times 2y} + \frac{2}{2 \times 3y}$$ Make common denominator of $6y$.

$$x = \frac{3}{6y} + \frac{2}{6y}$$ Add fractions.

$$x = \frac{5}{6y}$$

$$x \times 6y = \frac{5}{6y} \times 6y$$ Multiply both sides by $6y$.

$$x \times 6y = 5$$

$$6y = \frac{5}{x}$$ Divide both sides by x.

$$y = \frac{5}{6x}$$ Divide both sides by 6.

Finding the solution of quadratic equations

If $ax^2 + bx + c = 0$

then $x = \dfrac{-b \pm\sqrt{b^2 - 4ac}}{2a}$

This formula would only be useful if the equation could not be easily factorised. Note that if $b^2 - 4ac$ is negative then there is no solution to the equation.

Example

Find the value of x for the following equations.

(i) $2x^2 + 3x - 1 = 0$

$$x = \frac{-3 \pm\sqrt{3^2 - 4 \times 2 \times -1}}{2 \times 2}$$

$$= \frac{-3 \pm\sqrt{9 + 8}}{4}$$

$$= \frac{-3 \pm\sqrt{17}}{4}$$

$x \cong 0.2808$ or $x \cong -1.7808$

Trigonometry

The angle between any two intersecting lines is defined as a fraction of a circle. This can be done in two ways using two different but related units of measurement – degrees and radians.

A circle is made up of either 360° or 2π radians.

Degrees	Radians
0	0
30°	$\frac{\pi}{6}$ or $\cong$ 0.524
60°	$\frac{\pi}{3}$ or $\cong$ 1.0472
90°	$\frac{\pi}{2}$ or $\cong$ 1.5708
180°	π or $\cong$ 3.1416

Example

Convert 10° into radians.

$$360° = 2\pi \text{ rad.}$$

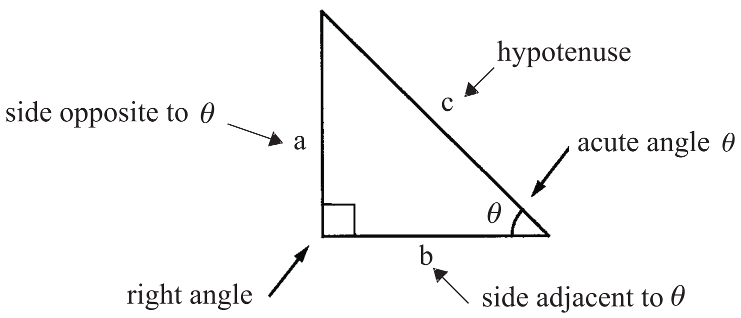
$$1° = \frac{2\pi}{360} \text{ rad.}$$

$$10° = 10 \times \frac{2\pi}{360} \text{ rad.}$$

$$10° = 0.1745 \text{ radians} \qquad \text{(using calculator)}$$

Trigonometric Ratios

In any right angled triangle the lengths of the sides of the triangle and the angles of the triangle are related by trigonometric ratios.



$$\text{cosine of } \theta \ (\cos \theta) = \frac{\text{side adjacent } \theta}{\text{hypotenuse}} = \frac{b}{c}$$

$$\text{sine of } \theta \ (\sin \theta) = \frac{\text{side opposite } \theta}{\text{hypotenuse}} = \frac{a}{c}$$

$$\text{tangent of } \theta \ (\tan \theta) = \frac{\text{side opposite } \theta}{\text{side adjacent } \theta} = \frac{a}{b}$$

These ratios are standard trigonmetric functions for any angle and can be found using tables or your calculator.

Example

Find $\sin(40°) = 0.6428$

$\sin(40 \text{ rad.}) = 0.7451$

Note: check that your calculator is in the correct mode, degree or radian, before doing these calculations).

Example

If sin θ = 0.2456 what is θ.

Solution

Use $\sin^{-1}\theta$ on your calculator.

0.2456 [Shift] [$\sin^{-1}$] [=] 0.2481 (using Casio fx 82 scientific calculator)

θ = 0.2481 radians

θ = 14.22°

Trigonometric Ratios of Any Angle

Consider the following:

Quadrant 2

$\cos\theta = -x$

$\sin\theta = y$

$\tan\theta = \frac{-y}{x}$

} Only Sine positive

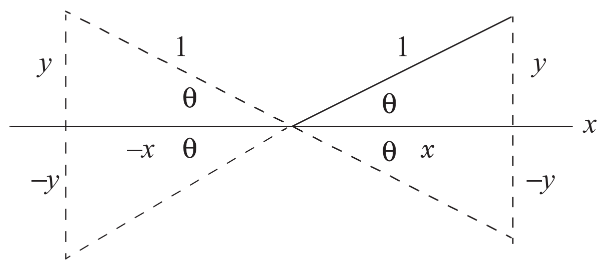
Quadrant 1

$\cos\theta = x$

$\sin\theta = y$

$\tan\theta = \frac{y}{x}$

} All positive



$\cos\theta = -x$

$\sin\theta = -y$

$\tan\theta = \frac{y}{x}$

} Only Tangent positive

Quadrant 3

$\cos\theta = x$

$\sin\theta = -y$

$\tan\theta = \frac{-y}{x}$

} Only Cosine positive

Quadrant 4

These patterns allow us to calculate the trig ratios of any angle.

Quadrant 1		Quadrant 2		Quadrant 3		Quadrant 4
$\cos\theta$	=	$-\cos(180 - \theta)$	=	$-\cos(180 + \theta)$	=	$\cos(360 - \theta)$
$\sin\theta$	=	$\sin(180 - \theta)$	=	$-\sin(180 + \theta)$	=	$-\sin(360 - \theta)$
$\tan\theta$	=	$-\tan(180 - \theta)$	=	$\tan(180 + \theta)$	=	$-\tan(360 - \theta)$

Example

Calculate the following ratios

(i) $\sin 120° = \sin(180 - 40)° = \sin 40° = 0.6428$

(ii) $\cos 210° = \cos(180 + 30)° = -\cos 30° = -0.8660$

Example

If $\sin\theta = 0.237$ find θ between 0 and 360°.

Solution

Using calculator $\theta = 13.71°$, but this is only the acute angle in Quadrant 1. The sin ratio can also be positive in Quadrant 2, so another solution is

$$\theta = 180 - 13.71°$$

$$\theta = 166.29$$

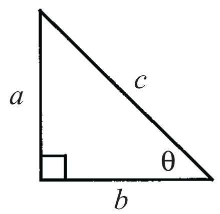
So solutions are $\theta = 13.71°$ and $166.29°$

Check answer by calculating backwards.

Other common identities a

Pythagoras rule

1. $a^2 + b^2 = c^2$
2. $\sin^2\theta + \cos^2\theta = 1$

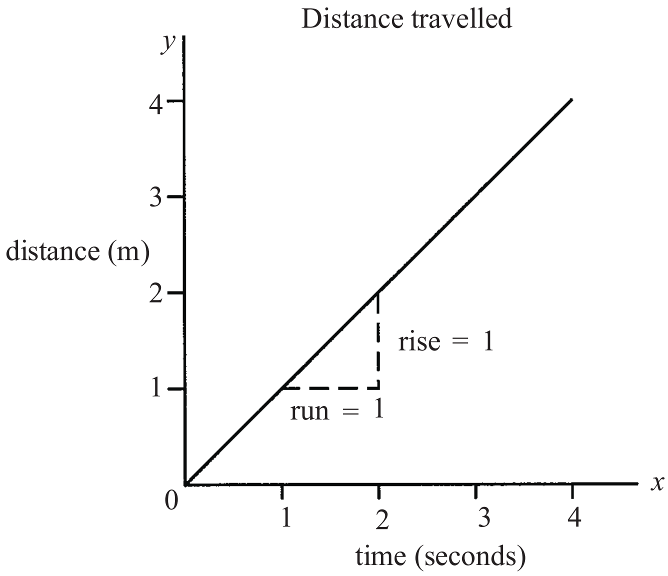


Graphing Data

When graphing data containing two variables the first step is to examine the data to determine which variable you have manipulated (the independent variable) and which variable (or variables) has changed as a result of changes to the independent variable. This second variable is called the dependent variable. When two variables are graphed the resultant relationship can take a number of different forms. The following are the most commonly seen forms.

Linear Relationships

The linear relationship between two variables can be written as $y = mx + b$ where x is the independent variable and y is the dependent, m is the value of the gradient (or slope) of the line and b the y intercept.



$$\text{Gradient } m = \frac{\text{rise}}{\text{run}} = \frac{1}{1} = 1$$

Intercept $b = 0$

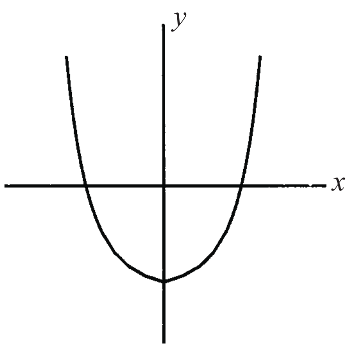
Equation is $y = x$

Parabolic Relationships

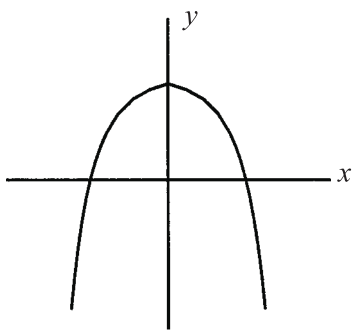
This relationship is represented by the equation

$$y = ax^2 + bx + c$$

If a is positive



If a is negative



The second parabolic is the typical path of a projectile.

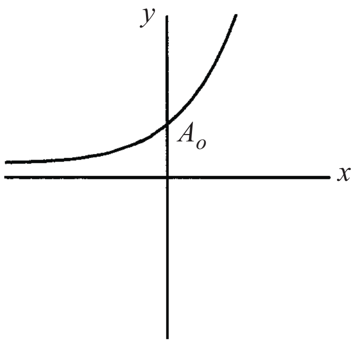
Exponential Relationship

These relationships are typically represented by the equation

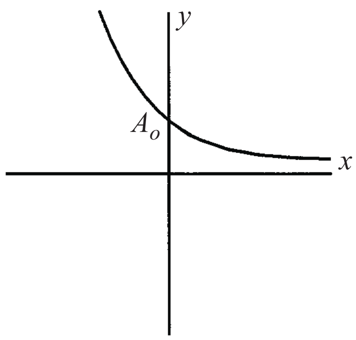
$$y = A_o a^{bx}$$

Often a has the value of the exponential constant, e,

If b is positive



If b is negative



The second function is typical of the reduction in the mass of a radioactive element over time.

Appendix 3

Conversion of Units and Fundamental Constants

Imperial	Metric
1 ft	0.3048* m
1 in	25.4* mm
1 mile	1.609 344* km
1 ft/min	0.005 08* m/s
1 mile/hr	0.447 04* m/s
1 ft^2	0.09290304* m^2
1 in^2	0.00064516* m^2
1 acre	4046.86 m^2
1 $mile^2$	2.58999 km^2
1 ft^3	28.3168 litres
1 UK gal	4.45609 litres
1 lb	0.45359237* kg
1 oz	28.3495 g
1 long ton	1.01605 Mg (tonne)
1 lb/ft^3	16.0185 kg/m^3
1 lb/hr	0.00012599 kg/s
2.953×10^{-4} inches Hg	1 pascal or 1 Nm^{-2}
29.92 inches Hg	1 atmosphere
29.92 inches Hg	1.013×10^5 Nm^{-2}

Exact conversion factors are terminated by an asterisk *

Fundamental Constants

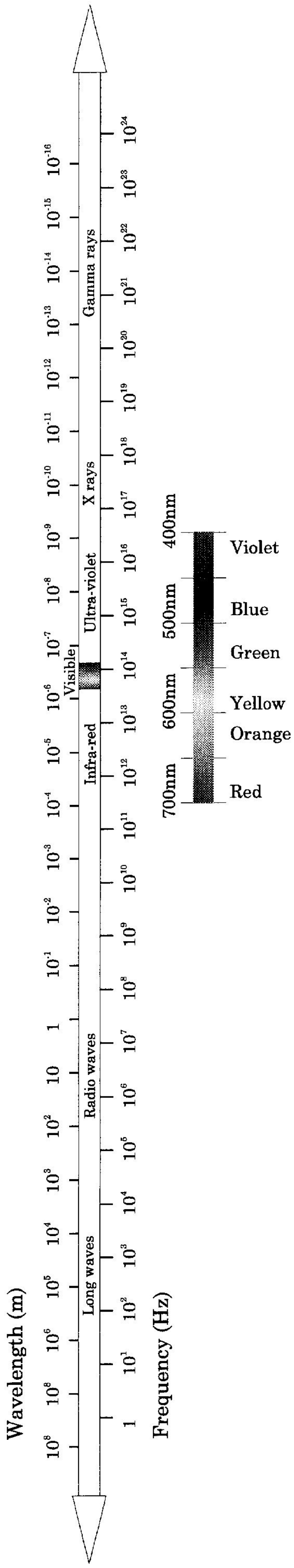
Speed of light in a vacuum (c)	299792458 ms^{-1}
Newtonian constant of gravitation (G)	6.67259×10^{-11} m^3 kg^{-1} s^{-2}
Electron mass (m_e)	$9.1093897 \times 10^{-31}$ kg
Planck's constant	6.63×10^{-34} Js

1 1.008 **H** Hydrogen																	2 4.003 **He** Helium
3 6.941 **Li** Lithium	4 9.012 **Be** Beryllium					Atomic # Mass **Symbol** Name						5 10.811 **B** Boron	6 12.011 **C** Carbon	7 14.007 **N** Nitrogen	8 15.999 **O** Oxygen	9 18.998 **F** Fluorine	10 20.180 **Ne** Neon
11 22.990 **Na** Sodium	12 24.305 **Mg** Magnesium											13 26.982 **Al** Aluminium	14 28.086 **Si** Silicon	15 30.974 **P** Phosphorus	16 32.066 **S** Sulphur	17 35.453 **Cl** Chlorine	18 39.948 **Ar** Argon
19 39.098 **K** Potassium	20 40.078 **Ca** Calcium	21 44.956 **Sc** Scandium	22 47.88 **Ti** Titanium	23 50.942 **V** Vanadium	24 51.996 **Cr** Chromium	25 54.938 **Mn** Manganese	26 55.847 **Fe** Iron	27 58.933 **Co** Cobalt	28 58.693 **Ni** Nickel	29 63.546 **Cu** Copper	30 65.39 **Zn** Zinc	31 69.723 **Ga** Gallium	32 72.61 **Ge** Germanium	33 74.922 **As** Arsenic	34 78.96 **Se** Selenium	35 79.904 **Br** Bromine	36 83.80 **Kr** Krypton
37 85.468 **Rb** Rubidium	38 87.62 **Sr** Strontium	39 88.906 **Y** Yttrium	40 91.224 **Zr** Zirconium	41 92.906 **Nb** Niobium	42 95.94 **Mo** Molybdenum	43 97.907 **Tc** Technetium	44 101.07 **Ru** Ruthenium	45 102.91 **Rh** Rhodium	46 106.42 **Pd** Palladium	47 107.87 **Ag** Silver	48 112.41 **Cd** Cadmium	49 114.82 **In** Indium	50 118.71 **Sn** Tin	51 121.76 **Sb** Antimony	52 127.60 **Te** Tellurium	53 126.90 **I** Iodine	54 131.29 **Xe** Xenon
55 132.91 **Cs** Caesium	56 137.33 **Ba** Barium	*	72 178.49 **Hf** Hafnium	73 180.95 **Ta** Tantalum	74 183.84 **W** Tungsten	75 186.21 **Re** Rhenium	76 190.23 **Os** Osmium	77 192.22 **Ir** Iridium	78 195.08 **Pt** Platinum	79 196.97 **Au** Gold	80 200.59 **Hg** Mercury	81 204.38 **Tl** Thallium	82 207.19 **Pb** Lead	83 208.98 **Bi** Bismuth	84 208.98 **Po** Polonium	85 209.99 **At** Astatine	86 222.02 **Rn** Radon
87 223.02 **Fr** Francium	88 226.03 **Ra** Radium	**	104 261.11 **Unq** Unnilquadium	105 **Unp** Unnilpentium	106 **Unh** Unnilhexium	107 **Uns** Unnilseptium	108 **Uno** Unniloctium	109 **Une** Unnilenium	110 **Uun** Ununnilium	111 **Uuu** Unununium	112 **Uub** Ununbium						

*	57 138.91 **La** Lanthanum	58 140.12 **Ce** Cerium	59 140.91 **Pr** Praseodymium	60 144.24 **Nd** Neodymium	61 144.91 **Pm** Promethium	62 150.36 **Sm** Samarium	63 151.97 **Eu** Europium	64 157.25 **Gd** Gadolinium	65 158.93 **Tb** Terbium	66 162.50 **Dy** Dysprosium	67 164.93 **Ho** Holmium	68 167.26 **Er** Erbium	69 168.93 **Tm** Thulium	70 173.04 **Yb** Ytterbium	71 174.97 **Lu** Lutetium
**	89 227.03 **Ac** Actinium	90 232.04 **Th** Thorium	91 231.04 **Pa** Protactinium	92 238.03 **U** Uranium	93 237.05 **Np** Neptunium	94 244.06 **Pu** Plutonium	95 243.06 **Am** Americium	96 247.07 **Cm** Curium	97 247.07 **Bk** Berkelium	98 251.08 **Cf** Californium	99 252.08 **Es** Einsteinium	100 257.10 **Fm** Fermium	101 258.1 **Md** Mendelevium	102 259.10 **No** Nobelium	103 262.11 **Lr** Lawrencium

Notes :

There is controversy over the naming of some of the heavier elements (104-108). These names are temporary.
Elements 110, 111 and 112 have been reported by scientists at GSI (Gesellschaft fur Schwerionenforschung),


Wavelength (m)
Frequency (Hz)
Long waves
Radio waves
Infra-red
Visible
Ultra-violet
X rays
Gamma rays
400nm
500nm
600nm
700nm
Violet
Blue
Green
Yellow
Orange
Red