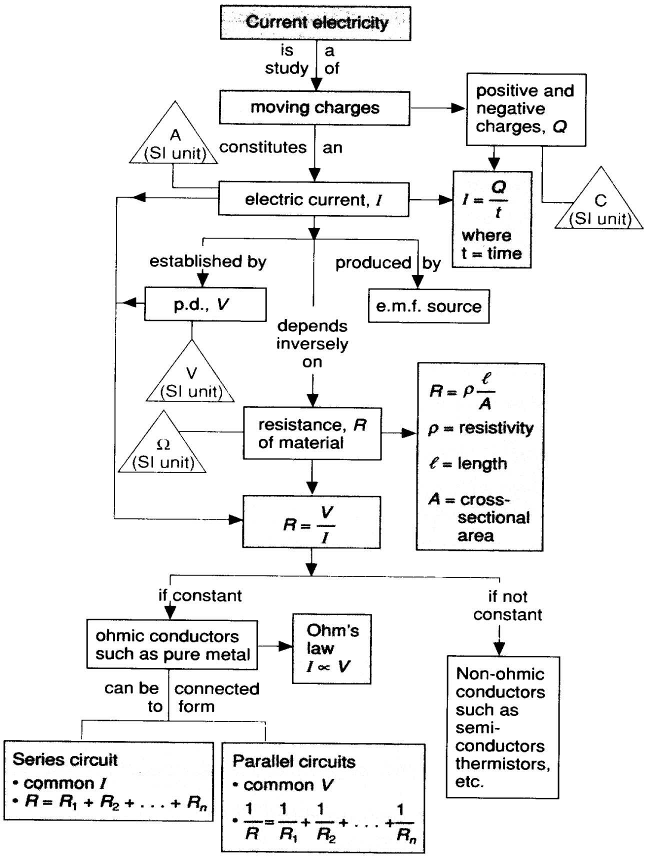
Electricity

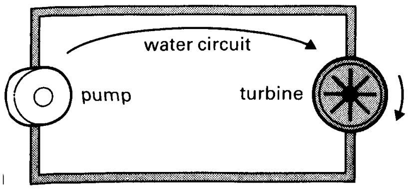
Contents

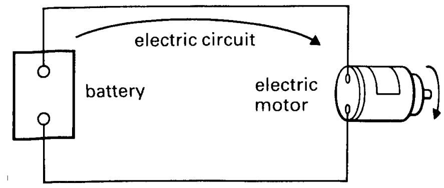
Concept Map



1. Current

Q. What is Electricity?
A. It is the flow of electrons around a wire. We call this flow the **current**.



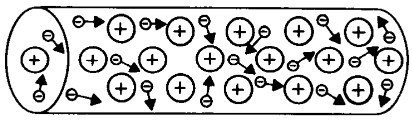


Analogy:
Electricity flowing in wires is hard to imagine, therefore you may find it easier to relate it to water flowing in pipes.

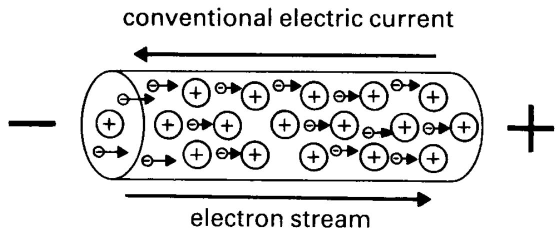
The Pump will make the water move through the pipe.
The battery makes the current go through the wires.

The water takes energy from the pump to the turbine.
The electrons carry energy from the battery to the motor.

- Free electrons move about randomly in a wire.



- When the battery is connected across the wire a current flows in the wire. i.e. the electrons in the wire all move in the same direction.)

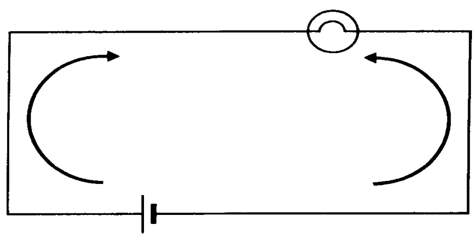


Q1. Which way does the **conventional current** flow around the circuit?

Q2. Which way do the electrons flow?

So the direction of the electrons is opposite to that of the conventional current.

Exercise:
1. Label the + and - terminals of the battery.
2. Indicate the direction of the conventional current.
3. Indicate the direction of the flow of electrons.



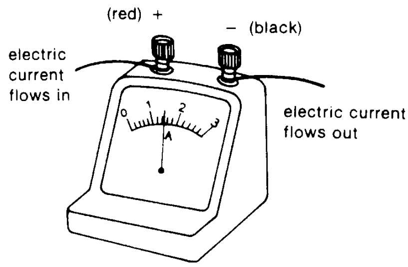
Measuring Current

Q3. What are the units that current is measured in?

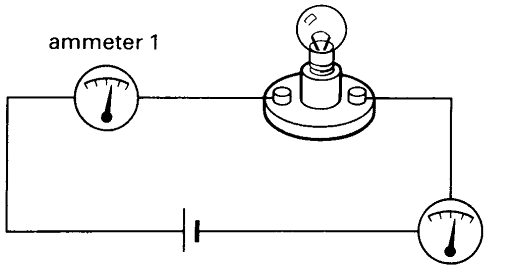
Unit: ______________________ Symbol: __________

Q4. What do we measure current with?

- An ammeter is placed at any point along the wire and it will tell us how much current is flowing in the wire.



Q5. What do you think you can say about the readings on *ammeter 1* and *ammeter 2* as shown below?



This is generally true:

the _____________ at all points in a _____________ circuit is the same.

Q6. Look at the two ammeters below. Are they set up the same?

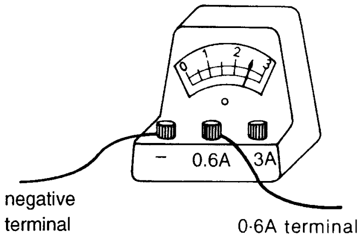


Figure 1

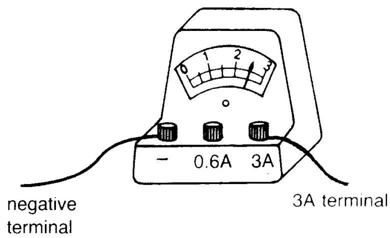
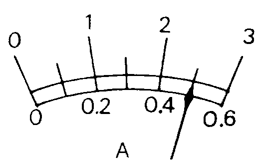
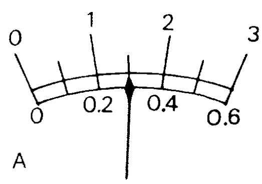


Figure 2

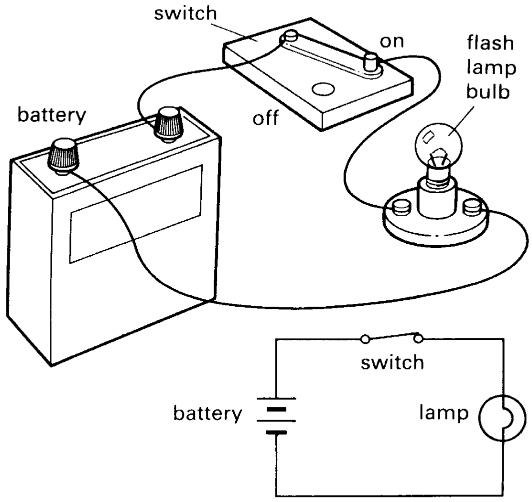
Q7. What reading is shown on the scale to the right if the ammeter had been connected as in *figure 1*?



Q8. What reading is shown on the scale to the right if the ammeter had been connected as in *figure 2*?



Electric Circuit Symbols



- Drawing the picture on the left would be difficult and take a lot of time.
- Much easier is the circuit below drawn using recognised symbols.
- The wires are shown by straight lines.
- All of the components have symbols, some of which look like the component, others do not.

The following symbols are the ones you may come across:

COMPONENT	CIRCUIT SYMBOL	COMPONENT	CIRCUIT SYMBOL
Joined wires		Fuse	
Wires crossing (not connected)		Solenoid (coil of wire)	
Switch		2-way switch	
Electric Cell		Earth	
Battery (joined cells)		Voltmeter	
AC Power Supply		Ammeter	
Light Bulb		Galvanometer (sensitive ammeter)	
Resistor		Capacitor	
Rheostat (variable resistor)		Transformer	

2. Electromotive Force

Q. What is Electromotive Force?
A. It is the force that makes the charges move around the circuit.

EMF Source

A device which changes energy into electrical energy.

Examples:

Cell (or battery)	Chemical energy → Electrical energy
Generator (or dynamo)	Kinetic energy → Electrical energy
Thermocouple	Thermal energy → Electrical energy

When a charge passes through a cell it gains energy from the cell.

This energy will later be dissipated in the rest of the circuit as the charge moves through the circuit.

The **electromotive force** of a cell is the **energy transfer** from non-electrical forms to electrical forms when **one coulomb of charge passes through the cell**.

$$E = \frac{W}{Q}$$

Where E =

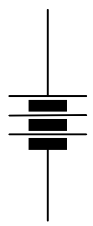
W =

Q =

Measuring EMF

The unit for EMF is the _______. EMF is measured with a ________________.

Q. Complete the diagram to show a voltmeter could be connected to the battery to measure its voltage.



Example:
The e.m.f. of a cell is 1.5 V. What energy is dissipated by the cell if it drives 0.4 C of charge round the circuit?

Using $E = \frac{W}{Q}$ *e.m.f.,* $E = 1.5\ V$
charge, $Q = 0.4\ C$

$$W = EQ$$
$$= 1.5 \times 0.4$$
$$= 0.6\ J$$

Questions:

1. The e.m.f. of a cell is 4 V. What energy is dissipated by the cell if it drives 8 C of charge round the circuit?

2. What is the e.m.f. of a cell if it uses 4.2 joules of energy as it pushes 6 coulombs of charge round a circuit?

3. The e.m.f. of a cell is 4 V. What energy is dissipated by the cell in 20 seconds if a current of 2 amperes flows in the circuit?
(Hint: you will first need to find how much charge flows round the circuit.)

3. Potential Difference

Q. Where does the light and heat energy produced by a light bulb come from?
A.

Just as energy is converted to electrical energy in the cell, in a bulb (or other similar electrical component) the electrical energy is converted to other forms of energy.

This form of energy conversion is known as a potential difference (p.d.).

SI Unit:

The equation for potential difference is

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

Where V =

W =

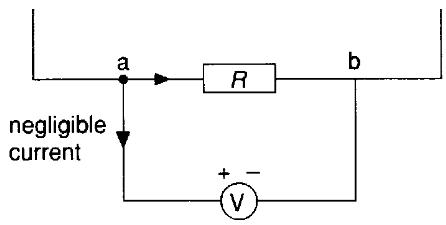
Q =

Measuring Potential Difference

Potential difference is measured in a similar manner to e.m.f. - that is with a voltmeter.

The circuit on the right shows the set up for measuring the potential difference across the resistor **R**.

Almost zero current flows through the voltmeter.



Example:
120 J of electrical energy are converted in a bulb as 10 coulombs of charge passes through the bulb. What is the voltage across the bulb?

4. Resistance

Current in a circuit depends upon the e.m.f. of the cell and the electrical resistance of the circuit. Resistance reduces the current flowing in a conductor (similar to friction reducing the speed of a moving object.)

Definition:

Resistance of a conductor is the ratio of the potential difference across the conductor to the current flowing through the conductor.

Unit:

The equation for resistance is

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

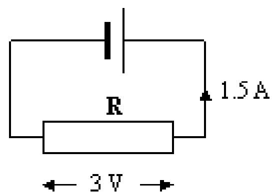
Where V =

I =

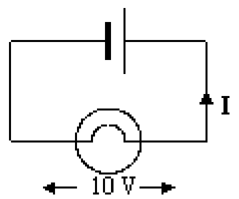
R =

Examples:

1. What is the value of the given resistor R?



2. What is the current flowing through the following circuit if the bulb has a resistance of 50 Ω?



Questions:

Q1. Draw the circuit symbol for a fixed resistor.

Q2. Do all conductors have resistance? Or do some conductors allow electricity to flow easier that others?

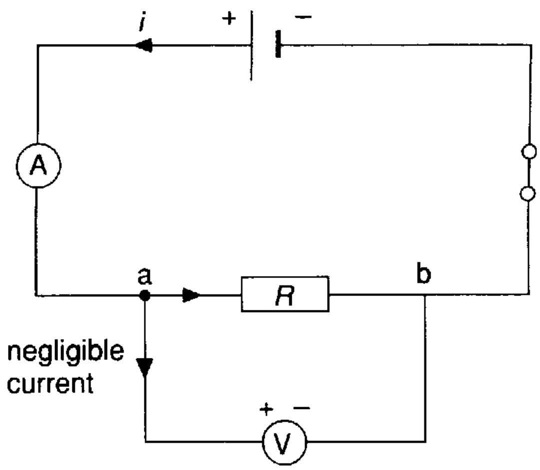
Q3. Is the resistance of a copper wire large or small? For most cases what value do we take for the resistance of a copper wire?

Q4. What is the purpose of using resistors in an electric circuit?

Q5. What is the meaning of the coloured bands often found around ceramic resistors?

Measuring Resistance

To measure the resistance of the component **R**, we use the following circuit:



We can find the current flowing through **R** from the ammeter reading.

We can find the potential difference across **R** from the voltmeter reading

R can be calculated from the equation:

$$V = I\,R$$

Example:

Ohm's Law

Ohm's Law states that:

Q. Ohm's Law can be expressed as an equation:

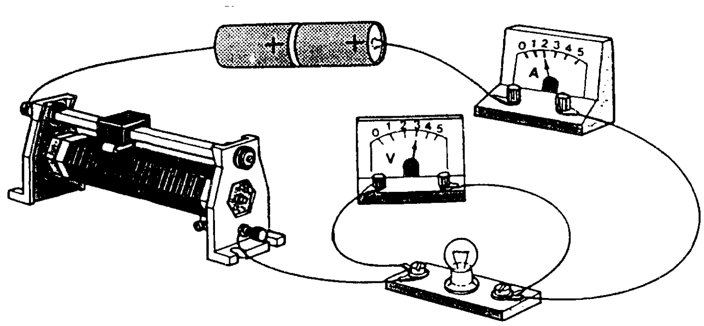
$$\frac{V}{I} = \textit{constant}$$

Where V =

I =

Investigating Ohm's Law

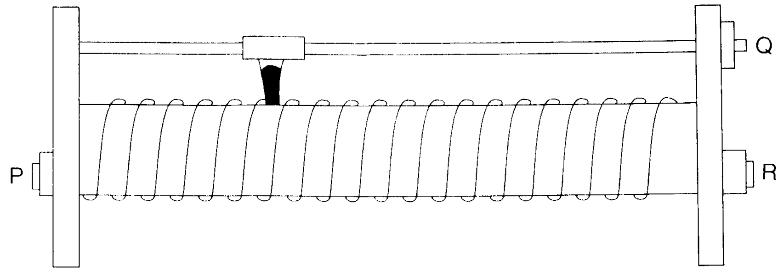
To measure the resistance of the component **X**, to see if it obeys Ohm's Law the following circuit is used:



Redraw the circuit using the standard circuit symbols.

What is the purpose of the rheostat in the circuit?

The Rheostat



Which terminals should the rheostat be connected to so that the current in a circuit could be altered? Show the path of the current when connected this way.

Example:

When the potential difference across a resistor, **R**, is 4 V the current passing through it is 2 A.

a) What is the resistance of the resistor, **R**?

b) If the p.d. across **R** is doubled to 8 V, will the resistance of **R** change?

c) What will be the current passing through the bulb?

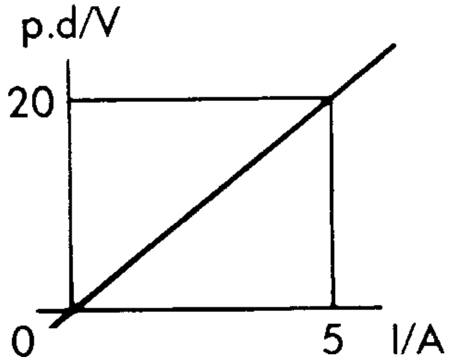
d) When the current is increased to a much higher value the resistor becomes hot. Would you still expect it to obey Ohm's Law? Why?

I/V Characteristic Graphs

If we plot the current against the voltage (p.d.) for a component we can see at a glance whether it obeys Ohm's Law

I/V Graph for an Object Obeying Ohm's Law

For a pure metal at a constant temperature Ohm's Law is obeyed and the Current-Voltage graph (I/V graph) would look like this:

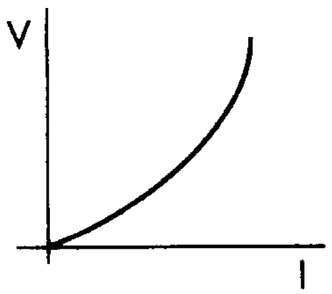


What is it about the graph that tells us this electrical component obeys Ohm's Law?

How could the resistance be found from this graph?

What is the resistance of the resistor shown on this graph?

I/V Graph for an object not obeying Ohm's Law - Bulb



A bulb does not obey Ohm's Law. It produces the following I/V characteristic graph.

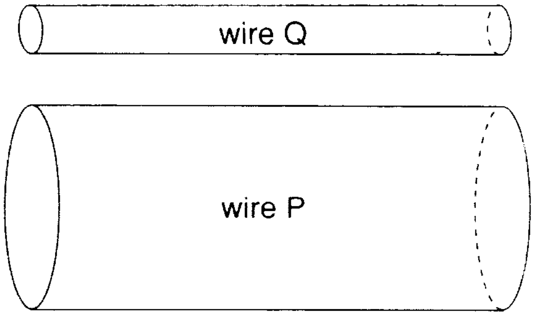
Explain why the bulb does not obey Ohm's Law as the current through the bulb becomes large.

Factors Affecting Resistance

There are several factors that affect the resistance of an object such as a wire:

1. Cross-sectional area of wire

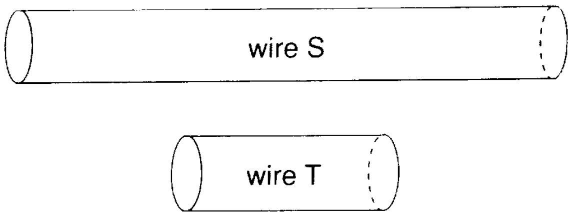
Q. Is it easier to drink Coca-Cola through a thick straw or a thin straw?



Q. Which of the above wires will allow electricity to pass through the easiest?

Q. Which of the above wires has the greatest resistance?

2. Length of wire



Q. Which of the above wires has the greatest resistance?

3. Material wire is made from

Wires of the same length and thickness but made of different materials will have a different resistances. This is because they have different **resistivities**. (**Units:** Ωm)

MATERIAL	RESISTIVITY	
Silver	1.6×10^{-8} Ωm	(good conductor)
Iron	10×10^{-8} Ωm	(conductor)
Polythene	$\sim 10^{16}$ Ωm	(good insulator)

Summary:

The 3 factors that affect resistance are:

1.

2.

3.

These can be placed together to find resistance:

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

Where	R	-
	ρ	-
	l	-
	A	-

Examples:

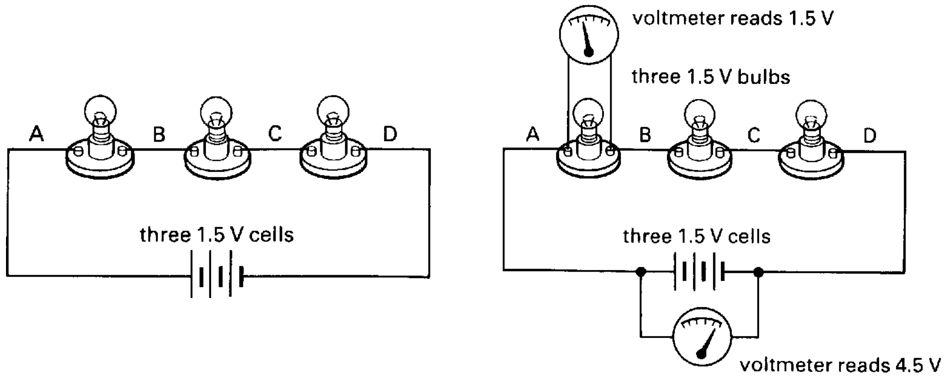
Q1. What is the resistance of a 1.5 m long piece of wire if it has a cross-sectional area of 2×10^{-8} m² and a resistivity of 4×10^{-8} Ωm?

Q2. What is the length of a piece of wire in a solenoid if the solenoid has a total resistance of 20 Ω and the wire has a cross-sectional area of 4×10^{-8} m² and a resistivity of 10×10^{-8} Ωm?

5. Series and Parallel Circuits

Series Circuits

Circuits in which all of the components are placed so that there is only one path for the current to go around are called series circuits.

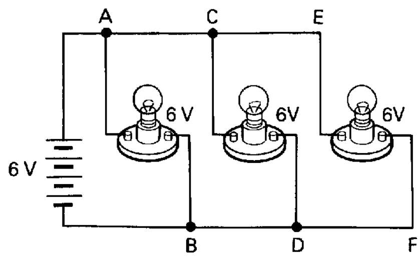


- **The current passing through each bulb is the _____________.**
- **The sum of the potential differences across the bulbs is equal to the**

  ____.

Parallel Circuits

Circuits in which the components are placed so that there are two or more paths for the current to go around are called parallel circuits.



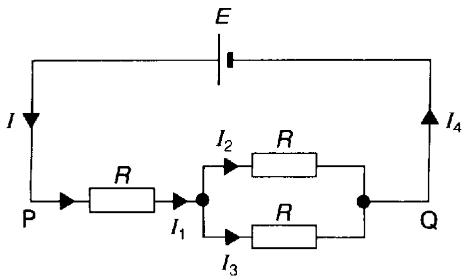
- **The potential difference across each bulb is equal to the EMF of the**

  _________________.
- **The sum of the currents in the bulbs is equal to the equal to the**

  ____.

Most circuits will contain some components that are in series and some that are in parallel.

Example:

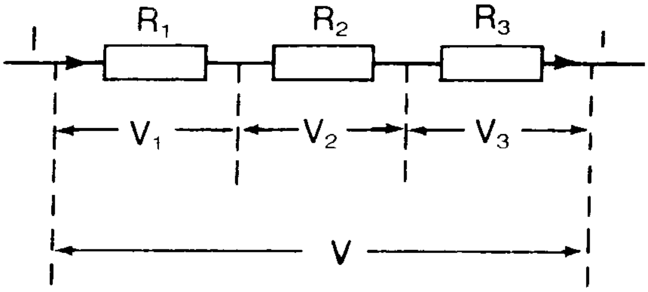


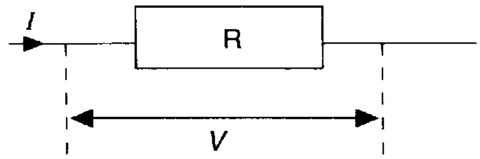
Effective Resistance

When we have two or more resistors in a circuit we can see what the combined effect of their presence is. This is known as the effective resistance of the resistors.

Resistors in Series

The following three resistors have a current I passing through them.

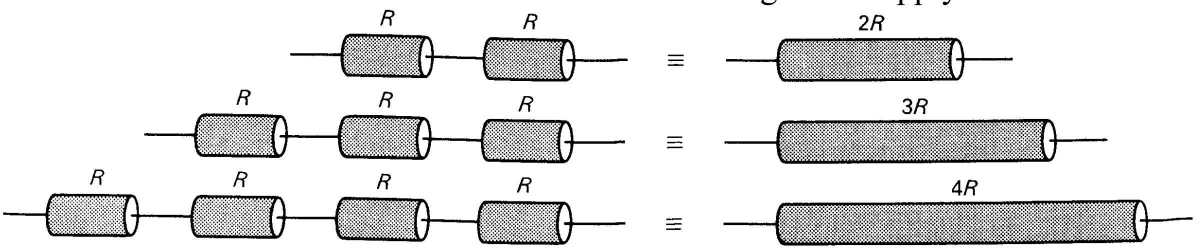




This circuit is equivalent to... *...this one.*

Thus the effective resistance of $\mathbf{R_1}$ and $\mathbf{R_2}$ and $\mathbf{R_3}$ is **R**.

If the resistors were identical to each other the following would apply:

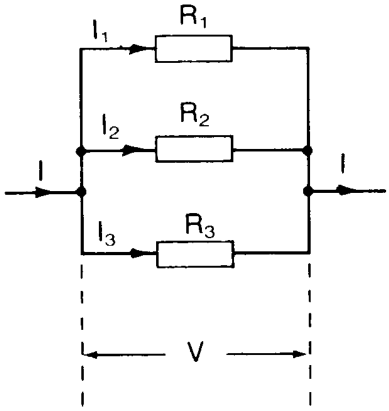


In general,

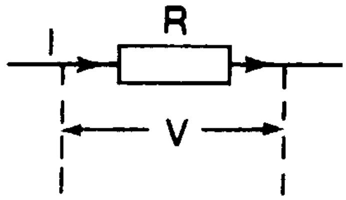
$$R_{Total} = R_1 + R_2 + R_3 + \ldots$$

Resistors in Parallel

The following three resistors have a potential difference V across them.

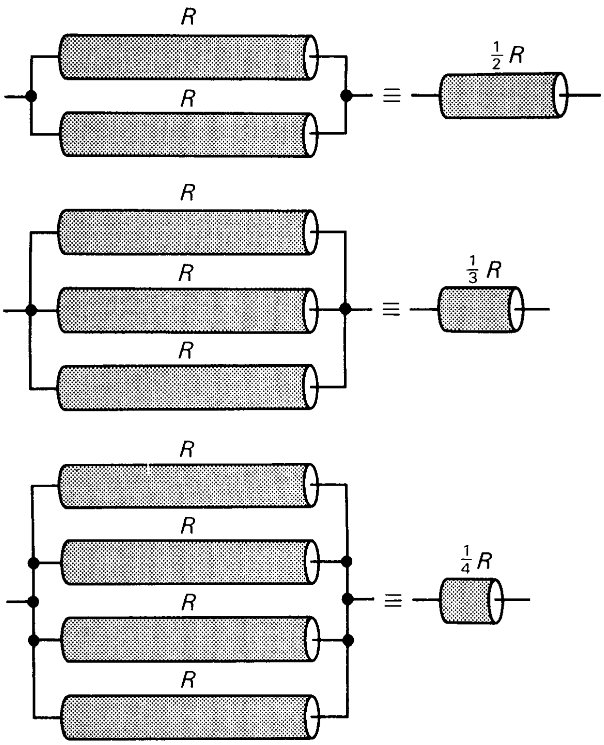


This circuit is equivalent to...



...this one.

If the resistors were identical to each other the following could be used:



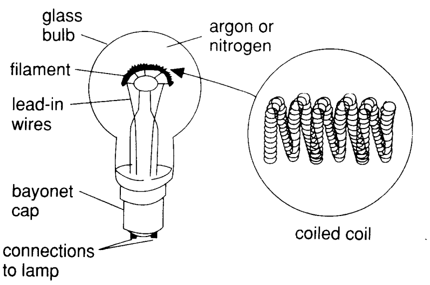
Where the effective resistance of the circuit, R, is given by the general equation:

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ..$$

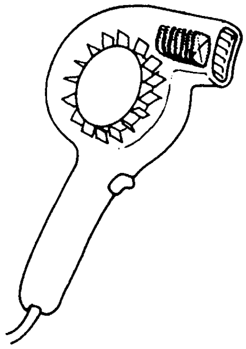
6. Practical Electric Circuits

In this section we will be considering the use of electricity in our homes.

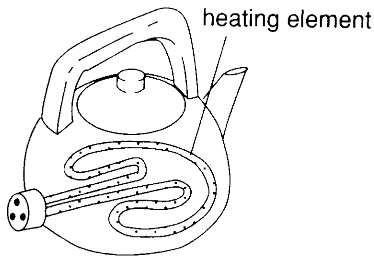
When an electric appliance is used electrical energy is changed into other forms of energy. For the following appliances state the energy changes that take place.



Light Bulb



Hair Dryer



Kettle

Power

Power is defined as the rate at which energy is released:

Where **P** -
I -
V -

Unit:

Notes:

- Other common units are:
  1 milliwatt (mW) is one thousandth of a watt,
  1 kilowatt (kW) is one thousand watts,
  1 megawatt (MW) is one million watts.

- This equation often used with the resistance equation **V=IR**.

Very often electrical components have the power stated on them.

Q1. What does it mean when a bulb has stated on it 60 W, 240 V?

Q2. What would be the current flowing through such a bulb?

Q3. Complete the following table to find the power, voltage or current of the given appliances.

APPLIANCE	POWER (W)	VOLTAGE (V)	CURRENT (A)
Lamp		240	0.25
Television	120		0.5
Hair dryer	500	250	
Air-con		250	8

Electrical Energy

The electrical energy used can be calculated from the equation:

Where **E** -
P -
t -

or,

Where **E** -
V -
I -
t -

Example:

Q. What is the energy used by a 100 W bulb switched on for 50 minutes?

As you can see from the example the joule is a small unit to measure electricity with. For home use we usually use another unit, the ____________________ (kWh).

1 kWh is the electrical energy used by a 1 kilowatt appliance in one hour. This is often referred to as a **unit** of electricity.

Example:

Complete the table to find the energy used by the appliances in the given time.

APPLIANCE	**POWER**	**TIME**	**ENERGY (kWh)**
Air-con	1500 W	8 h	
Refrigerator	200 W	24 h	
Fan	50 W	8 h	
Iron	2 kW	30 min	

Cost of Electricity

Electricity is bought from the PUB by the unit (kWh).

Examples:

Q1. What is the cost of running a 2 kW air-conditioner from 9 p.m. to 7 a.m. if the cost of electricity is 15¢ per unit?

Q2. A 2 kW kettle uses 3¢ of electricity in boiling some water in 5 minutes. What is the cost of a kWh of electricity?

Electricity in the Home

The electricity supply to our homes comes from the PUB and will pass through the electricity meter, main switch and then into the circuits in the house.

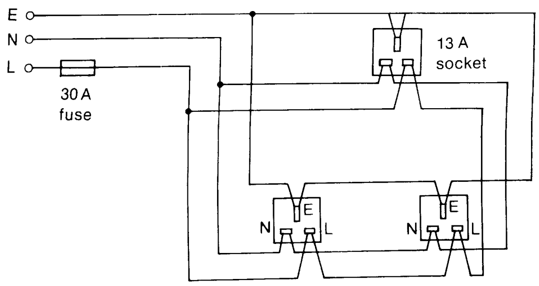
There are several circuits, usually:

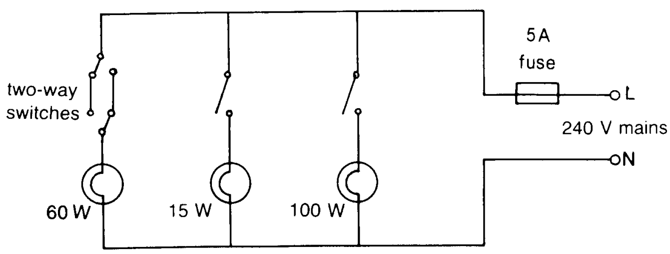
- one for lighting,
- one or more for power sockets,
- one for the cooker,
- one for the water (immersion) heater.

Each circuit has its own fuse.

Most of the circuits have three wires, Live, Neutral and Earth.

Examples of a Power and a Lighting Circuit:

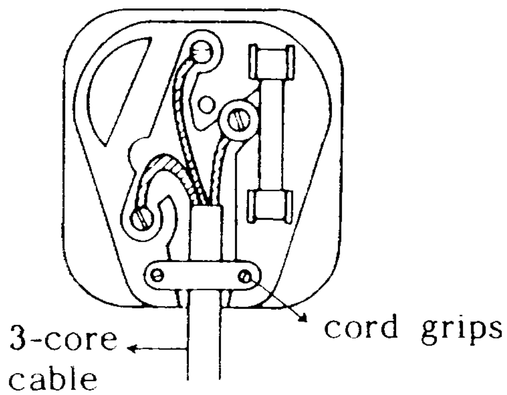




The power circuit consists of three '*rings*' of wire connected in parallel to each power socket. Hence it is often referred to as a *'ring main'*.

Q. Why do we form rings for the power circuit?

A Three-Pin Plug



1. What are the correct colours of the three wires found in a three pin plug? *(on the diagram identify the wires and give their correct colours)*

2. Which wire is the fuse connected to?

Switches
Used to turn on and off the power in electrical appliances.

Consider the following cases of a fault in the appliance:

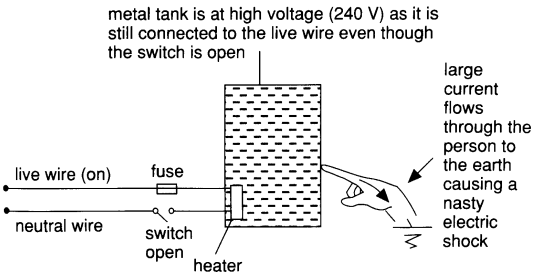


Figure 1

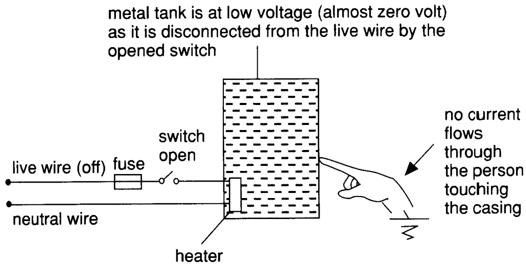
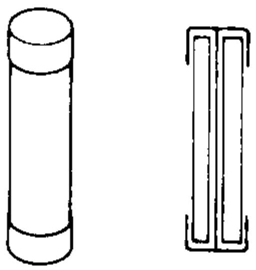


Figure 2

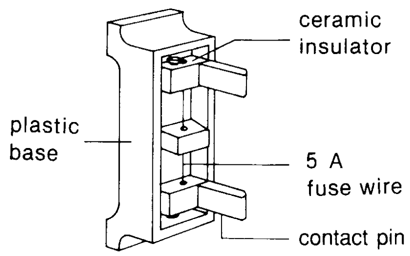
Q. Is it safer to place a switch in the live wire or the neutral wire? Why?

Fuses

Q1. Names the **two** different types of fuse (*pictured below*) found in our homes?



Type 1



Type 2

Q2. What is the purpose of having a fuse in a circuit?

Q3. How does a fuse work?

Note:
Not all fuses are the same, typical fuse ratings are 1A, 3A, 5A and 13A. We always choose a fuse of the next highest power rating.

a) If a bulb takes a current of 3.1 A, which fuse would you choose?

b) If an appliance is stated to have a power rating of 300 W and is to be used with a 240 V supply, which fuse would you use?

Q4. In which wire, live or neutral, would it be best to place the fuse? Why?

Earthing

To complete a circuit we need only two wires, the live and neutral wires. But if something goes wrong with our appliance, then the following may occur (*figure 1*).

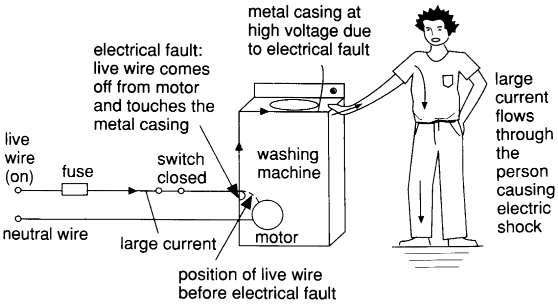


Figure 1

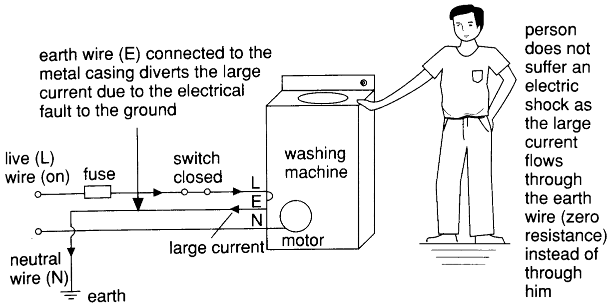


Figure 2

So we use a third wire, the earth wire (*figure 2*), to allow the current to return by a path of low resistance.

Q. Which part of the appliance must the earth wire be connected to?

Dangers Of Electricity

Electric current flowing through our bodies will cause electric shock (>1 mA) or death (>100 mA).

The major dangers of electricity are:

1. Damaged insulation to wires
   - Can cause electric shock.

2. Overloading of wires, connecting too many plugs to one socket
   - Wires heat up, outer insulation (plastic) may melt, causing:
     short circuit,
     electric shock or
     starting a fire.

3. Getting water near to electricity
   - Water enables current to flow - short circuit.
   - On contact with skin, water will reduce the resistance of the skin, meaning that the risk of electrocution will be higher.