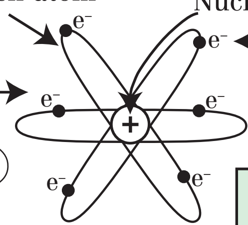
# ELECTRICAL ENERGY Static Electricity

The positively charged nucleus is orbited by negatively charged electrons. These do not escape because opposite charges attract.

Normally the number of positive and negative charges is equal in each atom

All materials are made of atoms




Nucleus – has positive charge

Electrons – have negative charge

Measured in Coulombs, C.

*Static electricity* is formed when electrical charges are trapped on an insulating material that does not allow them to move. You can charge up a material by . . .

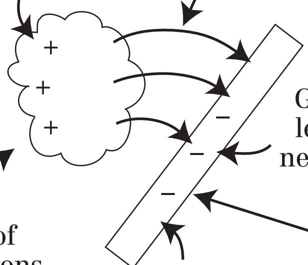
Like charges repel

Unlike charges attract

**1) Friction**

Wool duster

Electrons (negative charge) rubbed off the wool onto the polythene rod.



Gain of electrons leaves an overall negative charge.

Loss of electrons leaves an overall positive charge.

Polythene rod

Clothing and aircraft can be charged by friction.

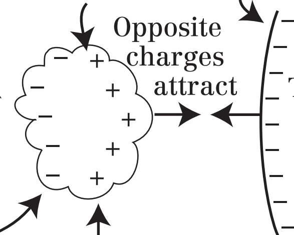
In all charging processes, it is always electrons that move as they can be removed from or added to atoms.

**2) Induction**

Overall neutral particle, e.g. dust.

Negatively charged surface (e.g. a TV screen).

Electrons repelled away.



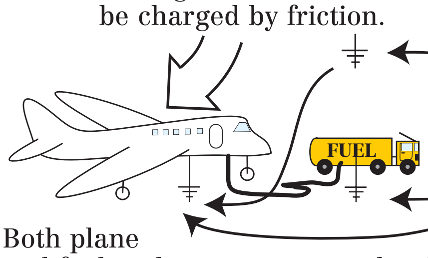
Opposite charges attract

This explains why TV screens tend to get very dusty.

Surplus of positive charges on this surface

E.g. polish

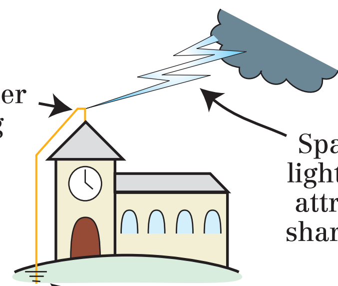
Antistatic sprays contain a conducting chemical to avoid the build up of charge.




Static electricity will flow to Earth if a conducting path is provided, as the charges can get further apart by spreading over the Earth.

Both plane and fuel tanker are connected to Earth before fuelling to prevent any sparks.

Copper lightning conductor



Sparks like lightning are attracted to sharp points.

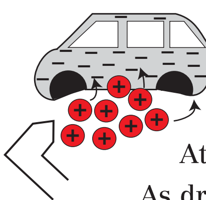
Large metal plate

E.g.

Danger of explosions – flammable vapours or dust ignited by sparks – earthing needed in these environments

**Uses and dangers of static electricity**

**Spraying paint and pesticides**

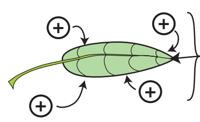


Negatively charged metal object.

Attraction

Spray gun is positively charged.

As drops all have the same charge, they repel giving a fine spray.

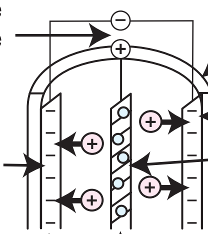


Negative charge induced on leaf by positive drops.

Positively charged droplets are attracted to leaf.

**Electrostatic precipitator**

Large voltage



Chimney

Negatively charged plate

Positively charged grid.

Smoke attracted and sticks to negative plates.

Smoke particles positively charged by contact with the grid.

When large particles are collected on the plates, they fall down the chimney due to their weight.

Prevents dirty smoke entering the atmosphere.

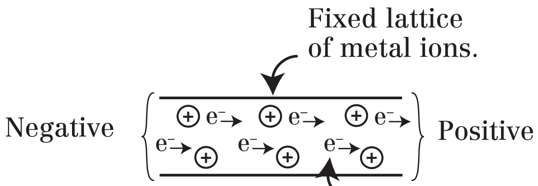
## Questions

1. Complete the following sentences. Like charges ________, unlike (opposite) charges ________.
2. What is the unit of electrical charge?
3. What is the difference between an insulator and a conductor?
4. Why would it not be possible to charge a copper rod by rubbing it, no matter how furiously you rubbed?
5. Explain in as much detail as possible how a balloon rubbed on a woolly jumper sticks to a wall.
6. Make a list of all the examples of static electricity in action mentioned in this page. Divide your list into cases where static electricity is useful, where it is a nuisance, and where it is dangerous. Try to add your own examples to the list.

# ELECTRICAL ENERGY Electric Currents

An electric current is a flow of charged particles.

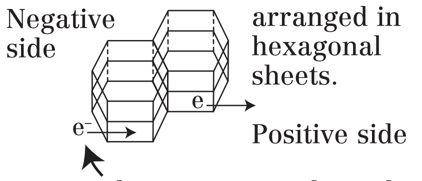
**Solids**




**Metals**

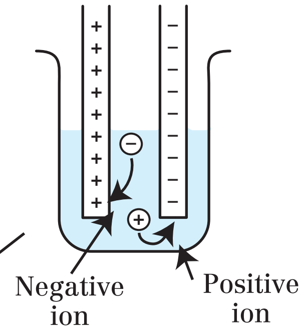
Electrons move from metal ion to metal ion, towards the positive end of the metal.

**Graphite**




Electrons move through the layers.

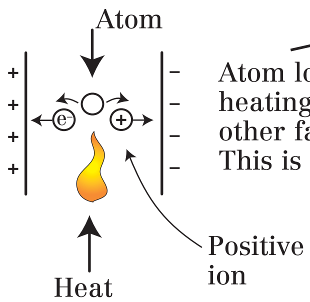
**Liquids**




Molten or dissolved *ionic* solids.

**What do all these have in common?**

**Gases**




Atom loses electrons due to heating (or by collision with other fast moving atoms). This is called ionization.

Current flows between plates.

Three conditions for an electric current to flow:

1. There must be charge carriers (electrons or ions).
2. They must be free to move.
3. There must be a potential difference to repel them from one side and attract them to the other.

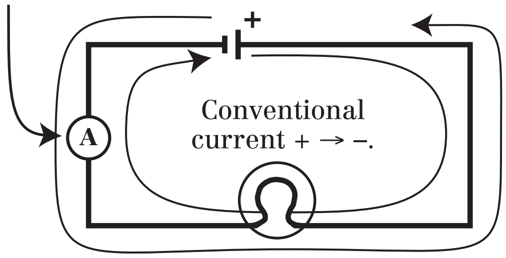
Current (in Amps) is the rate of flow of charge; the number of Coulombs of charge flowing past a point per second.

$$\text{Current (A)} = \frac{\text{Charge (C)}}{\text{time (seconds, s)}}$$

1 Amp = 1 coulomb per second

In equations we usually use $I$ for current and $Q$ for charge. Hence $I = Q/t$.

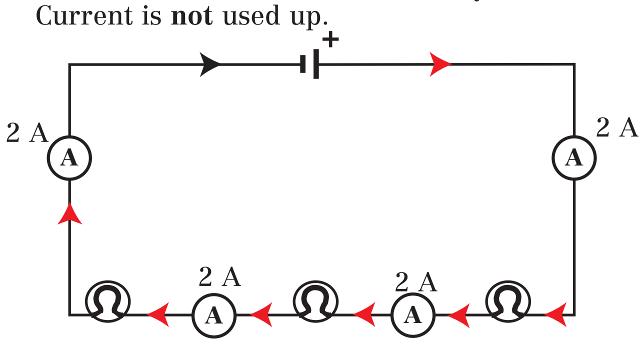
Electric current is always measured with an ammeter, always placed in series.



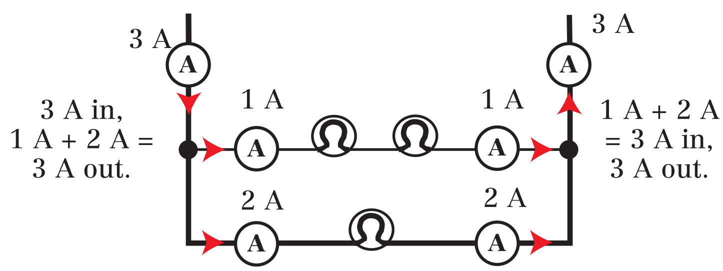

Electron current – → +.

**Current rules**

1. The current is the same all the way round a series circuit. Current is **not** used up.



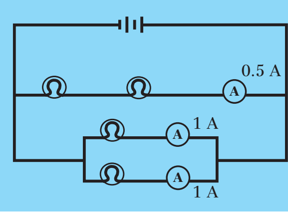

2. The current flowing into a junction = current flowing out.




These rules mean that charge is conserved. It does not 'pile up' anywhere in the circuit.

## Questions

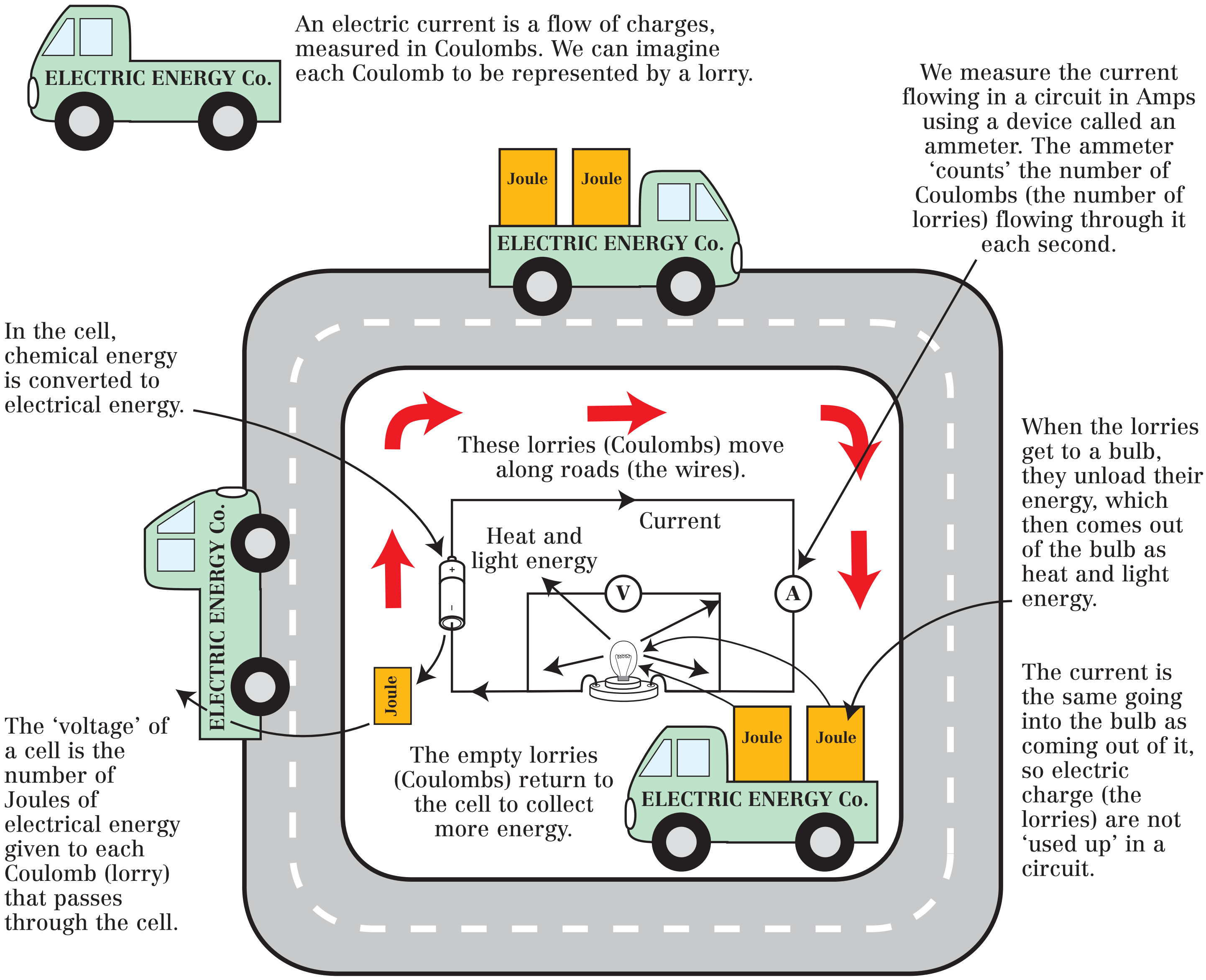
1. Why must ionic solids be molten or dissolved to conduct an electric current?
2. In a circuit 4 C of charge passes through a bulb in 2.5 s. Show that the current is 1.6 A.
3. An ammeter in a circuit shows a current of 1.2 A.
   a. The current flows for 2 minutes. Show the total charge passing through the ammeter is 144 C.
   b. How long would it take 96 C to pass through the ammeter?
4. In the following circuit, how many Amps flow through the battery?
5. The laws of circuit theory were all worked out in the 1800s. The electron was discovered in 1897. Discuss why we have conventional direct current flowing from positive to negative, when we know that the electrons actually flow from negative to positive.



# ELECTRICAL ENERGY Potential Difference and Electrical Energy

What actually happens in an electric circuit?

We can use a model to help us understand what is happening.




We can measure the energy difference between the loaded lorries going into the bulb and the empty ones leaving it using a voltmeter. The voltmeter is connected *across* the bulb to measure how much energy has been transferred to the bulb by comparing the energy (Joules) carried by the lorries (Coulombs) before and after the bulb. *Each Volt represents one Joule transferred by one Coulomb.* The proper name of this is potential difference (because the current has more potential to do work before the bulb than after it) but is often called the voltage.

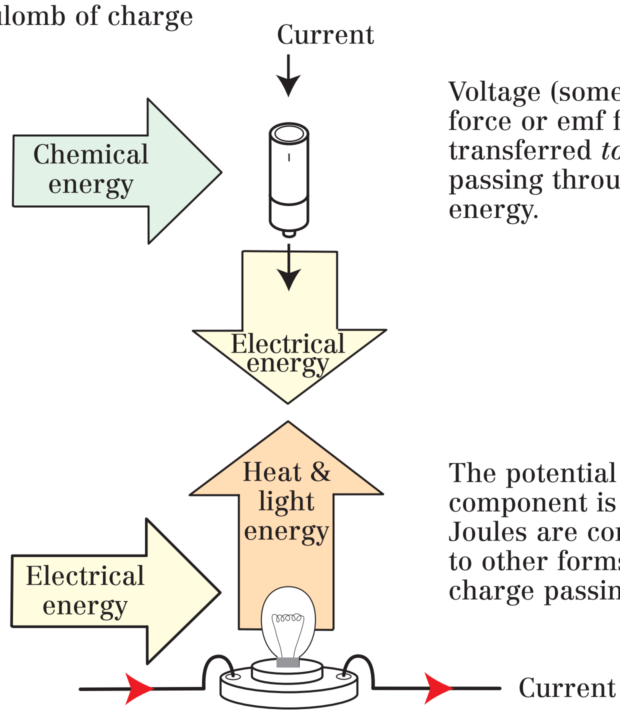
**Questions** Use the lorry model to explain:

1. Why the ammeter readings are the same all the way round a series circuit.
2. Why the total current flowing into a junction is the same as the total current flowing out.
3. Why all the bulbs in a parallel circuit light at full brightness.
4. Why the bulbs get dimmer as you add more in a series circuit.
5. Why the cell goes 'flat' more quickly if you add more bulbs in parallel.
6. Should a 'flat' battery be described as discharged or de-energized? Discuss.
7. This model cannot explain all the features of a circuit. Try to explain:
   a. How the lorries know to save some energy for the next bulb in a series circuit.
   b. Whether it takes time for the first full lorries to reach the bulb and make it light up.
   c. Whether there are full lorries left in the wires when you take the circuit apart.

# ELECTRICAL ENERGY Energy Transfers in Series and Parallel Circuits

1 Volt = 1 Joule of energy per Coulomb of charge

The voltage of a cell is a measure of how many Joules of chemical energy are converted to electrical energy per Coulomb of charge passing though it.




Voltage (sometimes called electromotive force or emf for short) is the energy transferred *to* each Coulomb of charge passing through a source of electrical energy.

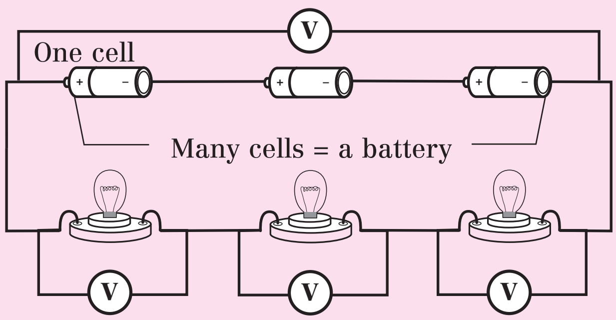
Potential difference is the energy given to a device *by* each Coulomb of charge passing through it.

The potential difference across a component is a measure of how many Joules are converted from electrical energy to other forms of energy per Coulomb of charge passing though the component.

A bulb converts electrical energy to thermal and light energy.
A motor converts electrical energy to kinetic energy.
A resistor converts electrical energy to thermal energy.
A loudspeaker converts electrical energy to sound energy.

As energy cannot be created or destroyed all the electrical energy supplied by the cell must be converted into other forms of energy by the other components in the circuit.

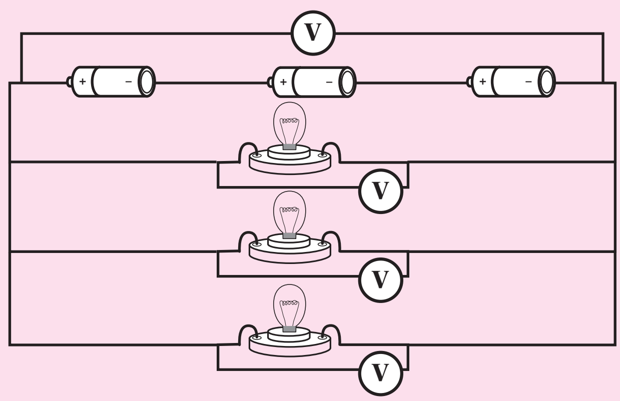
N.B. Voltmeters connected in *parallel*.




This means that in a *series* circuit the sum of the voltages across the components must equal the voltage across the cell.

The current is the *same* through all components, the potential difference is *shared* between components.

N.B. Voltmeters connected in *parallel*.




In a *parallel* circuit, each Coulomb of charge only passes through one component before returning to the cell. Therefore, it has to give all the energy it carries to that component. Therefore, the potential difference across each component is the same as the potential difference of the cell.

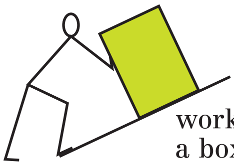
Potential difference is the *same* across all components, current is *shared* between components.

## Questions

1. What is a Joule per Coulomb more commonly called?
2. A cell is labelled 9 V, explain what this means.
3. Explain whether or not voltage splits at a junction in a circuit.
4. A 1.5 V cell is connected in series with a torch bulb. The bulb glows dimly. Explain why adding another cell, in series, will increase the brightness of the bulb.
5. Considering the same bulb as in question 2, adding a second cell in parallel with the first will make no difference to the brightness. Why not?
6. When making electrical measurements we talk about the *current through* a component, but the *voltage across* a component, explain why.
7. Try to write down a formula relating voltage, energy, and charge.

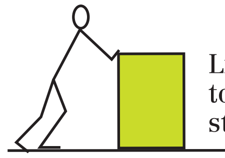
# ELECTRICAL ENERGY Resistance

Resistance is a measure of how much energy is needed to make something move or flow.



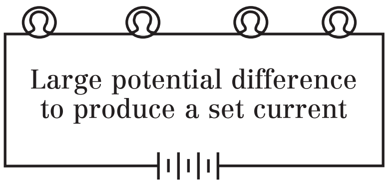
Large amount of work needed to move a box at steady speed

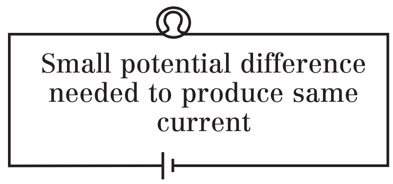
**High resistance**



Little work needed to move a box at steady speed

**Low resistance**




We *define* resistance as the ratio of the potential difference across a component to the current flowing through it.

$$\text{Resistance } (\Omega) = \frac{\text{potential difference (V)}}{\text{current (A)}}$$

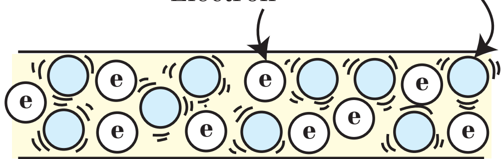
Unit = Ohms, Ω

i.e. if we have a high resistance then a bigger push is needed to push the current round the circuit. Note that this is not Ohm's Law, just the definition of resistance.

**What causes resistance in wires?**

In the lorry analogy on p45, the lorry had to use some energy (fuel) to move along the roads (wires). This represents the resistance of the wires.

Wires have resistance because the electrons moving through the wire bump into the positive metal ions that make up the wire.

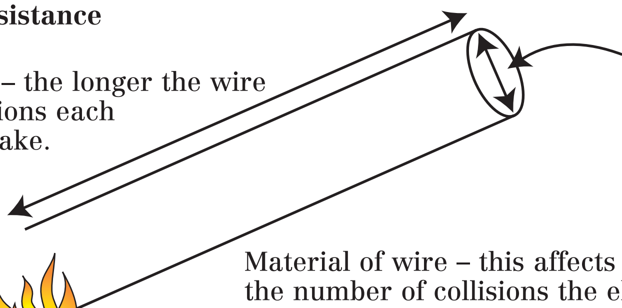



The electrons give some of their kinetic energy to the metal ions, which makes them vibrate so electrical energy is converted to thermal energy and the wire gets warm.

The same process happens in a resistor, but the materials are chosen to increase the number of collisions making it more resistant to charge flow.

**Factors affecting resistance**

Length of wire – the longer the wire the more collisions each electron will make.



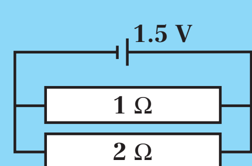
Width of wire – the wider the wire the more electrons can flow at any one time, hence you get a bigger current for the same potential difference, so a lower resistance.

Material of wire – this affects size and layout of the metal ions and so the number of collisions the electrons make.

Temperature – the hotter the wire the more the metal ions vibrate and so the more likely electrons are to collide.

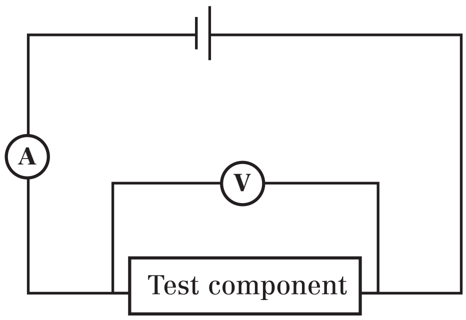
## Questions

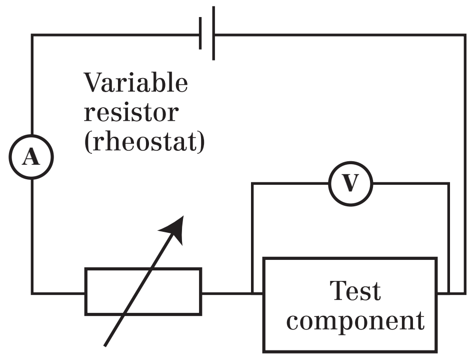
1. Show that a resistor with 5 V across it and 2 A flowing through it has a resistance of 2.5 Ω.
2. A 12 Ω resistor has 2.4 V across it. Show that the current flowing is 0.2 A.
3. A lamp has a resistance of 2.4 Ω and 5 A flows through it. Show the potential difference is 12 V.
4. The potential difference across the lamp in (3) is doubled. What would you expect to happen to a. the filament temperature, b. the resistance, c. the current?
5. In the following circuit, which resistor has the largest current flowing through it?
6. Why do many electronic devices, e.g. computers, need cooling fans?



# ELECTRICAL ENERGY Electrical Measurements and Ohm's Law

Experimental technique for measuring resistance




**Finding the resistance of a component for a given current**

Use meter readings and the formula Resistance (Ω) = potential difference (V) / current (A) to find the resistance.

Datalogging could be used to do this

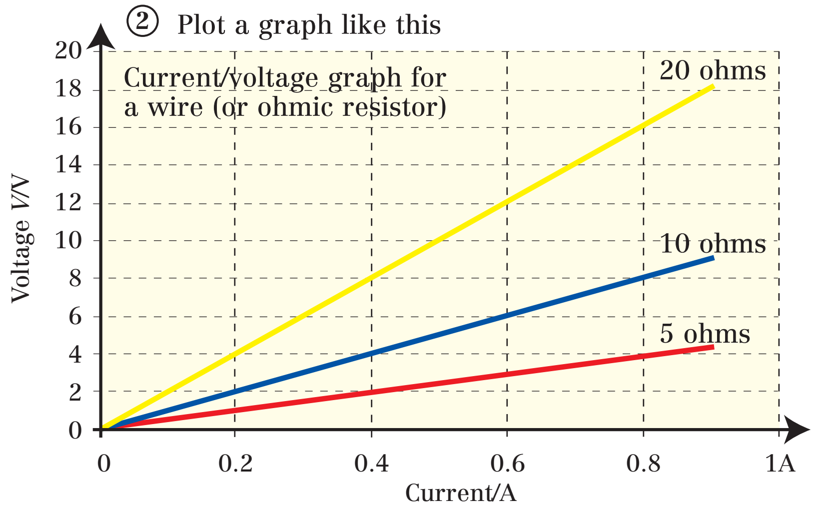
Use voltmeter and ammeter sensors.
Computer software automatically plots voltage vs. current as the variable resistor is altered.

**Finding the resistance of a component for a range of currents**

① Record voltmeter and ammeter readings for many different settings of the variable resistor in a table.

| Voltage across component (Volts) | Current through component (Amps) |
|---|---|
| | |

② Plot a graph like this




③ Gradient of graph $= \dfrac{\text{change in } y}{\text{change in } x}$

$= \dfrac{\text{change in potential difference, V}}{\text{change in current, A}}$

= Resistance, Ω

The steeper the line the greater the resistance.

N.B. Beware, sometimes these graphs are plotted with the axes reversed. Then the resistance is not the gradient, it is $^1/_{\text{gradient}}$.

**Ohm's Law**

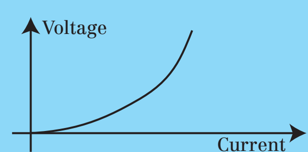
A component where the current is directly *proportional* to the voltage is said to obey Ohm's Law and is called *ohmic*.

This means:
1. A graph of *V vs. I* is a straight line through the origin.
2. $V = I \times R$ where *R is constant whatever the value of the current or voltage*.

Note that the definition of resistance applies to all components; they are only ohmic if their resistance does not change as the current changes.

## Questions

1. Calculate the gradients of the three lines in the graph above and confirm they have the resistances shown.
2. 1.5 A flows in a 1 m length of insulated wire when there is a potential difference of 0.3 V across it.
   a. Show its resistance is 0.2 Ω.
   b. If 0.15 A flows in a reel of this wire when a potential difference of 3 V is placed across it, show that the length of the wire on the reel is 100 m.
3. Current and voltage data is collected from a mystery component using the method above. When plotted the graph looks like this:
   Is the resistance of the component increasing, decreasing, or staying the same as the current increases?



# ELECTRICAL ENERGY Power in (Ohmic) Electrical Circuits

The general definition of power is : Power (W) $= \dfrac{\text{energy transferred (J)}}{\text{time taken (s).}}$

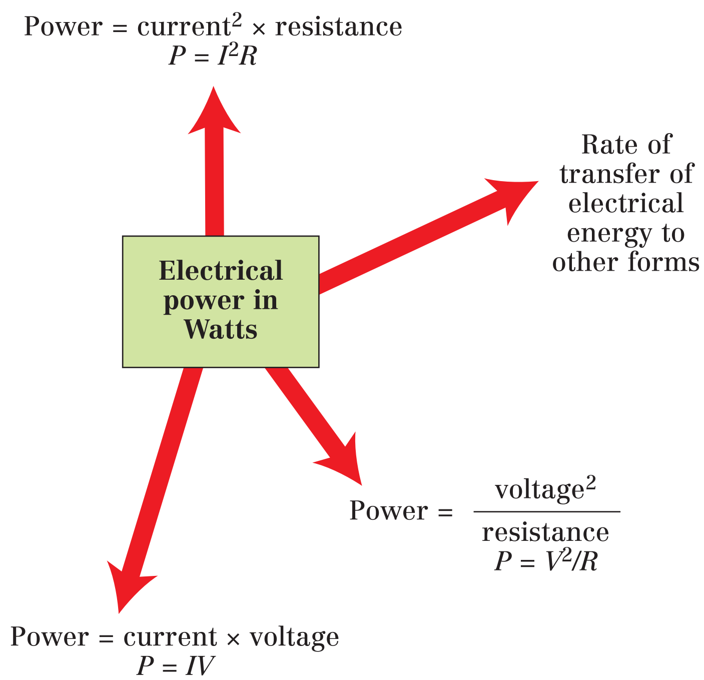
We also know that 1 Volt = 1 Joule per Coulomb.

As a formula we represent this as potential difference (Volts) $= \dfrac{\text{energy transferred (Joules)}}{\text{charge passing (Coulombs).}}$

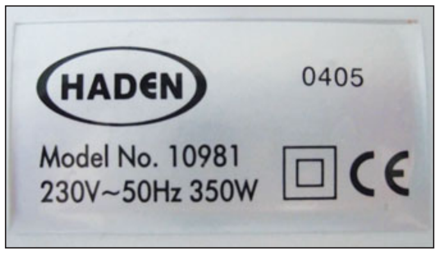
We also know that current (Amps) $= \dfrac{\text{charge passing (Coulombs)}}{\text{time taken (seconds).}}$

Then current × voltage $= \dfrac{\text{charge passing}}{\text{time taken}} \times \dfrac{\text{energy transferred}}{\text{time taken}} = \dfrac{\text{energy transferred}}{\text{time taken}}$ = Power

Also as voltage = current × resistance then



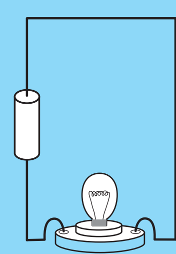

Mains appliances use 230 V and always have a power rating.




We can use this information to calculate the current that flows through them when working normally.

| Device | Voltage (V) | Power (W) |
|---|---|---|
| Filament bulb | 230 | 60 |
| Energy efficient lamp | 230 | 9 |
| Kettle | 230 | 1500 |
| Microwave oven | 230 | 1600 |
| Electric cooker | 230 | 1000–11 000 |
| TV set | 230 | 30 |

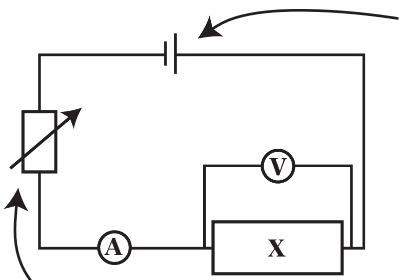
### Questions



1. Redraw the circuit using standard circuit symbols adding voltmeter to measure the potential difference across the lamp and an ammeter to measure the current through it.
   a. The voltmeter reads 6 V. How many Joules of energy are transferred per Coulomb?
   b. The ammeter reads 2 A. How many Coulombs pass through the lamp each second?
   c. Hence, how many Joules per second are transferred to the lamp?
   d. If the voltmeter now reads 12 V and the ammeter still reads 2 A then how many Joules are transferred to the lamp each second?
2. A 1.5 V cell is used to light a lamp.
   a. How many Joules does the cell supply to each Coulomb of electric charge?
   b. If the current in the lamp is 0.2 A, how many Coulombs pass through it in 5 s?
   c. What is the total energy transferred in this time?
   d. Hence, show the power of the lamp is 0.3 W.
3. A 6 V battery has to light two 6 V lamps fully. Draw a circuit diagram to show how the lamps should be connected across the battery. If each draws a current of 0.4 A when fully lit, explain why the power generated by the battery is 4.8 W.
4. Use the data in the table above to show that the current drawn by an 'energy efficient' lamp is over 6× less than the current drawn by a normal filament bulb.
5. Show that a 60 W lamp with a potential difference of 240 V across it has a resistance of 960 Ω.

# ELECTRICAL ENERGY Properties of Some Electrical Components

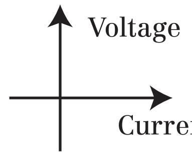
A graph of voltage against current (or *vice versa*) for a component is called its characteristic.
This circuit can be used to measure the characteristic of component X.

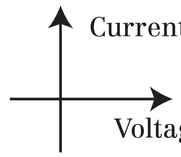



The cell can be reversed to measure negative values of current and voltage.

The current and voltage are recorded for a wide range of settings of the variable resistor.

N.B. Check carefully whether current or voltage is plotted on the $x$ axis.

If  gradient = resistance

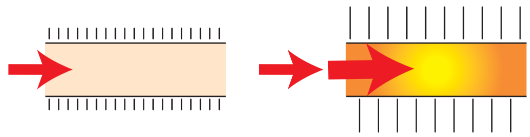

If  gradient = $^{1}/_{\text{resistance}}$


All the following components are *non-ohmic* as their resistance is not independent of the current flowing through them.

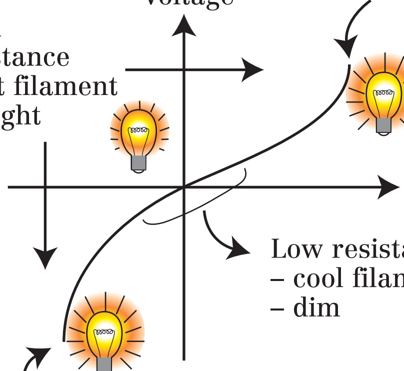
**1. Filament lamp**

Symbol 

As the current increases, the filament wire in the bulb becomes hotter.



Eventually it glows red, and then white, hot.




High resistance
– hot filament
– bright

As the current increases the resistance increases.

Power = current$^2$ × resistance

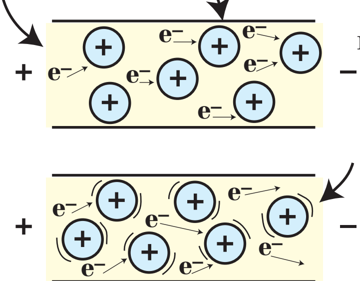
Power output = brightness increases as current increases

Low resistance
– cool filament
– dim

The more collisions the electrons make the more energy they transfer to the wire and the hotter it gets.

Eventually the filament gets so hot it melts and the bulb fails (if the potential difference exceeds the design potential difference).

Increasing current in the wire means the electrons make more collisions with fixed ions in the wire.



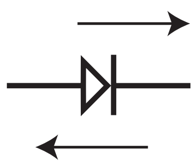

This in turn makes the ions vibrate more increasing the number of collisions still further.

Electrons find it harder to move; you need a greater potential difference to drive the same current so the resistance increases.

**2. Diode**

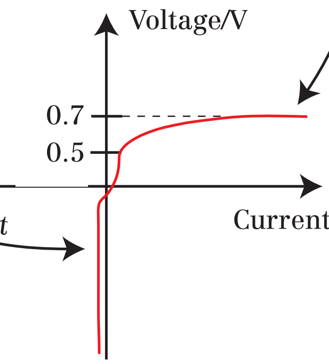
Symbol

A diode only allows current to flow in one direction.



Forward bias – very low resistance, high current flow

Reverse bias – extremely high resistance, negligible current flow




Small gradient

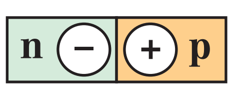
Large gradient

In the reverse direction, the current is almost negligible until very large voltages are reached when the diode may fail.

The forward current 'turns on' at about 0.5 V and very large currents can be achieved by 0.7 V when there is almost no resistance in the diode.

Diodes are made from two types of semiconductor

n-type – excess of negative charges

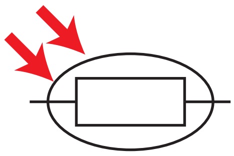



p-type – shortage of negative charge. The spaces left are called holes and behave as positive charges.

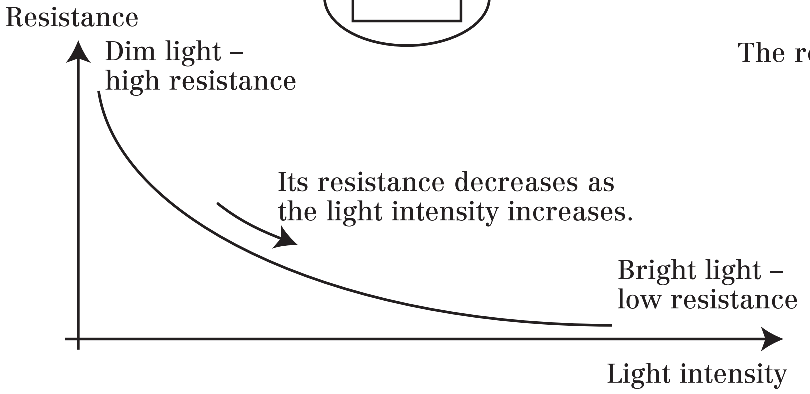
Electrons will flow n → p and holes p → n. Therefore, the diode will conduct when the n-type end is negative and the p-type end is positive.

**3. Light dependent resistor (LDR)**

Symbol



As its name suggests this is a resistor whose resistance changes depending on the intensity of the light falling on it.

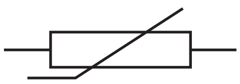



The resistance changes in a non-uniform way.

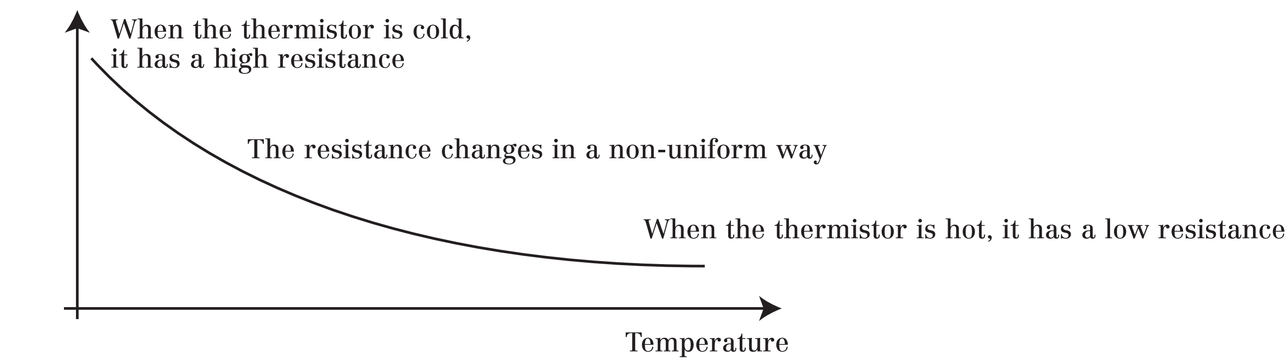
Used to control electrical circuits that need to respond to varying light levels, e.g. switching on lights automatically at night.

**4. Thermistor**

Symbol



This is a resistor whose resistance varies depending on temperature. Its resistance decreases as temperature increases.



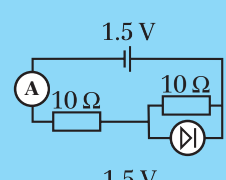

Notice that this is the opposite behaviour to a wire, whose resistance increases with increasing temperature.

Thermistors are used to control circuits that need to respond to temperature changes, e.g. to switch off a kettle.

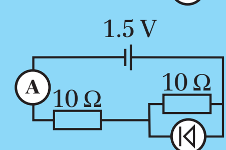
## Questions

1. Draw the circuit symbols for: a. A filament lamp. b. An LDR. c. A thermistor. d. A diode.
2. Sketch a graph of current against voltage for a filament lamp. Explain in terms of the motion of electrons through the filament the shape of the graph.
3. Show that a thermistor with a potential difference of 3 V across it and a current of 0.2 A flowing through it has a resistance of 15 Ω. If the temperature of the thermistor was raised, what would you expect to happen to its resistance?
4. Show that an LDR with a potential difference of 1.5 V across it and a current of $7.5 \times 10^{-3}$ A (7.5 mA) flowing through it has a resistance of 200 Ω. If the LDR is illuminated with a brighter light, with the same potential difference across it what would you expect to happen to the current flowing in it and why?
5. Sketch a graph of current against voltage (both positive and negative values) for a diode. Use it to explain why a diode only passes current in one direction.
6. Consider the following circuits. In which circuit will the ammeter show the greatest current?
7. A student plans to use a thermistor to investigate how the temperature of the water in a kettle varies with time after it is switched on.
   a. Draw a circuit involving an ammeter and voltmeter the student could use.
   b. Explain how they would use the ammeter and voltmeter readings together with a graph like the one printed above on this page, to find the temperature of the water at any given time.

a)

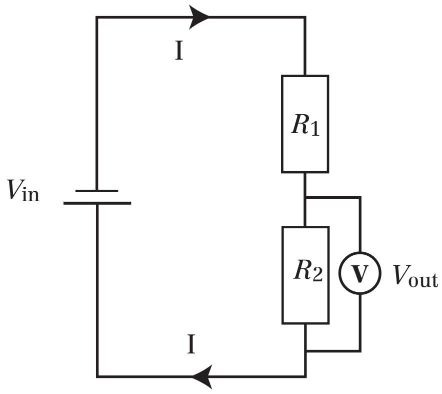



b)



# Potential Dividers

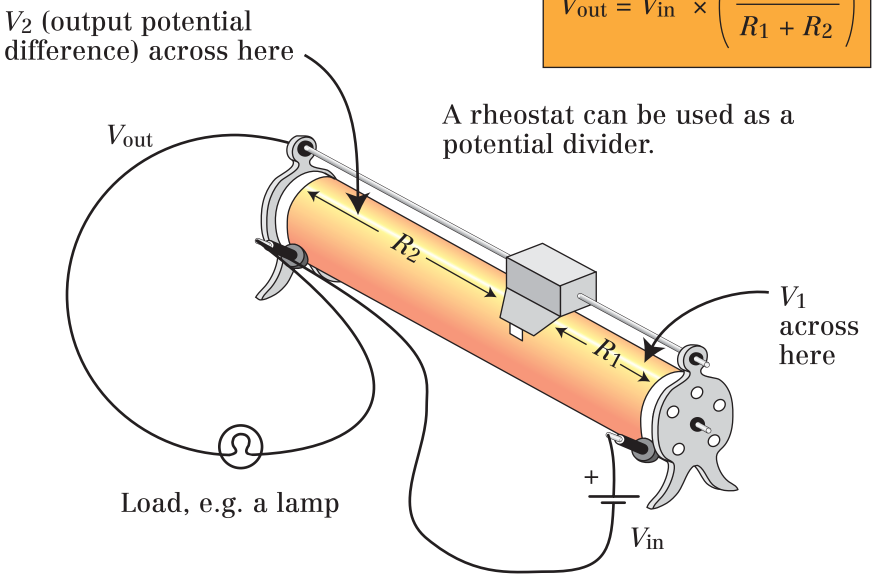
Two resistors in series form a potential divider.




The potential difference of the cell, $V_{in}$, is divided between the two resistances in the ratio of their resistances.

The output voltage can be calculated using the formula:

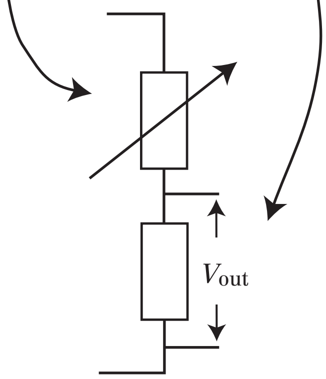
$$V_{out} = V_{in} \times \left(\frac{R_2}{R_1 + R_2}\right)$$




Slider divides the resistance into two separate resistors, $R_1$ and $R_2$. The position of the slider determines the relative size, hence ratio, of the two resistances.

The current in both resistors is the same as they are in series. The resistor with the greater value will take more voltage to drive the current through it so has the greater potential difference across it.

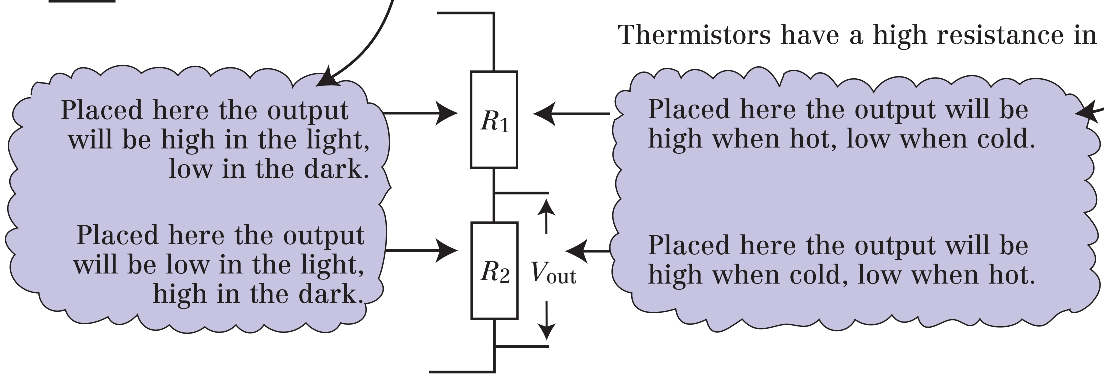
If one of the resistors is a variable resistor, the ratio of the resistances can be altered. This means you can have a variable output voltage.




If one of the resistors is an LDR, the output voltage depends on the light level. LDR has a large resistance in the dark.

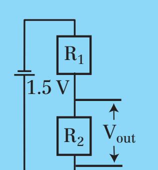
If one of the resistors is a thermistor, the output voltage depends on temperature.

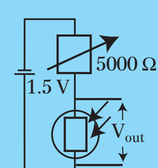
Thermistors have a high resistance in the cold.




## Questions

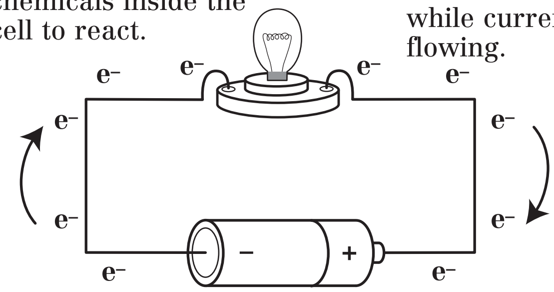
1. Use the formula above to calculate $V_{out}$ if $R_1$ and $R_2$ in the circuit provided have the following values:
   a. R1 = 10 Ω, R2 = 20 Ω. b. R1 = 20 Ω, R2 = 10 Ω. c. R1 = 1 kΩ, R2 = 5 kΩ.
   d. R1 = 1.2 kΩ, R2 = 300 Ω.
2. For each of the pairs of resistors in question 1, decide whether R1 or R2 has the greater potential difference across it.
3. An LDR has a resistance of 1000 Ω in the light and 100 000 Ω in the dark. In the circuit, the variable resistor is set to 5000 Ω. Calculate $V_{out}$ in the light and in the dark. If the resistance of the variable resistor is reduced, will the values of $V_{out}$ increase or decrease?
4. Draw a potential divider circuit where the output rises as the temperature rises. Suggest a practical application of this circuit.



Electron flow allows chemicals inside the cell to react.

Chemicals only react while current is flowing.



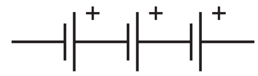

Eventually the reaction is complete and no further stored chemical energy can be released from the cell.

Electric cells convert stored chemical energy into electrical energy.

Circuit symbols

Cell

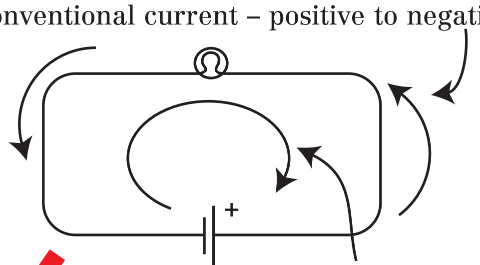

Battery (many cells)




A number of cells joined are a battery.

Current produced by cells only ever flows one-way.

Conventional current – positive to negative



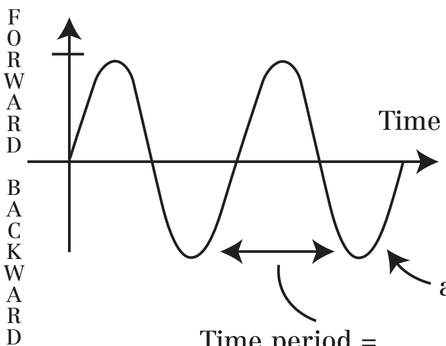

Electron current – negative to positive

Both these currents are *direct* currents (or d.c.). They flow consistently in one direction.

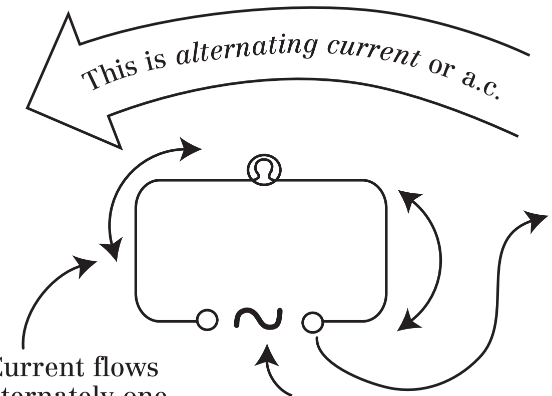
Compare this with mains electricity.

The capacity of a cell is measured in *Amp-hours*. 1 Amp-hour means the cell can deliver a current of 1 Amp for 1 hour. Since 1 Amp-hour = 3600 C the energy stored (Joules) in a cell can be calculated from voltage (V) × capacity (Amp-hours) × 3600 C.

'Rechargeable' cells use another source of electricity, often the mains, to force the electrons the 'wrong way' around the circuit. This, in a specially designed cell, reverses the chemical reaction, storing the electrical energy as chemical energy. It would be more correct to say the battery has been 're-energized'.

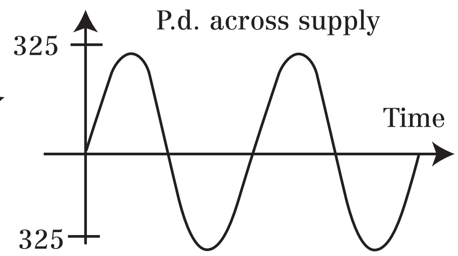



Time period = $^1/_{\text{frequency}}$




Current flows alternately one way then the other around the circuit.

a.c. supply symbol




Peak value of supply potential difference = 325 V. But, because it only has the peak value for a short time the supply transfers an equivalent power to a 230 V direct current supply.

In the UK, the frequency is 50 Hz (cycles per second).

Alternating currents are widely used because:

- They are easier to generate (p83–85).
- They are easier to distribute (p86–7) than direct currents.

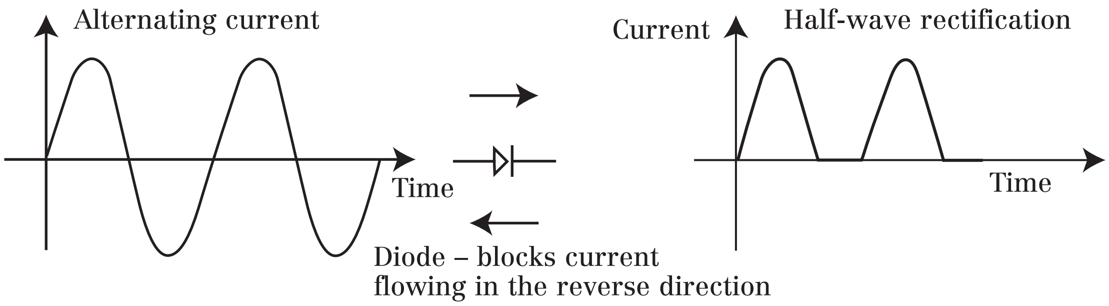
Many devices need direct current to work so alternating current often has to be converted to direct current (p54).

## Questions

1. Sketch a labelled graph of the variation of supply potential difference with time (for 10 seconds) for alternating current of frequency 2 Hz, and peak value 3 V. Add to the graph a line showing the output from a battery of terminal potential difference 2 V.
2. The capacities of two cells are AA = 1.2 Amp-hours and D = 1.4 Amp-hours. How long will each cell last when supplying:
   a. A current of 0.5 A to a torch bulb? b. 50 mA to a light emitting diode?
3. Some people claim that battery powered cars do not cause any pollution. A battery is just a store of electrical energy so where do battery-powered cars really get their energy from? Hence, are they really non-polluting, or is the pollution just moved elsewhere?
4. Draw up a table of advantages and disadvantages of batteries compared to mains electricity. Consider relative cost, how they are used, potential power output, and impact on the environment.

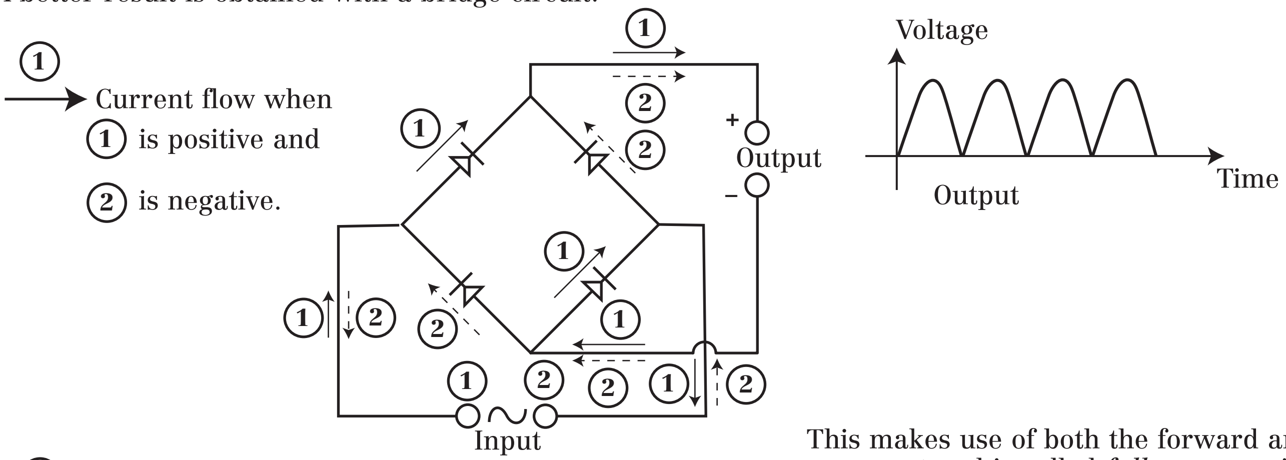
# ELECTRICAL ENERGY Diodes, Rectification and Capacitors

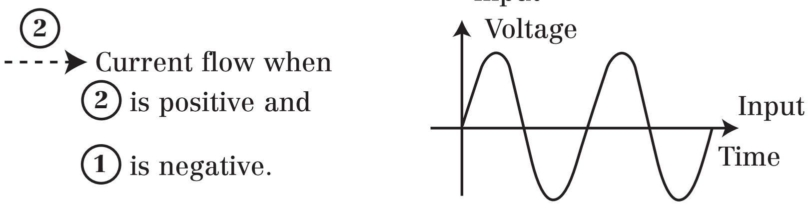
Although alternating current is easier to generate and distribute, many appliances, especially those with microchips, need direct current. The process of converting alternating to direct current is called *rectification*.




We now have direct current that flows one way around a circuit, but it is only flowing for half the time, and even then the voltage is rising and falling.

A better result is obtained with a bridge circuit.

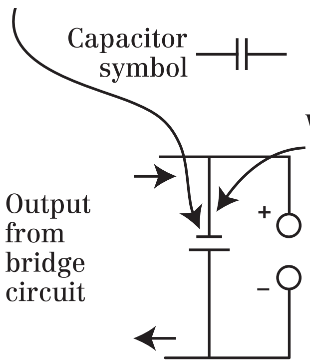


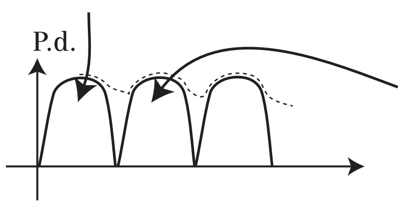

This makes use of both the forward and reverse current and is called *full wave rectification*.

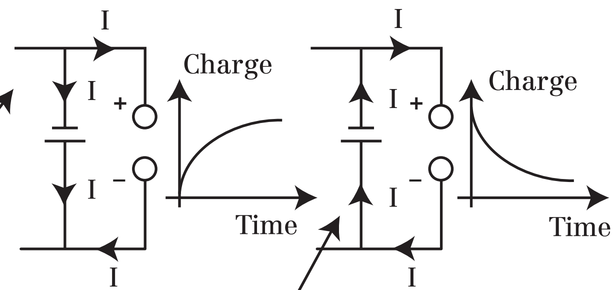
The direct current produced still has a rising and falling voltage. We say it is *unsmoothed*.

A capacitor is a component that can store charge.




When the potential difference is high, it stores some of the charge.

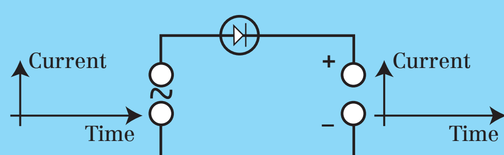



As the potential difference starts to fall it releases the charge. This helps to keep the current and potential difference up and we say the direct current is smoothed.

## Questions

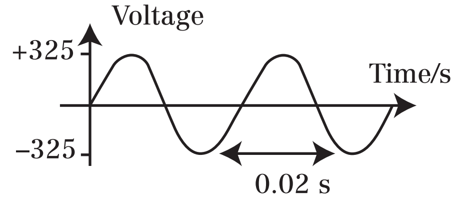
1. What is a diode?
   a. Complete the graphs in the circuit below to show the effect of the diode.
   b. Why is the output an example of direct current? Why do we say it is 'unsmoothed'?
   c. If the diode were reversed what would be the effect, if any, on the direct current output?
2. What name do we give a device that stores charge?
3. Explain the difference between full wave rectification and half-wave rectification. Illustrate your answer with voltage–time graphs.
4. Draw a circuit that produces full wave rectification. Show how the current flows through the circuit.



# ELECTRICAL ENERGY Mains Electricity and Wiring

N.B. Never inspect any part of mains wiring without first switching off at the main switch next to the electricity meter.

The UK mains electricity supply is alternating current varying between +325 V and –325 V with a frequency of 50 Hz. It behaves as the equivalent of 230 V direct current.




Earth connection is connected to the Earth, usually by a large metal sheet buried in the ground.

Live connection varies between +325 V and -325 V with respect to neutral.

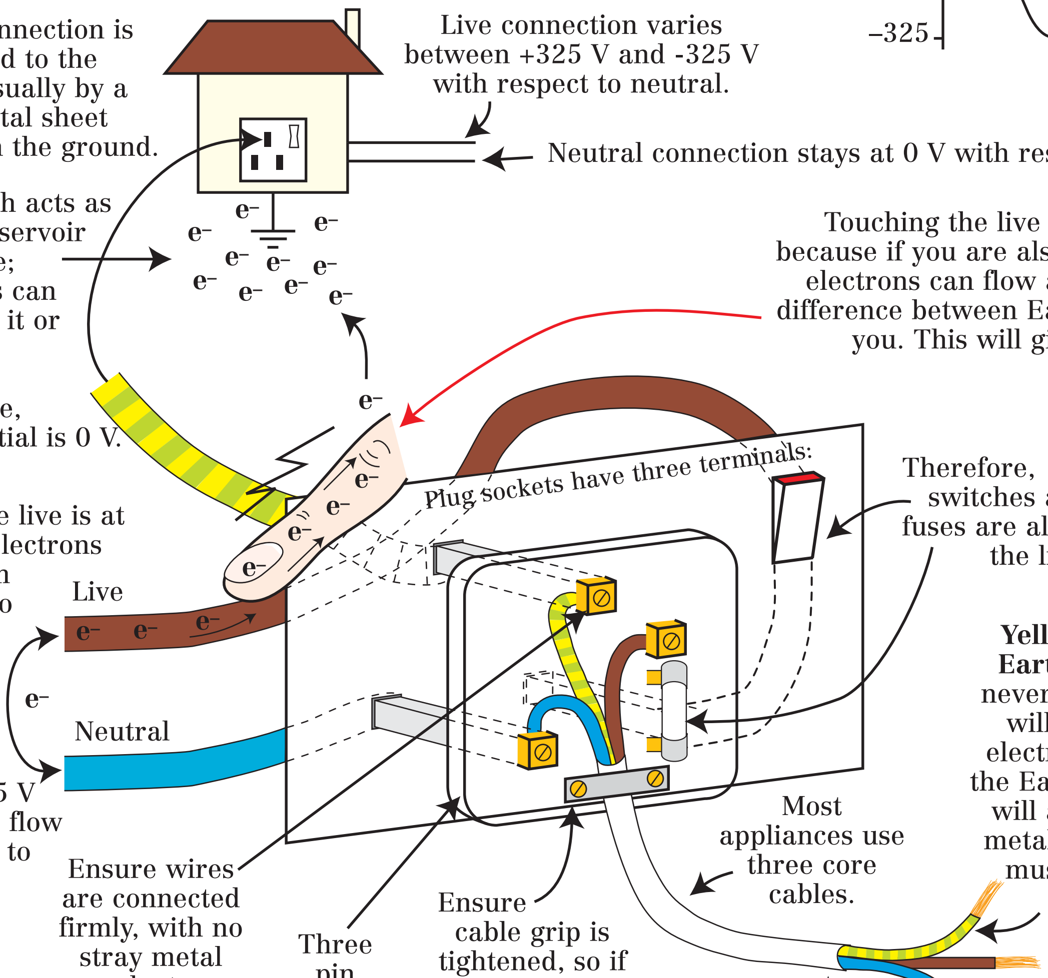
Neutral connection stays at 0 V with respect to the Earth.

The Earth acts as a vast reservoir of charge; electrons can flow into it or out of it easily. Therefore, its potential is 0 V.

Touching the live wire is dangerous because if you are also connected to Earth, electrons can flow across the potential difference between Earth and live, through you. This will give you a shock.

When the live is at +325 V electrons flow from neutral to live.

When the live is at –325 V electrons flow from live to neutral.




Therefore, switches and fuses are always placed in the live wire.

**Yellow/green wire – Earth wire.** This can never become live, as it will always conduct electrons into or out of the Earth, so its potential will always be 0 V. All metal cased appliances must have an Earth connection.

Ensure wires are connected firmly, with no stray metal conductors.

Three pin plug

Ensure cable grip is tightened, so if the cable is pulled, the conductors are not pulled out of their sockets.

Most appliances use three core cables.

**Brown wire, live.**

**Blue wire, neutral.** Needed to complete the circuit.

Inner insulation to separate the conductors.

Outer insulation to protect the conductors from damage.

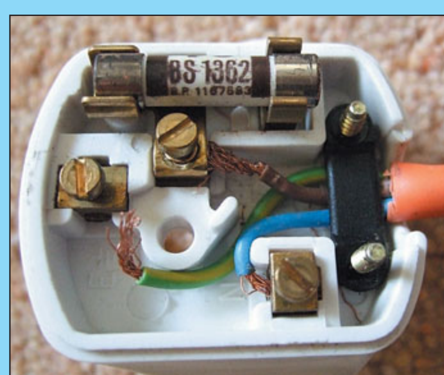
The current drawn by an appliance can be calculated using the equation:

$$\text{Current} = \frac{\text{Power}}{\text{voltage}} = \frac{\text{Power}}{230\text{ V}}$$

Power ratings can be found on the information label on the appliance.

## Questions

1. What colours are the following electrical wires: live, neutral, Earth?
2. My kettle has a power output of 1 kW and my electric cooker 10 kW. What current will each draw? Why does the cooker need especially thick connecting cables?
3. Some countries use 110 V rather than 230 V for their mains supply. Suggest how the thickness of the conductors in their wiring would compare to the conductors used in the UK. How will this affect the cost of wiring a building? What advantages does using a lower voltage have?
4. Study this picture of a three-pin plug – how many faults can you find?
5. Placing a light switch in the neutral wire will not affect the operation of the light but could make changing a bulb hazardous. Why?



# ELECTRICAL ENERGY Electrical Safety

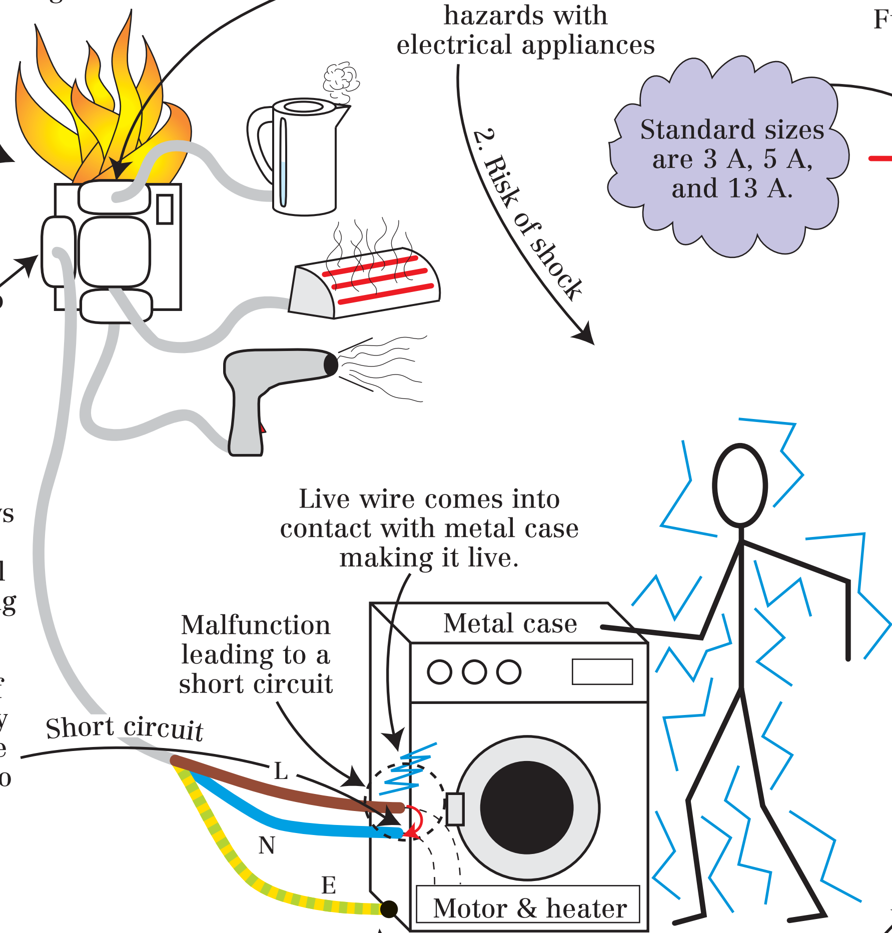
N.B. Never inspect any part of mains wiring without first switching off at the main switch next to the electricity meter.

There are two main hazards with electrical appliances

1. Risk of fire – due to overheating if too much current flowing.

Stacking too many appliances into one socket.

If current flows directly from live to neutral without passing through the appliance. This occurs if there is a very low resistance path leading to very large current.



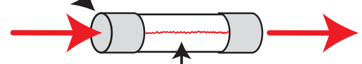

Live wire comes into contact with metal case making it live.

Malfunction leading to a short circuit

Earth wire connected to case

Fuses and the Earth wire prevent this.

Standard sizes are 3 A, 5 A, and 13 A.



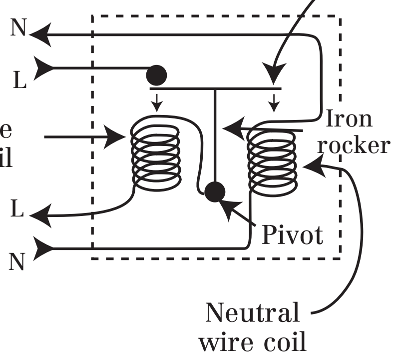

A fuse is a very thin piece of wire, a weak link in the circuit. If too much current is drawn, it overheats and melts, breaking the circuit, before the wires become very hot and become a fire risk.

If a malfunction occurs, a very large current flows from live to Earth directly.

The very large current in the live wire melts the fuse and breaks the circuit. The case is no longer live so cannot give a shock.

Fuses need to have a higher rating than the normal working current of the appliance but not so high that they may not fuse if a fault develops.

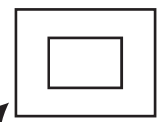
Residual current devices (r.c.d) can act like an Earth wire and fuse.




If the current in both coils is the same, the rocker stays level. If a fault develops, current in the neutral wire falls and the iron rocker is attracted magnetically to the live coil breaking the circuit.

Advantages:
1. Acts faster than a fuse, which has to melt.
2. Trips even if not all the current goes to Earth.
3. Easily resettable once the fault is corrected.

Some appliances have a completely insulated (e.g. plastic) outer case so cannot become live even if a fault develops. They are *double insulated*. An Earth wire is not needed but fuses are still used to prevent too much current flowing causing a fire.



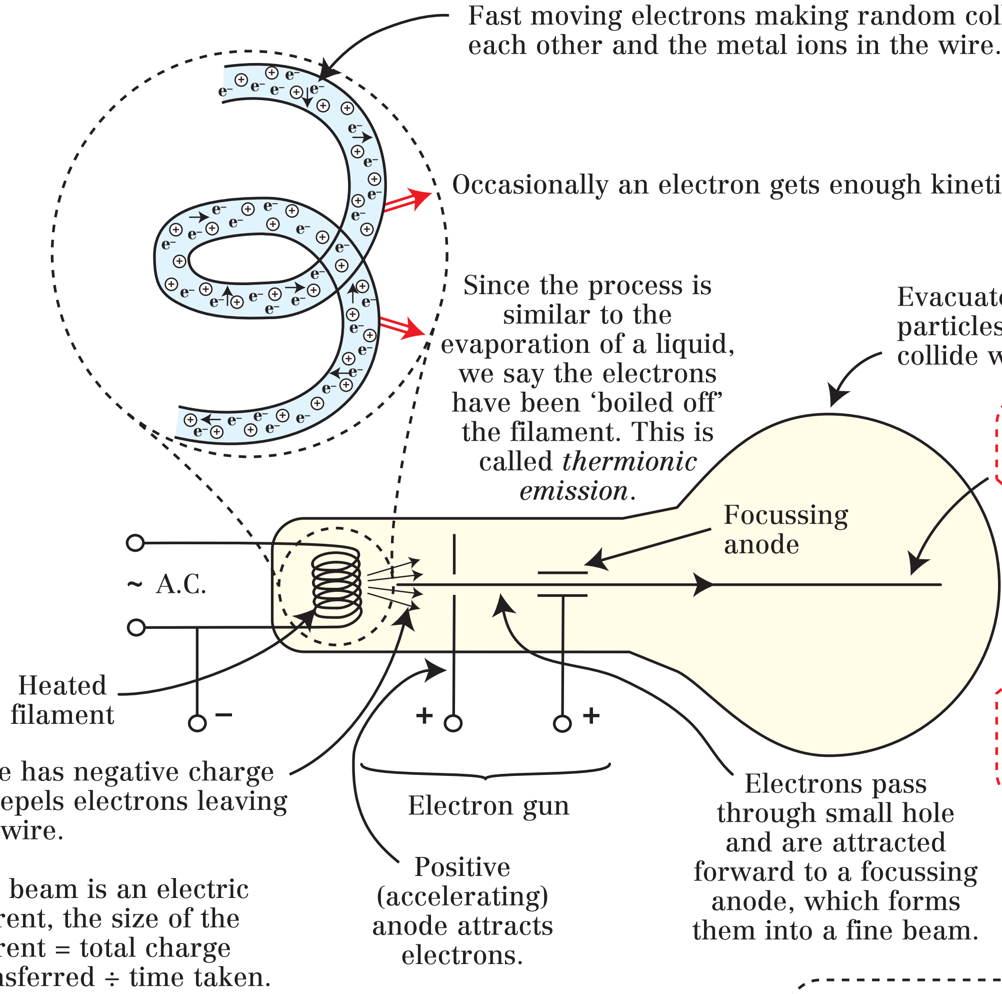
Symbol on case

## Questions

1. Choose (from 3 A, 5 A, and 13 A) the most appropriate fuse for the following:
   a. An electric iron of power output 800 W.
   b. A table lamp of power output 40 W.
   c. A washing machine of total power 2500 W.
2. Explain why a fuse must always be placed in the live wire.
3. Explain why a double insulated appliance does not need an Earth wire, but does need a fuse.
4. The maximum current that can be safely drawn from a normal domestic socket is 13 A. At my friend's house, I notice a 2.5 kW electric fire, an 800 W iron, and three 100 W spot lamps all connected to a single socket. What advice should I give my friend? Use a calculation to support your answer.
5. While using my electric lawnmower I cut the flex, and the live wire comes into contact with the damp grass. An r.c.d will make this wire safe very quickly. What is an r.c.d and how does it work in this case?

# ELECTRICAL ENERGY Electron Beams

Not all electric currents flow in wires. It is possible to produce a beam of electrons travelling through a vacuum.




Kinetic energy of the electrons = electronic charge × accelerating voltage between anode and cathode.

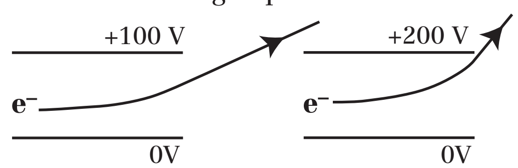
N.B. Voltage is energy per unit charge.

Hence KE (J) = e × V

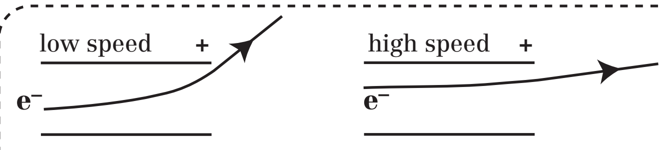
The beam is an electric current, the size of the current = total charge transferred ÷ time taken.

$$\text{Therefore current} = \frac{\text{rate of flow of electrons} \times \text{electronic charge}}{\text{time.}}$$

The beam can be deflected by charged plates.




The larger the charge on the plates (i.e. the potential difference across them) the greater the deflection.




The greater the kinetic energy of the electrons, i.e. the faster they are moving, the less time they spend between the plates and the smaller the deflection.

## Questions

1. Describe the process of thermionic emission. Why is it important that the electron beam be produced in a vacuum?
2. What would happen to the kinetic energy of the electrons produced by an electron gun if the potential difference between the heated filament and the accelerating anode was increased?
3. What would happen to the charge transferred per second (the current) in the electron beam if the heater temperature was increased but the accelerating potential was not changed? Would the kinetic energy of the electrons change?
4. Given that the charge of one electron is $1.6 \times 10^{-19}$ C, show that the kinetic energy of an electron in the beam is $3.2 \times 10^{-17}$ J when the accelerating potential is 200 V.
5. If the current in the electron beam is 2 mA, show that the number of electrons boiled off the filament each second is about $1.3 \times 10^{16}$ [charge on the electron = $1.6 \times 10^{-19}$ C].
6. Use the answers to questions 4 and 5 to show that the total energy delivered by the beam per second (i.e. its power) is 0.4 W.
7. An electron beam passes through two charged plates as shown in the diagram. What would be the effect on the deflection of:
   a. Increasing the potential difference across the deflecting plates?
   b. Decreasing the accelerating voltage across the electron gun?