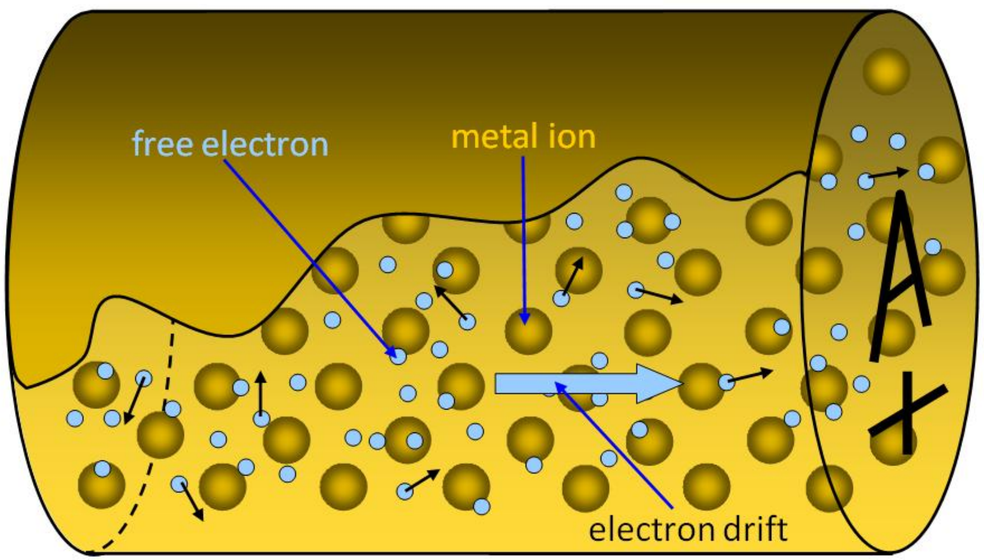
Current Electricity



Resistance

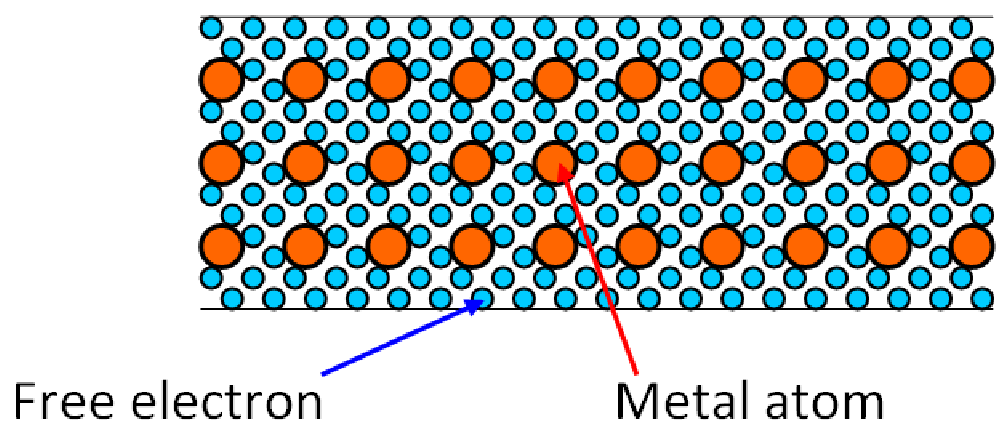
The resistance of any conducting material depends on the following factors:

(a) the material itself (actually how many free electrons there are per metre cubed)

(b) its length

(c) its cross-sectional area and

(d) its temperature



Resistivity

The property of the material that affects its resistance is called the resistivity of the material and is given the symbol ρ.

Resistivity is defined as follows:

> The resistivity of a material is defined as the resistance between two opposite faces of a 1 m^3 specimen of the material.

The units for resistivity are Ωm.

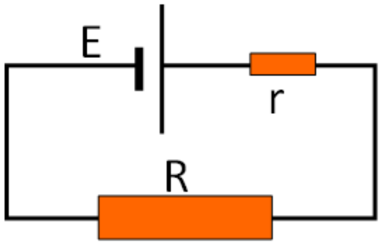
Resistivity is related to resistance of a specimen of length L and cross sectional area A by the formula:

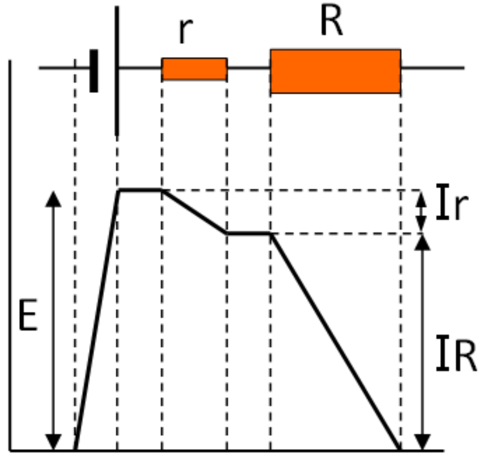
> Resistivity (ρ) = RA/L

E.M.F and internal resistance

All cells have a resistance of their own and we call this the **internal resistance** of the cell. The voltage produced by the cell is called the **electromotive force** (e.m.f) and this produces a p.d (V = IR) across the cell and across the external resistor (Ir).

The e.m.f (E) of the cell can be defined as the maximum p.d that the cell can produce across its terminals, or the open circuit p.d since when no current flows from the cell no electrical energy can be lost within it.





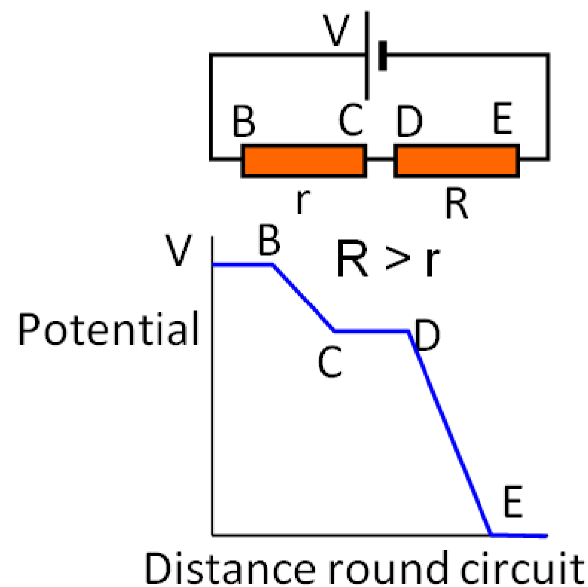
E = V + Ir = IR + Ir

Potential round a circuit

The electrical potential energy of a unit charge at a point in a circuit is called the potential at that point.

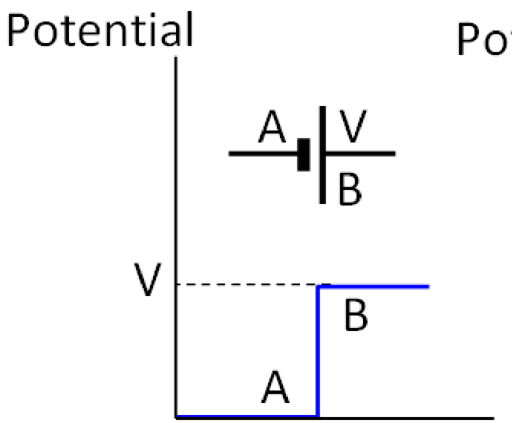
Potential difference between two points in a circuit is the work done in moving unit charge (i.e. one coulomb) from one point to the other

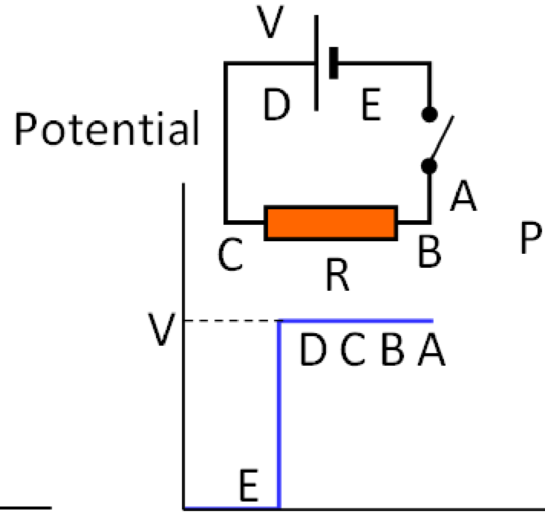
The units for potential difference are therefore Joules per coulomb, or volts.
(1 volt = 1 Joule/coulomb).

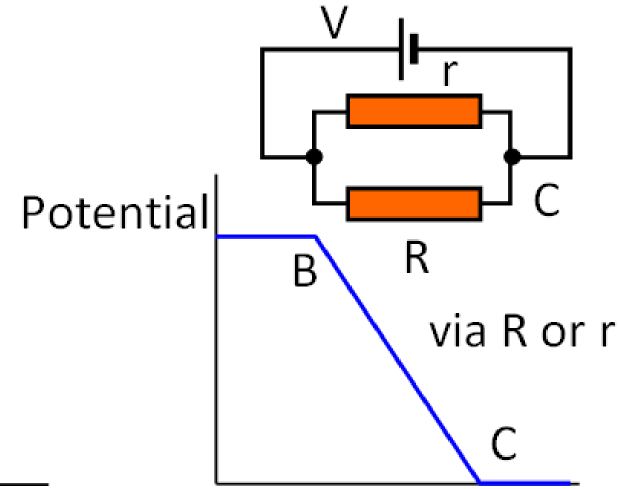


From the cell to B there is no resistance and so no loss of electrical energy or drop in potential. In the resistors r and R energy is converted to heat and so the potential drops from B through to E. From E to the cell there is no loss of electrical energy and so the potential at E is the same as that at the negative terminal of the cell – zero.

Potential and energy







Electrical energy = Charge x Potential difference (Voltage)

Joules = Coulombs x Volts = Amps x Time x Volts

Electrical energy = ItV

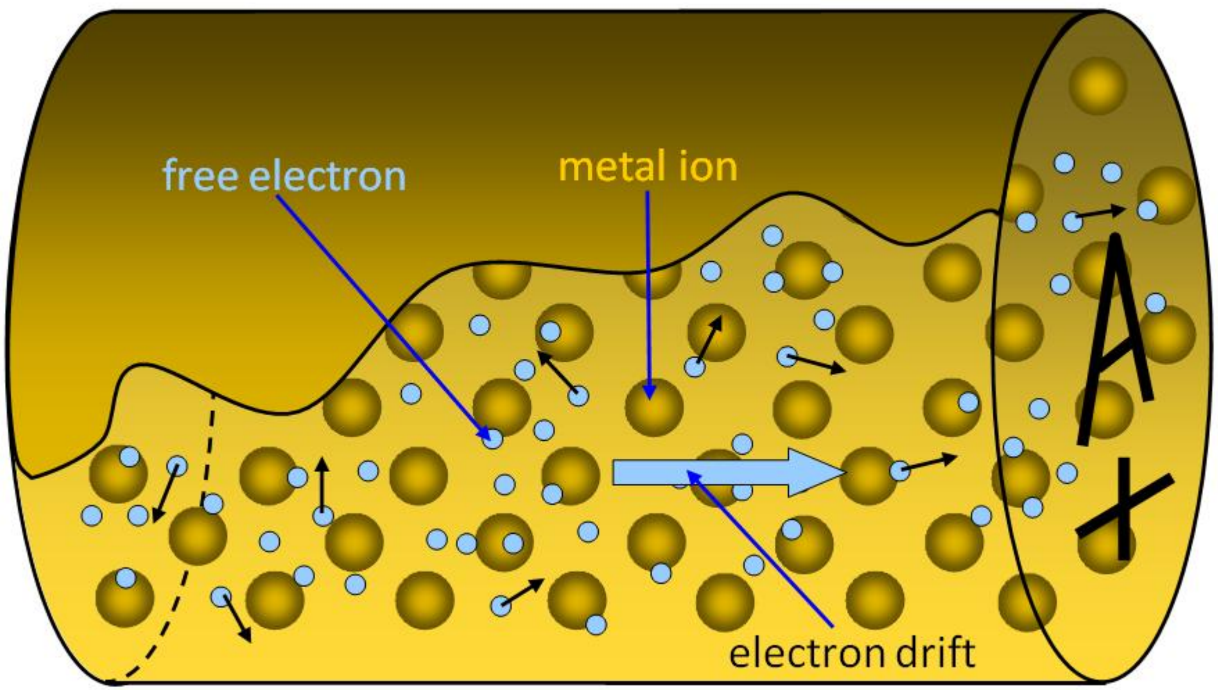
Free electron motion in a wire

The free electrons in a metal have three distinct velocities associated with them:

(a) a random velocity (about 10^5 ms^{-1})

(b) a velocity with which electrical energy is transferred along the wire (about 10^8 ms^{-1})

(c) a drift velocity of the electrons as a whole when a current flows through the wire (this depends on the applied voltage but is usually a few mms^{-1} for currents of a few amps in normal connecting leads).

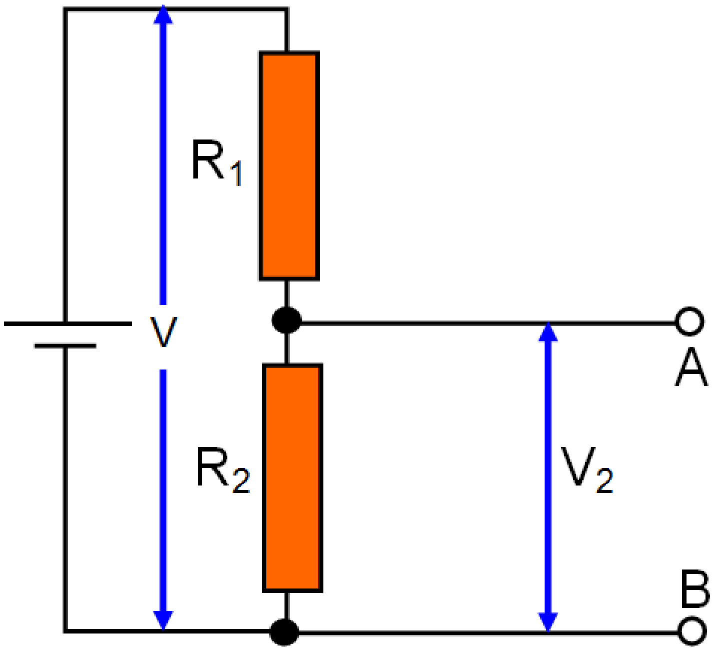


Potential divider

The output voltage across AB is given by:

Output voltage (V_2) = (R_2/[R_1 + R_2])V

The input voltage (V) in this case is supplied by the battery and is constant. The current flowing through both resistors is the same (series circuit) and so the output voltage across one of them depends simply on the two resistance values and the input voltage.



Charge flow and electric current

- Electric charge in a solid is carried by particles called electrons. One electron has a very tiny charge and so for practical measurement of electric charge we use units called COULOMBS.
- A coulomb (C) is an AMOUNT of electric charge in just the same way that a litre is an AMOUNT of water.
- One coulomb is the charge of roughly six million million million electrons!
- The movement of this charge round a circuit is called the **electric current**.
- Electric current is the rate of flow of charge round a circuit. The current at a point in the circuit is the amount of charge that passes that point in one second.

- **A current of 1 A is flowing in a circuit if a charge of 1 coulomb passes any point in the circuit every second.**

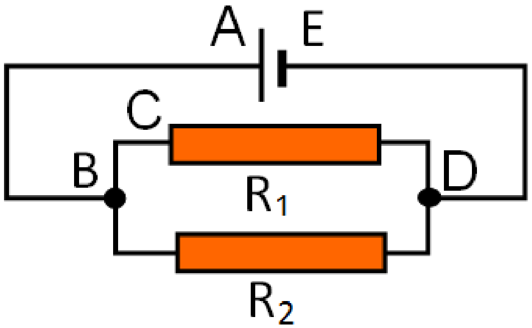
- Electric current is measured in AMPERES (AMPS, symbol A).

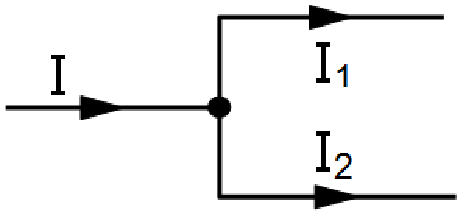
Kirchhoff's rules (1)

1. The algebraic sum of the currents at a junction is zero. In other words there is no build up of charge at a junction

2. The sum of the changes in potential round a closed circuit must be zero.

Rule 1 is about charge conservation while rule 2 is about energy conservation.



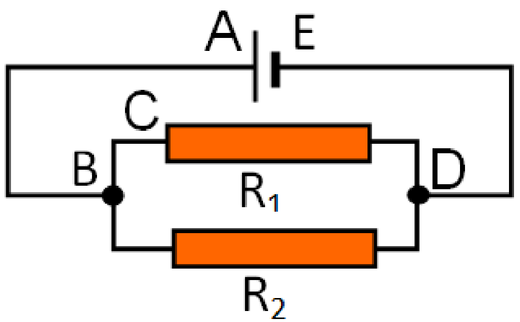


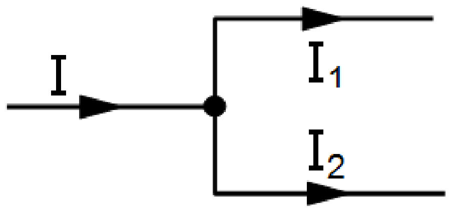
Kirchhoff's rules 2

Rule 1

At the point B there is a junction

Current flowing from the cell (I) = Current in R_1 (I_1) + current in R_2 (I_2)





Rule 2

Round loop A,B,C,D,E: p.d across cell = - p.d across R_1

This represents a gain of potential in the cell but a loss in R_1

Round loop B,C,D,B: p.d across R_1 = - p.d across R_2

In this equation there is a minus because we are moving 'against' the current in R_2

Resistors in series and parallel

Resistors in series

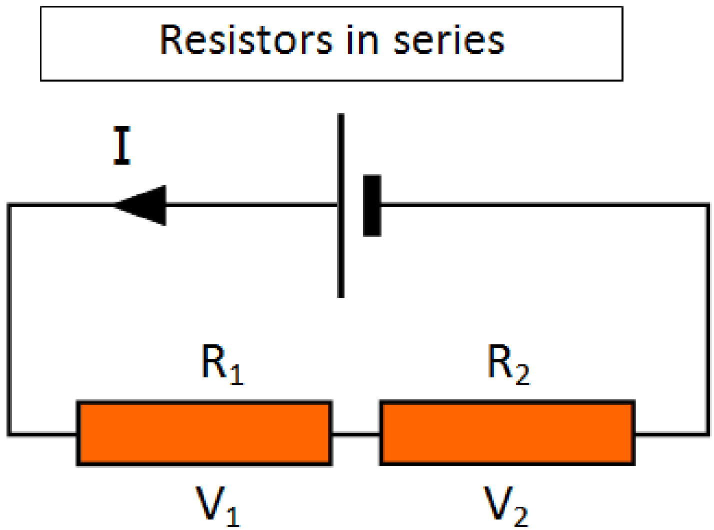
The current (I) flowing through R_1 and R_2 is the same and so the potential differences across them are $V_1 = IR_1$ and $V_2 = IR_2$

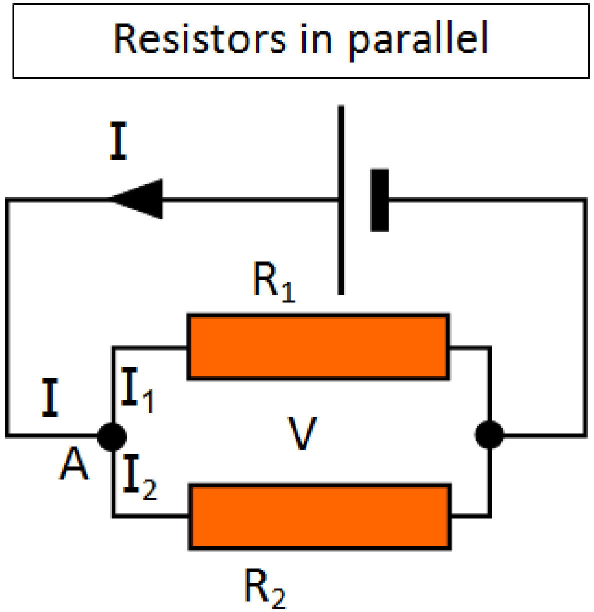
Resistors in series: $\mathbf{R = R_1 + R_2}$

Resistors in parallel:

The potential difference (V) across each of the two resistors is the same, and the current (I) flowing into junction A is equal to the sum of the currents in the two branches.

Resistors in parallel: $\mathbf{1/R = 1/R_1 + 1/R_2}$





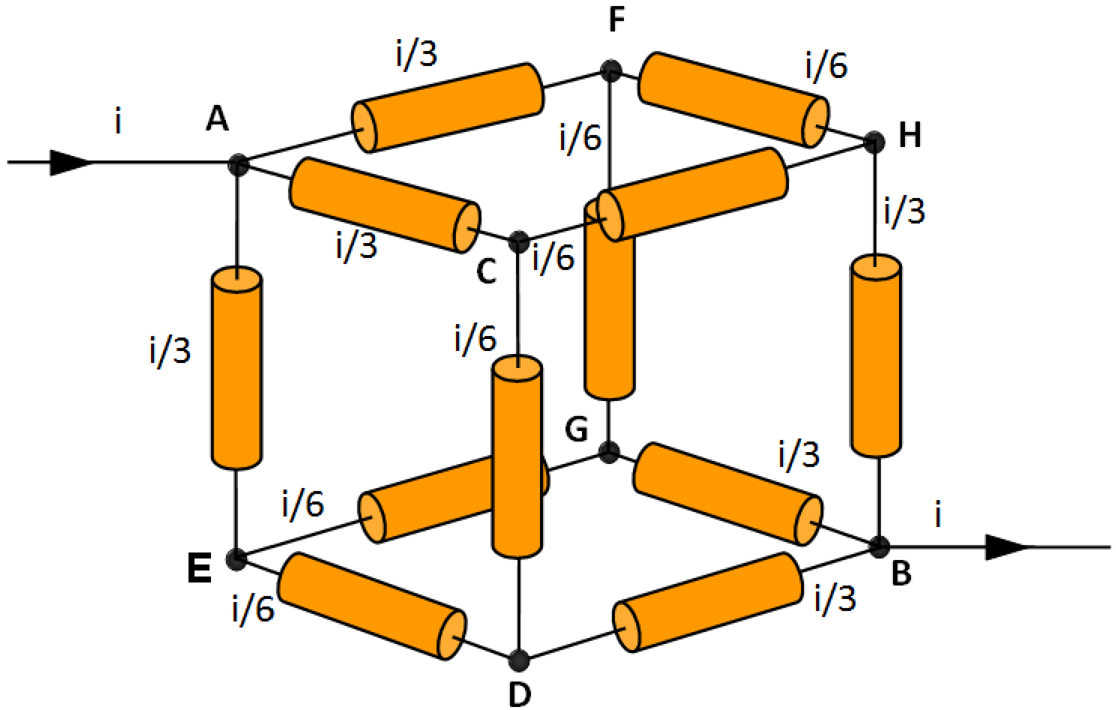
Resistance networks (1)

Twelve resistors in the form of a cube.

The problem is to find the resistance (R) between the points A and B on each cube. Each arm of the cube has a resistance r.

We can take any path through the network between the points A and B. Such a path could be ACDB.

IR = i/3 r + i/6 r + i/3 r = I 5/6 r Therefore: Total resistance (R) = 5/6 r



Resistance and temperature

When a material is heated its resistance will change. This is due to the thermal motion of the atoms within the specimen

The equation for this variation is:

$$R_\theta = R_o[1+ \alpha\theta + \beta\theta^2 + . .$$

where R_θ is the resistance of the specimen at some temperature θ °C and R_o the resistance at 0°C. In this equation $\beta \ll \alpha$ and so the change by the following simplified equation as long as the temperature change is not too great.

$$R_\theta = R_o[1+ \alpha\theta]$$

Here α is called the temperature coefficient of resistance and is defined as the increase in resistance per degree rise divided by the resistance at 0 °C

$$\alpha = [R_\theta - R_o]R_o\theta$$

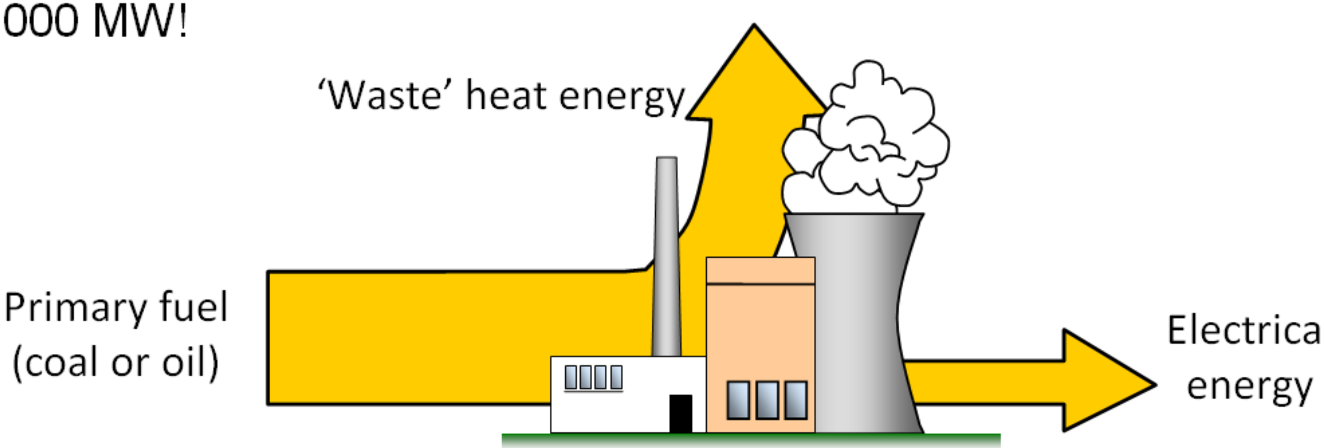
Electrical power

Electrical power = voltage x current

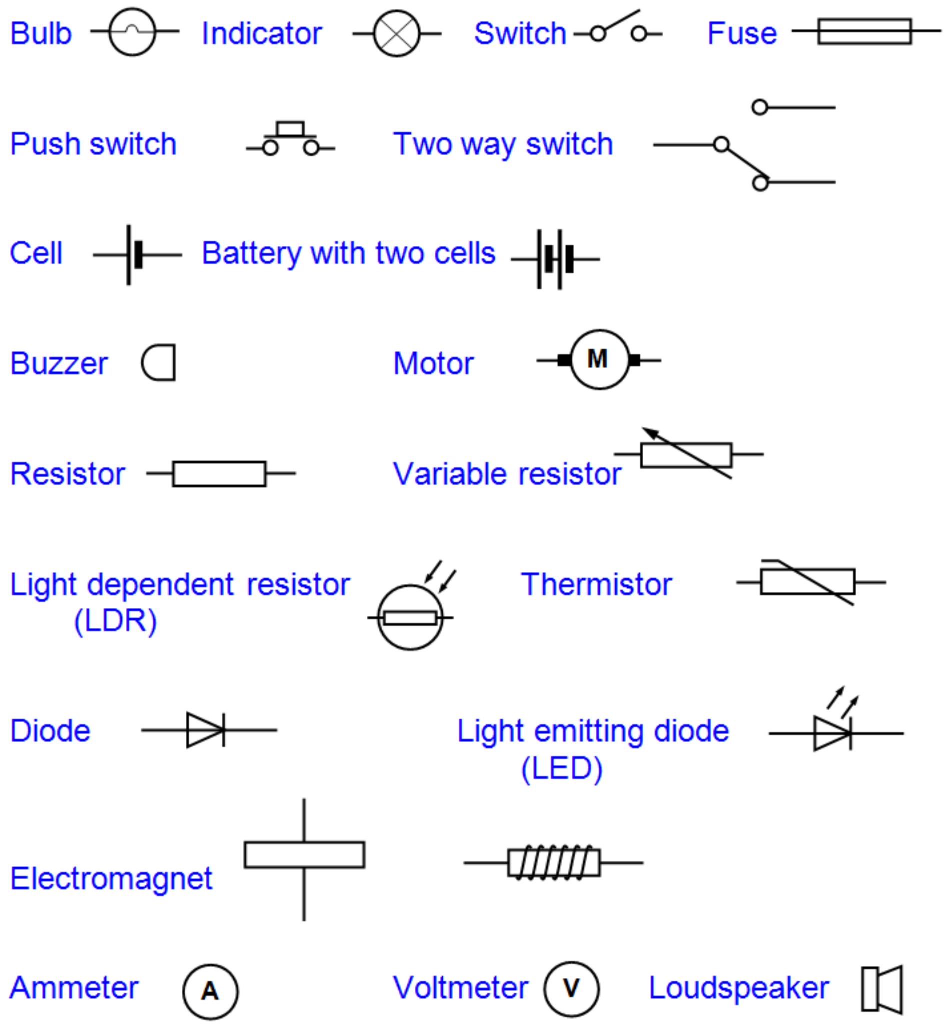
Power = VI
or
Electrical power = VI = I^2R = V^2/R

[Power is measured in watts with current in amps and voltage in volts].

For large amounts of power we use kilowatts kW (1000 W) and megawatts (1000 000 W). A large power station will operate at over 1000 MW!



Electrical symbols



Resistance and Ohm’s Law

The ratio of the current in a conductor to the potential difference (voltage difference) between it ends is a constant as long as the temperature stays constant.

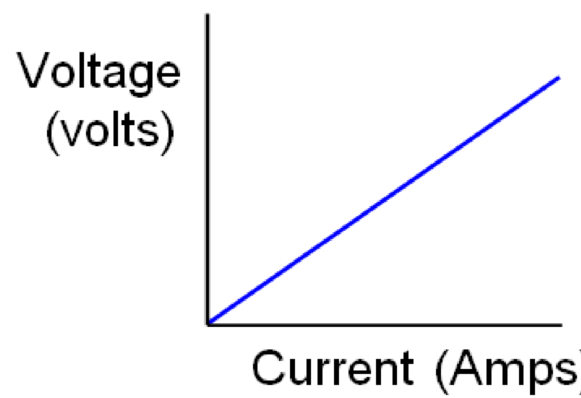
This constant is called the RESISTANCE of the conductor.

Resistance = Voltage (V)/Current (I)

$$R = V/I$$

Voltage = Current x Resistance

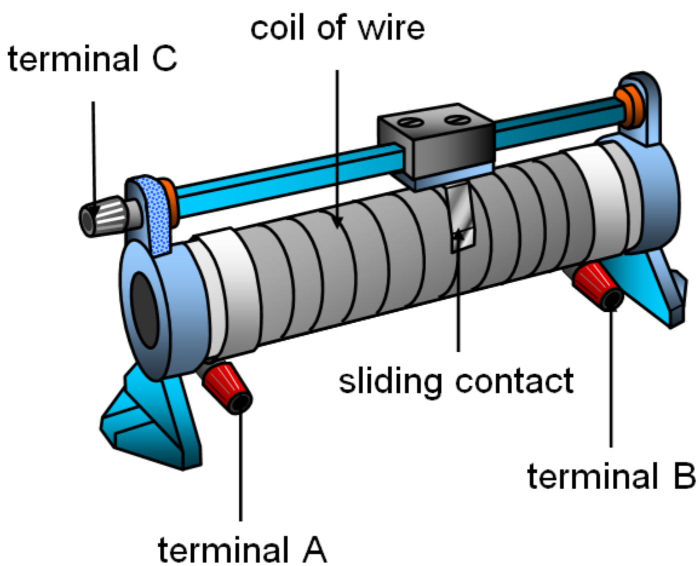
or $$V = IR$$

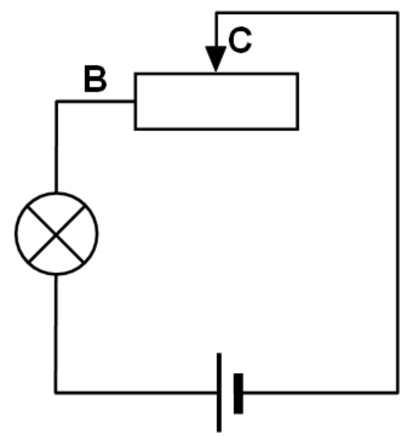


Variable resistor (rheostat)

A long wire has a bigger resistance than a short one of the same material and diameter.

One way of increasing the length of wire in a circuit is to use a device called a **variable resistor** or **rheostat**. This is made of a length wire wrapped round a former. It can either be a straight as in the picture or wrapped round into a circle.





Series and parallel circuits

Series **(Figure 2)**
In a series circuit the potential is shared between the two bulbs and so the potential difference across each bulb is only half that across a single bulb. The RESISTANCE of two components (bulbs or resistors) in series is GREATER than that for a single component.

Parallel **(Figure 3)**
In a parallel circuit the potential across each bulb is the same as it was in the circuit with the single bulb. Each bulb in the parallel circuit ‘feels’ the full potential difference across it. The current flowing through each bulb is therefore the same as that through the single bulb. The RESISITANCE of two components (bulbs or resistors) connected in parallel is LESS than that of a single component.

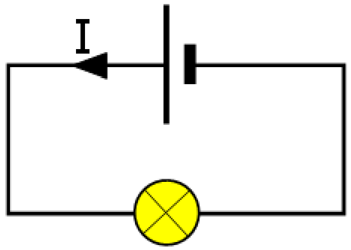


Figure 1

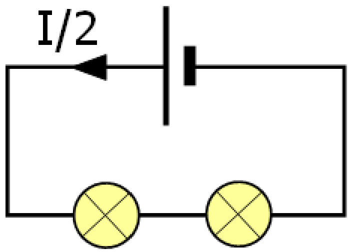


Figure 2

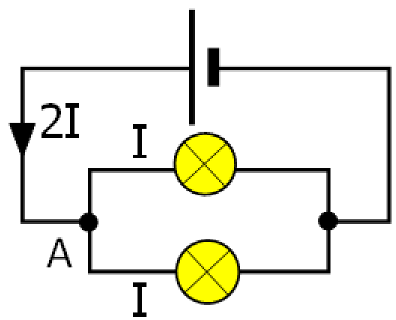
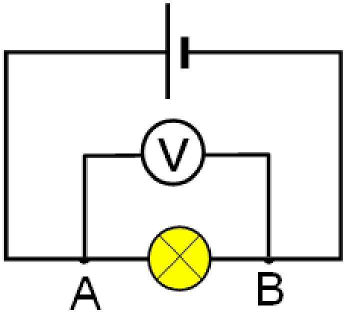


Figure 3

Electrical energy

The voltage between two points on a circuit is called the potential difference between those two points. The potential difference (p.d.) between two points in a circuit is 1 V if 1 joule of electrical energy is changed to other forms of energy when 1 C passes from one point to the other.



The voltmeter measures the difference in the energy of the electricity between points A and B, i.e. before and after it has passed through the bulb.

At A the electricity has a lot of energy but at B most of this energy has been changed into heat and light in the bulb.

Energy = joules = volts x charge = voltage x current x time
Joules= volts x coulombs
Volts = joules per coulomb

Current and electron flow

As a charge moves round a circuit from the positive to the negative it loses energy. An electric current is a flow of negatively charged electrons which flow away from the negative terminal of a supply, round the circuit and back to the positive terminal. However the ‘traditional’ view of current flow is from positive to negative.