Generation of Energy

Introduction

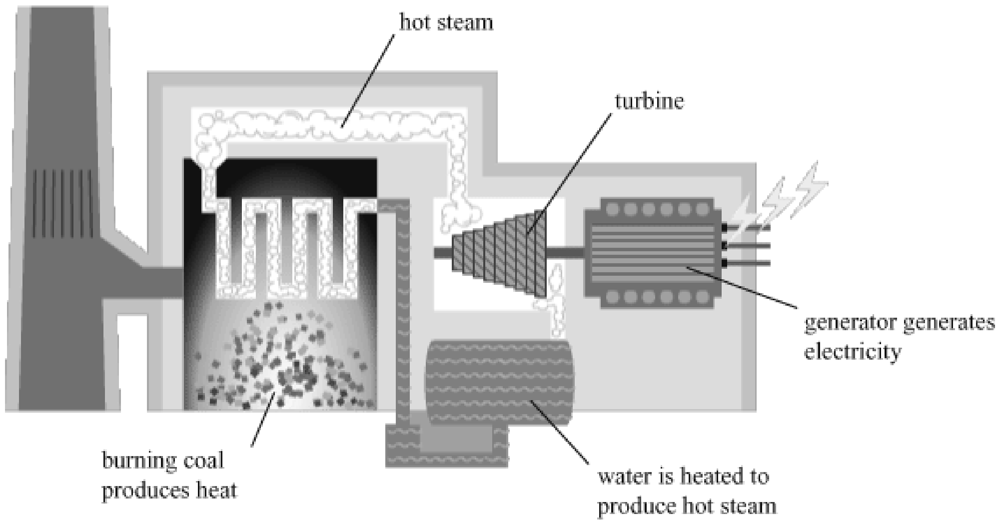
Most of our energy continues to be supplied by non-renewable sources such as nuclear and fossil fuels (coal, oil and gas). These sources are not present in unlimited quantities and will eventually run out. Alternative methods of meeting our demand for energy continue to be investigated. The renewable sources of energy (wind, solar, tidal etc.), which will never run out and will always be available, now meet some of our demand for energy.

Energy from renewable or non-renewable sources of energy has to be turned into electricity in a power station.

Generation of Electricity

Thermal Stations

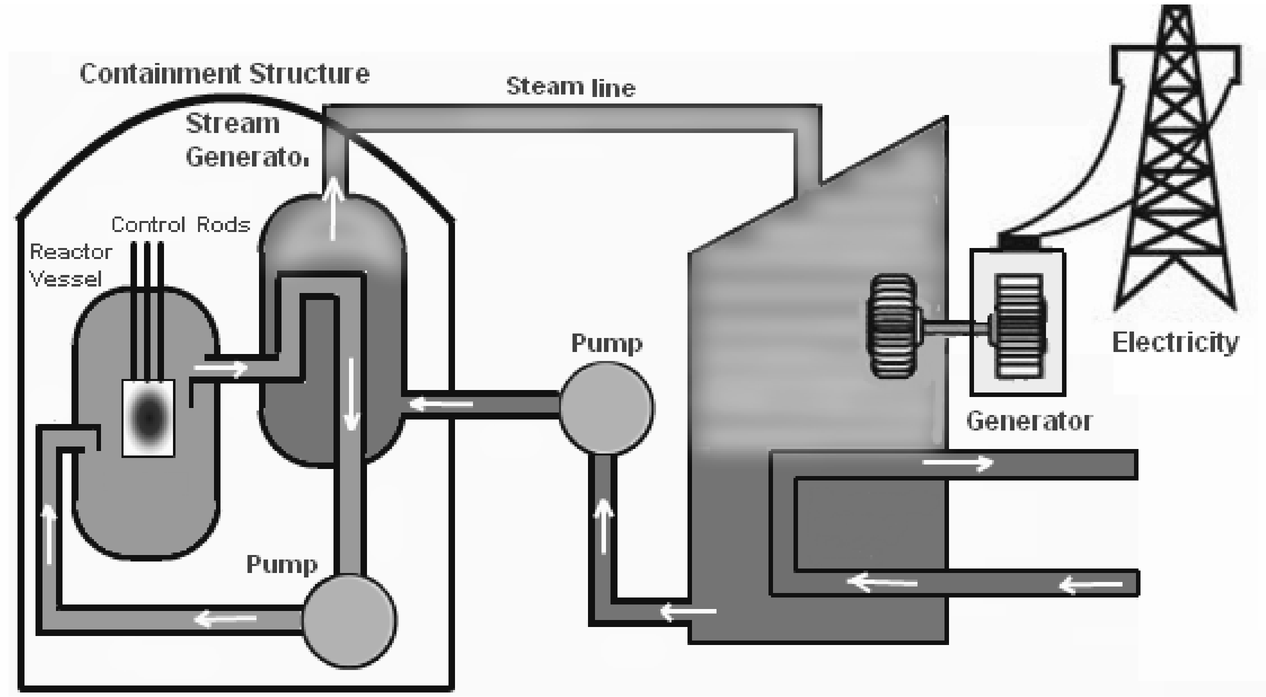
Thermal power stations generate electricity by burning fossil fuels.
Oil or coal is burned causing chemical energy to change to heat, which turns water into steam in the boiler.



The steam then travels at high pressure and turns a turbine as it passes.
The turbine then turns the generator which converts kinetic energy into electrical energy.

Nuclear Power Stations

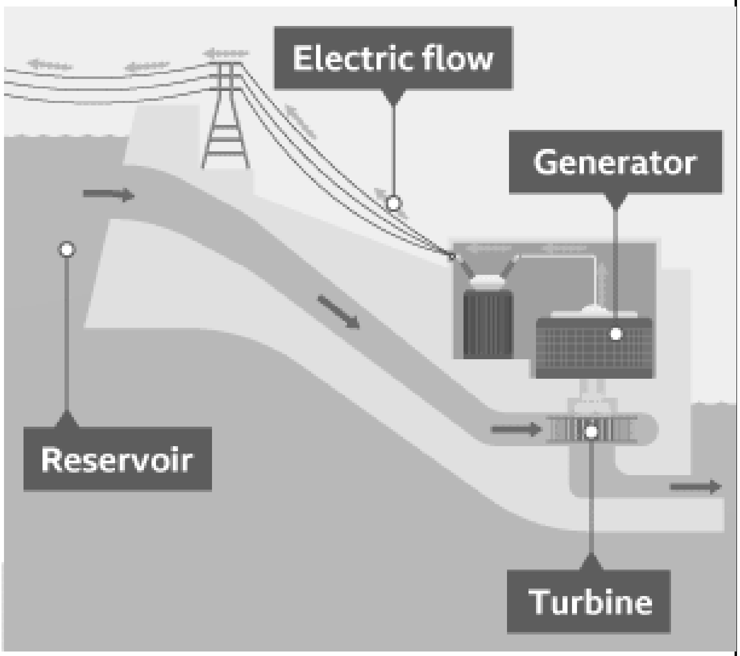
Nuclear power stations make use of the energy stored inside unstable atoms. The energy changes which occur inside a nuclear power station are similar to the changes in a thermal power station. Instead of chemical energy being burned to produce heat, nuclear energy itself is used to heat water in the nuclear reactor.



Unlike power stations which burn fossil fuels nuclear power stations do not release harmful green house gases into the environment. Nuclear fuel will also not run out as quickly as the fossil fuels and produces huge amounts of energy.

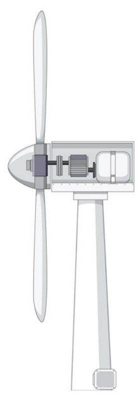
Many people, however, are opposed to nuclear plants as they are fearful of the catastrophic problems which may arise if something goes wrong and are concerned about radioactive waste.

Hydroelectric Power Stations



Hydroelectric power stations convert the kinetic energy of moving water into electrical energy. The water which is stored high up behind a dam has gravitational potential energy. This is changed to kinetic energy as the water is released and rushes down through tubes inside the dam. The moving water drives turbines which in turn rotate generators, which may be built inside the dam.

Wind Turbines



Wind turbines have huge blades mounted on a tall tower. The blades are connected to a generator. As the wind blows, it transfers some of its kinetic energy to the blades, which turn and drive the generator.

Wind turbines may be grouped together in windy locations to form wind farms.

Tidal Power

The movement of the tides flowing in and out can be harnessed using a turbine and generator combination, similar to wind power. The turbine is rotated by the flowing water and this rotates the generator resulting in electrical energy.

Solar Power

Solar cells (also known as photovoltaic cells) generate electricity. These devices convert light energy into electrical energy. Small solar cells are used in calculators.

A group of solar cells may be described as an array. An array of solar cells may be used to power road signs in remote areas, and larger arrays are used to power satellites in orbit around the Earth.

Biomass

Some power stations burn wood from forests of fast-growing trees. These power stations work in the same way as traditional thermal stations. Burning wood also puts carbon dioxide into the atmosphere but the next generation of trees absorb it again in photosynthesis. So, biomass is carbon neutral. Other organic material can also be burnt to generate electricity.

Sugar from sugar cane can be changed into alcohol to power cars.

Advantages and Disadvantages of Sources

Energy Source	Advantages	Disadvantages
Fossil Fuels	Reliable	Create pollution and will run out
Nuclear Power	Reliable	Will run out and produce radioactive waste that is hard to dispose of
Hydroelectricity	Clean and cheap to run	Expensive to set up and output could be affected by drought
Wind	Clean and cheap to run	Expensive to set up and wind does not always blow
Solar	Clean and cheap to run	Not always sunny and output does not always outweigh initial cost to set up
Tidal	Clean, cheap to run and produces a lot of electricity once running	Very expensive to set up and could be hazardous to local wildlife
Biomass	Does not release carbon dioxide and reduces landfill	Expensive and requires a lot of land

Efficiency of Energy Generation

All methods of energy generation have both advantages and disadvantages. Efficiency of electricity generation is also important because the better the method of generating electricity, the less energy is wasted. Once the electricity is generated, it needs to be transported from the power station or generator to the consumer. This is done using a system of pylons and cables called the National Grid.

Some energy is 'lost' in the transmission lines as heat, due to resistance in the cables and a small amount of sound energy. If you have ever stood near a pylon you may have heard a faint buzzing noise, as some energy is transferred to sound.

Energy in the Home

The way we use electricity in the home affects the amount of electricity we need to generate. If we waste energy then we need to make more.

There are steps we can take in order to reduce our carbon footprint and the amount of energy we use, such as:

- have roof and cavity wall insulation installed to reduce the heat energy lost from our homes
- have our windows double or triple glazed to reduce heat loss through our windows
- switch off unwanted lights and appliances to reduce unnecessary energy use
- make use of energy efficient electrical appliances such as low energy light bulbs where possible

Electrical Power

To compare different components it is often useful to compare the **rate** at which energy is transformed, that is the energy transformed **each second.** This electrical energy transformation each second is known as the **power.** The power of an appliance can be found using the following equation:

$$\boxed{P = \frac{E}{t}}$$

Power (P) is measured in watts, W, energy (E) is measured in joules, J, and time (t) is measured in seconds, s.

1 watt is equivalent to the transfer of 1 joule per second.

Example 1

An electric kettle uses 540 kJ of electrical energy in 5 minutes.
Calculate the power rating of the kettle.

E = 540 kJ = 540 000 J
t = 5 mins. = 300 s

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

$$= \frac{540\,000}{300}$$

$$= 1\,800 \text{ W}$$

Example 2

An electric motor on a ceiling fan with a power rating of 115 W is switched on for 3 minutes.
Calculate the energy used by the electric motor.

P = 115 W
t = 3 mins. = 180 s

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

$$115 = \frac{E}{180}$$

$$115 \times 180 = E$$

$$E = 20\ 700\ J$$

Electrical Power

Electrical energy is not free ! Every household pays for the amount of electrical energy used. The amount of energy used is determined by the power rating of the appliances and the length of time the appliances are used for. Every appliance has a power rating marked on it, in either watts (W) or kilowatts (kW). The greater the power rating of the appliance. the more energy it uses per second. The table below gives approximate power ratings for a number of household appliances.

Appliance	Power Rating (W)
Computer	250
Dishwasher	1200
Vacuum Cleaner	600
Toaster	1200

Efficiency

Appliances and devices (machines) can be used to transform one kind of energy into another. For example, an electric motor transforms electrical energy into kinetic energy. This energy might be further transformed into potential energy if the motor is used to drive a lift. However, not **all** the electrical energy which is supplied to the motor will be transformed into the final **useful** form of energy. Some may be transformed into heat, due to friction, and sound.

Although no energy has been destroyed, some is 'wasted' as it cannot be used. This makes the machine inefficient. Efficiency is measured by expressing the **useful** energy output as a percentage of the **total** energy input.

$$\textbf{\% Efficiency} = \frac{\textbf{useful energy output}}{\textbf{total energy input}} \times 100$$

The formula, above, can also be applied to power rather than energy.

Example 1

What is the efficiency of a light bulb which uses 550 J of electrical energy and gives out 110 J of light?

$$\% \text{ Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100$$

$$= \frac{110}{550} \times 100$$

$$= 20\ \%$$

Example 2

A power station produces 150 000 kW of heat, which gives out 60 000 kW of electrical power. Calculate its efficiency.

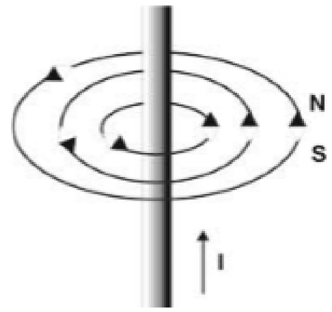
$$\% \text{ Efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100$$

$$= \frac{60\,000}{150\,000} \times 100$$

$$= 40\ \%$$

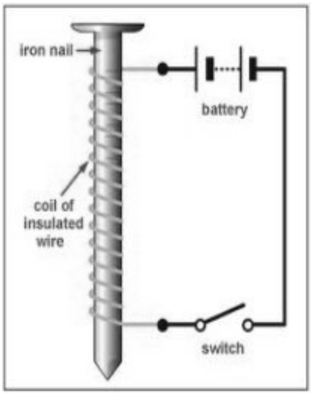
Electromagnetism

Current Carrying Wire



When a current passes through a wire, a magnetic field is produced. By wrapping a wire round a soft iron core an electromagnet is produced.

The more wires that are wound together the greater the strength of the electromagnet. When the current is switched off, the magnetic field fails.

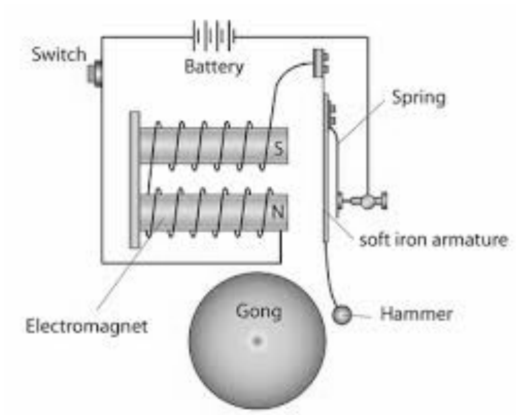


The Simple Electromagnetic

A simple electromagnet, like the one to the left, is easy to make and can be used to demonstrate the on–off mechanism which is put to use in many ways.

Typical uses of this effect are seen in a bell and a relay.

The Bell



In the bell the clapper is pulled towards the gong by the electromagnet but this causes a break in the circuit and the electromagnet fails.

The spring attached to the clapper makes the clapper return to its original position and the whole action starts again.

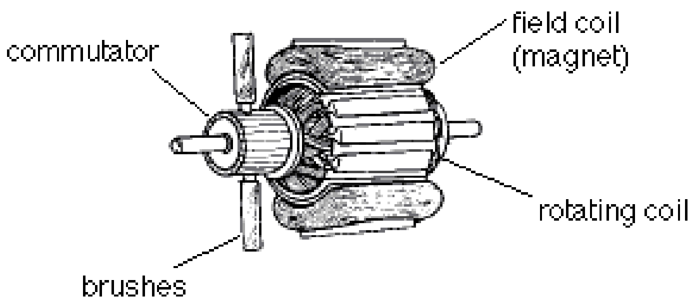
The Relay

A relay is an electromagnetic switch which can be used to operate a high current circuit.

The Electric Motor

When a wire carrying a current is placed between the poles of a magnet then the wire has a force acting on it. The direction of the force can be changed by reversing either the current or the direction of the magnetic field.

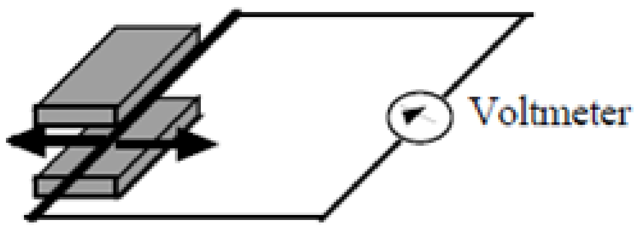
In an electric motor, coils of wire are placed between the poles of a magnet and, as a current flows in the wires, the coils will rotate. The coils will keep on rotating because of the **commutator**. This is a ring split into two which reverses the direction of current. Current is fed in to the coils by the **brushes**.

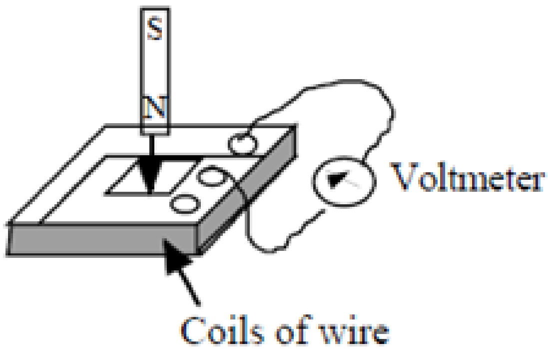


Induced Voltage

If a conductor cuts across the lines of a magnetic field, then a voltage will be induced across the ends of a conductor. Note the magnet can move with the conductor stationary or vice versa. An induced voltage will be produced provided the conductor experiences a **changing magnetic field.**

Magnets with opposite poles facing.





The Size of the Induced Voltage

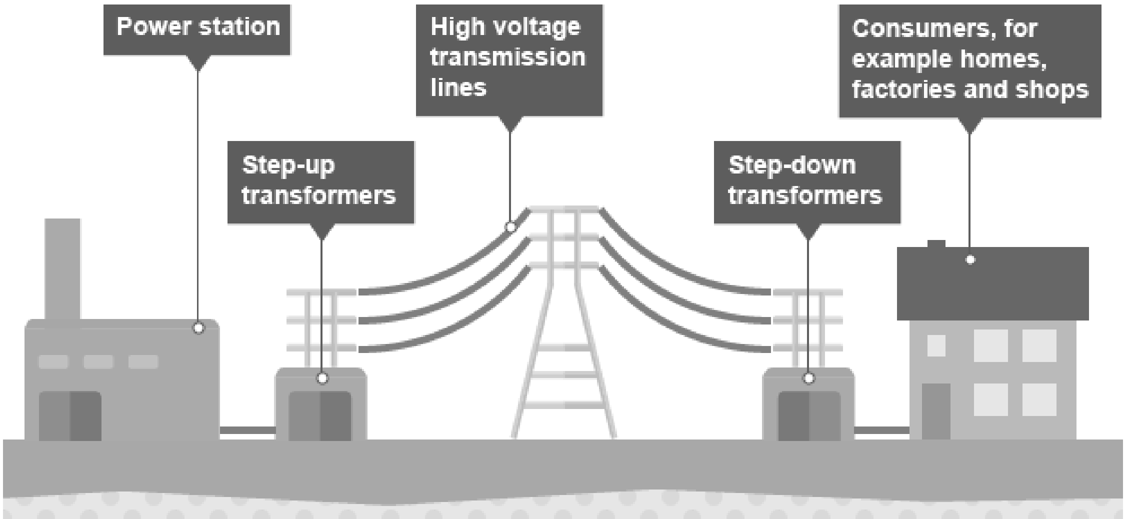
The size of the induced voltage depends on –

- **the magnetic field strength**
- **the number of coils**
- **the speed of the motion**

This is the foundations of electricity generation.

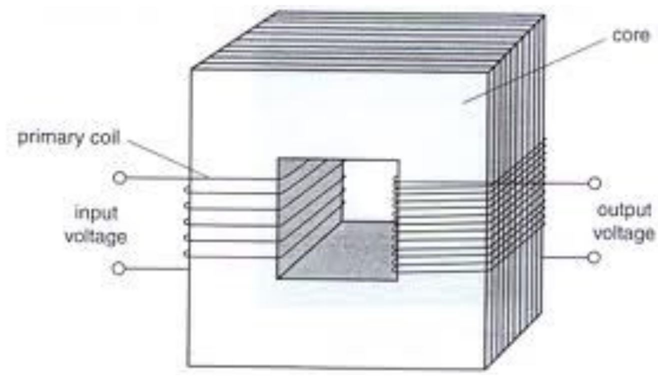
Transformers

Transformers use electromagnetism to change the size of an alternating voltage or current.



Transformers reduce the loss of energy as heat by ensuring that the electricity in the transmission lines has a low current.

A transformer is made up of an iron core and two coils of wire (the primary coil and the secondary coil) as shown opposite.



Electrical & Electronic Circuits

Charge

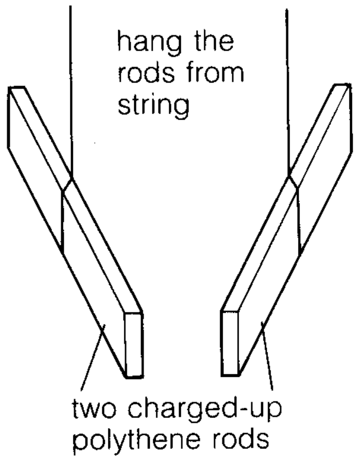
There are two types of electrical charge, **positive and negative.**

Electricity is a **flow of tiny, negatively charged particles called electrons.** Electrons are much smaller than atoms.

You carried out experiments in which pieces of plastic were rubbed to give an electrical charge.

Any material can be given an electric charge by rubbing.

When plastic rods which both had positive charges were brought close to each other the rods moved away - they repelled.

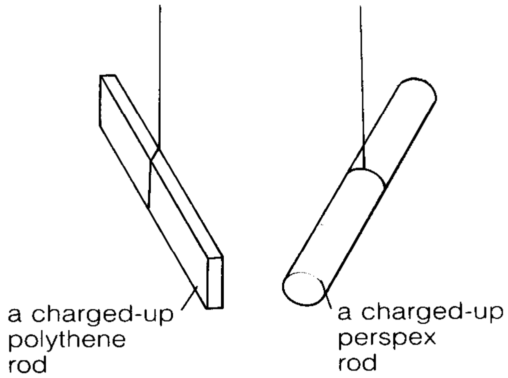


Positive is repelled by positive.
Negative is repelled by negative.

We say that **like charges repel**.

When a positively charged rod is brought close to a negatively charged rod they attract.

Positive charges are the opposite of negative charges.



We say that **opposite charges attract.**

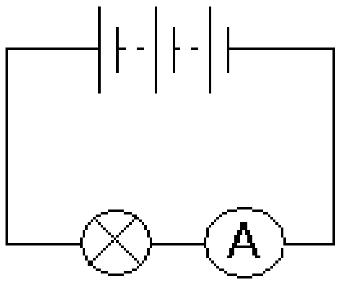
Current

Current is the flow of charges (electrons) around a circuit.

Current is measured in amps - short for Amperes. The symbol for amps is A.

Measuring Current

Current is measured with an ammeter, **to measure current the ammeter is placed in the circuit along side the component.**



The ammeter in the circuit, above, is measuring the current flowing through the bulb.

Voltage

Batteries provide electrons with the energy to move. The push a battery gives to electrons is called the voltage of the battery.

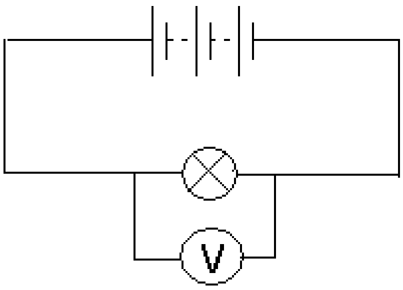
Voltage is a measure of the energy given to the charge (electrons) in a circuit.

When batteries are joined together the voltages can add or cancel depending on the way the batteries are joined.

Voltage is measured in Volts. The symbol for volts is V.

Measuring Voltage

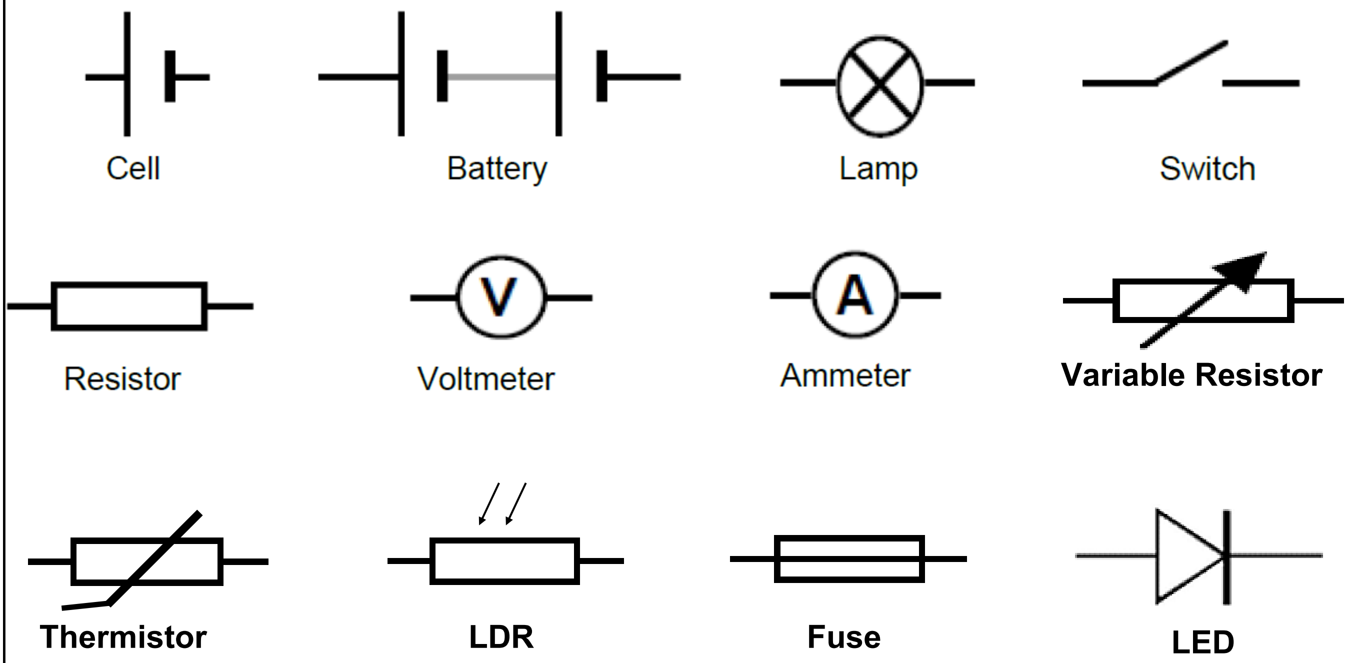
Voltage is measured with a voltmeter, **to measure the voltage across a component the voltmeter is placed across the component.**



The voltmeter in the circuit, above, is measuring the voltage across the bulb.

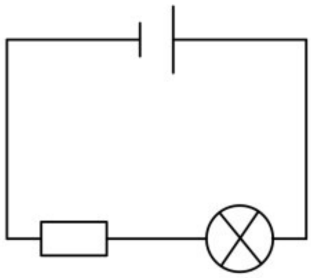
Circuit Symbols

Each electrical component is represented by a symbol, which is easy to draw. As you know the symbols are used when drawing electrical circuits. All the scientists in the world - no matter their language - have agreed to use the same symbols.



Series Circuits

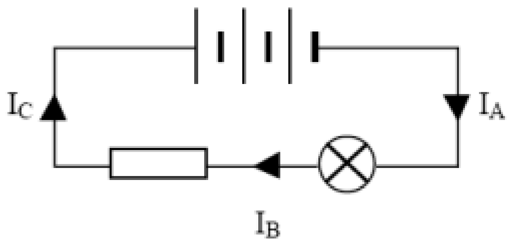
A series circuit is a circuit in which the components are connected one after the other, in series. There is only one path for the current to follow. Any break in the circuit will stop the flow of charge and cause the whole circuit to stop working.



A series circuit with a cell, a lamp and a resistor.

Current in a Series Circuit

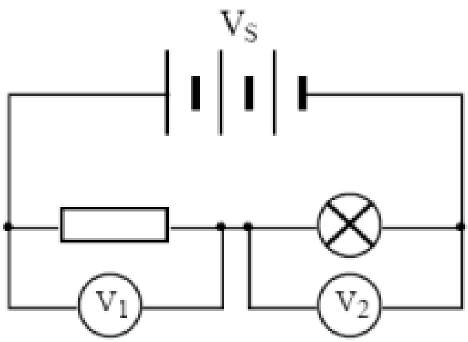
In a series circuit the current is the same at all points because there is only one path for the current to flow through.



$$\boxed{I_A = I_B = I_C}$$

Voltage in a Series Circuit

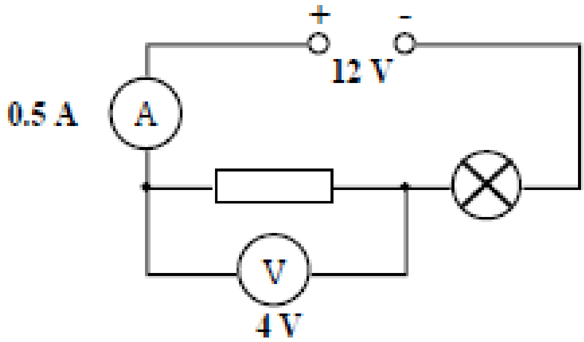
The sum of the voltages across the components in a series circuit is equal to the voltage of the supply.



$$\boxed{V_s = V_1 + V_2}$$

Series Circuit Example

In the circuit below the ammeter reading is 0.5 A and the voltmeter reading is 4 V.



(a) What is the current through the lamp?

The current through the lamp is 0.5 A as the current is the same at all points in a series circuit.

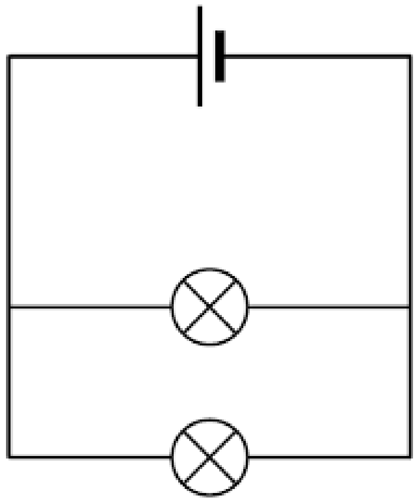
(b) What is the potential difference across the lamp?

Voltage across lamp = Supply voltage - voltage across resistor

= 12 - 4

= 8 V

Parallel Circuits

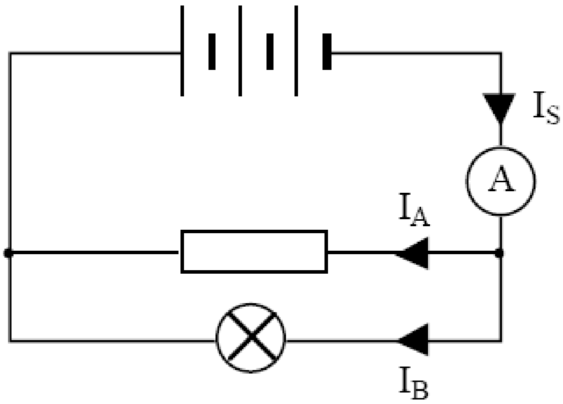


A parallel circuit is a circuit which has more than one path (branch) for the current to follow.

A break in one of these paths will not prevent other paths from carrying charge.

The parallel circuit, opposite, has a component on each branch.

Current in a Parallel Circuit



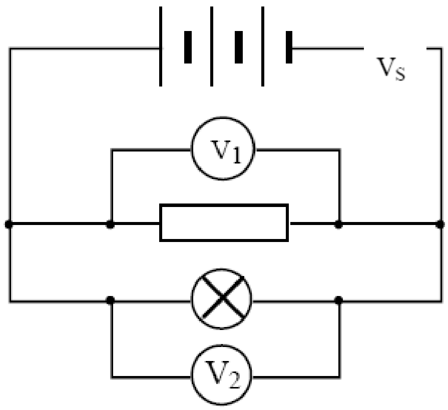
In a parallel circuit the current has **more than one** path to follow.

This means that the supply current splits through each parallel branch.

$$\boxed{I_s = I_A + I_B}$$

Voltage in a Parallel Circuit

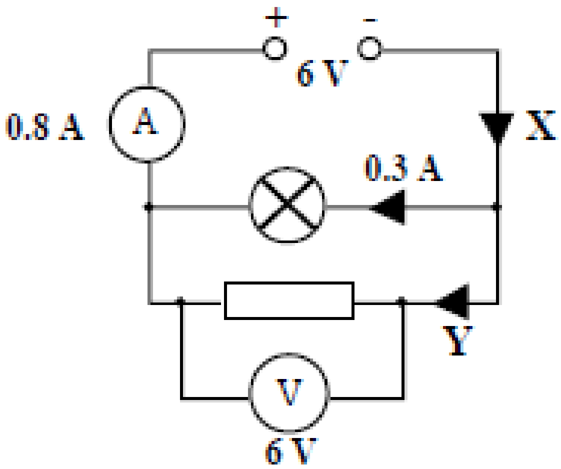
In a parallel circuit the voltage across each branch (each component) is the same.



$$\boxed{V_s = V_1 = V_2}$$

Parallel Circuit Example

In the parallel circuit below the ammeter reads 0.8 A, the current through the lamp is 0.3 A and the voltmeter reads 6 V.



(a) What is the voltage across the lamp?

The voltage across the lamp is 6 V as the voltage across each branch in a parallel circuit is the same.

(b) What are the current values at X and Y?

The current at X is 0.8 A as it is the supply current (it has not split between the branches yet).

The current at Y is 0.8 - 0.3 = 0.5 A (as the supply current of 0.8 A is split between the branches).

Resistance

Materials oppose current and some materials oppose it more than others. This opposition to current is called resistance. Every material has an electrical resistance. **The greater the resistance, the smaller the current that flows.**

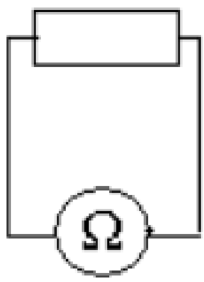
Every electrical component has resistance. Components called resistors are used to provide resistance in circuits.

Resistors cause electrical energy to be changed to heat energy.

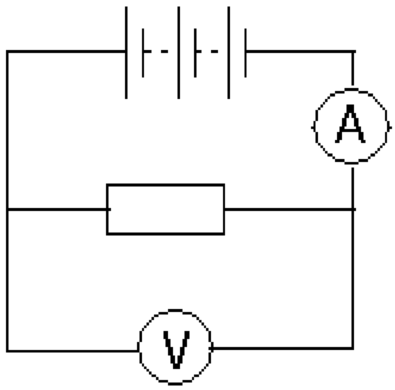
Resistance is measured in ohms. The Greek letter omega (W) is the symbol for ohms.

Measuring Resistance

Resistance can be measured with an ohmmeter.
To measure resistance, connect the ohmmeter directly across the resistor or component.



Alternatively resistance can be calculated from ammeter and voltmeter values.



The current through the resistor (or component) is measured with an ammeter and the voltage across it is measured with a voltmeter.
The resistance is then calculated using :

$$\textit{resistance} = \frac{\textit{voltage}}{\textit{current}}$$

Resistance has the symbol R, voltage V and current I. So

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

This relationship is known as **Ohm's Law**.

For resistors, the resistance remains approximately constant for different values of current. **This means that the V/I = constant (R).**

Ohm's Law Example

The current through a resistor is 0.2 amps when the voltage across it is 6 volts. Calculate the resistance.

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

$$= \frac{6}{0.2}$$

$$= 30W$$

Variable Resistors

Variable resistors are resistors in which the resistance can be changed. This can be done by altering the length of wire in the variable resistor. The longer the wire, the greater the resistance. Variable resistors are used to control the current flowing in a circuit.

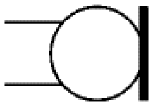
Variable resistors have many uses. They are are used in volume or brightness controls on televisions, dimmer switches on lights, thermostats etc.

Input Devices

An **input device** is one which changes some other form of energy into electrical energy so that the electrical signal produced can be processed by the electronic system.

Microphone

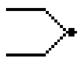
A microphone changes **sound energy** into **electrical energy**. It is used as an input device in radio **transmitters and karaoke machines.**



microphone symbol

Thermocouple

A thermocouple is a device, which can produce a small voltage when it is heated. It can be made by twisting together two wires made from different metals e.g. iron and copper. By heating such a junction, **heat** is changed to **electrical energy**.

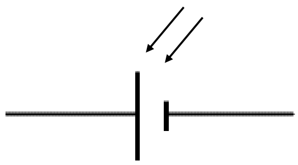


thermocouple symbol

Thermocouples can be used to measure very high temperatures.

Solar Cell

A solar cell is made of a substance that produces a voltage when light falls on it, i.e. it transforms **light energy** to **electrical energy**.



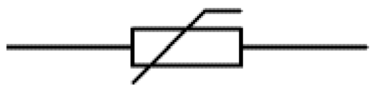
solar cell symbol

Banks of solar cells are used to produce electrical energy to power instruments in space crafts. They are also used in photographic light meters to measure light intensity. As the light gets brighter, the output voltage increases.

The following input devices are environmentally sensitive devices. The conditions in which they are placed are of importance.

Thermistor

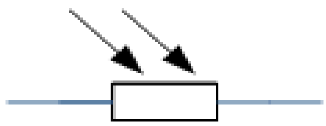
A ***thermistor*** is made of a substance which has a resistance that changes as it is heated or cooled. **The temperature changes the resistance of the thermistor.** Thermistors are devices which can be used to measure temperatures over a wide range.



thermistor symbol

Light Dependent Resistor (LDR)

A ***light dependent resistor*** is made of a substance which has a resistance which changes as the light level changes. **The resistance of an LDR decreases as the light gets brighter.** This makes it very useful for a range of devices like smoke detectors, automatic lighting controls and burglar alarm systems.



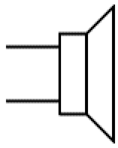
LDR symbol

Output Devices

An **output device** is one which changes electrical energy, from the process part of an electronic system, into some other useful form of energy.

Loudspeaker

A loudspeaker changes **electrical energy** into **sound energy**. It can be used as an output device in radios, TVs and iPods.



loudspeaker symbol

Electric Motor

An electric motor changes **electrical energy** into **kinetic energy.** Electric motors are used in a number of devices such as fans, power tools and disk drives.

motor symbol

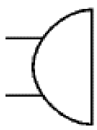
Solenoid

A solenoid is a device that uses an electromagnet to produce movement in a straight line. **Electrical energy** changes to **kinetic energy** in a solenoid. Solenoids are used in the central locking systems of a car and washing machine doors.

solenoid symbol

Buzzer

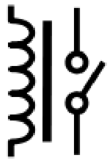
A buzzer changes **electrical energy** into **sound energy**. Buzzers are used in a number of devices such as smoke detectors and microwave ovens.



buzzer symbol

Relay

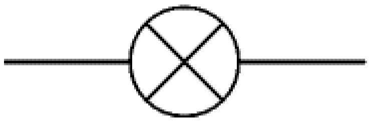
A relay is a switch, which is operated by an electromagnet. When an electric signal is passed through the electromagnet, the switch in the relay can be switched on or off. **Electrical energy** changes to **kinetic energy** in a relay. Relays can be used in air conditioning controls or heating controls (thermostats) and lifts.



relay symbol

Bulbs

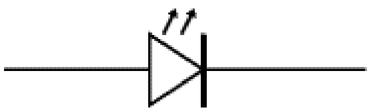
A standard bulb is made of a very thin strand of wire (the filament) sealed inside a glass bulb. The wire glows white hot when there is a large enough electric current in it. The bulb changes **electrical energy** into **heat** and **light energy.** Bulbs are used in torches and lamps.



bulb symbol

Light Emitting Diodes (LEDs)

LEDs are made from semiconductor material. They convert **electrical energy** to **light energy** when they are placed in a circuit correctly. LEDs are used to indicate when something is on, off or on standby, such as a TV or computer. They are now being used widely for lighting as they are efficient.

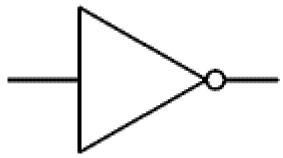


LED symbol

Logic Gates

Logic Gates are part of a family of electronic devices in which the output signals are controlled by the states of the input signal(s). Logic gates are digital devices, which means that they use the logic levels (0 and 1). Each gate has a **truth table** which shows how the output of the gate varies with the input(s). The three common gates are:-

The NOT-gate



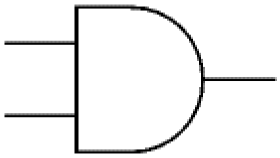
NOT-gate symbol

Input	Output
0	1
1	0

Truth Table for a NOT-gate

From the truth table of the NOT-gate it is clear that the output of the NOT -gate is 'not' the same as the input. The NOT-gate is also known as an **inverter** since it inverts the input signal.

The AND-gate



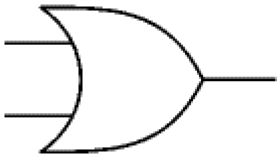
AND-gate symbol

Input	Input	Output
0	0	0
0	1	0
1	0	0
1	1	1

Truth Table for an AND-gate

From the truth table of the AND-gate it is clear that the output of the AND -gate is logic 1 when both input A and input B are at logic 1.

The OR-gate



OR-gate symbol

Input	Input	Output
0	0	0
0	1	1
1	0	1
1	1	1

Truth Table for an OR-gate

From the truth table of the OR-gate it is clear that the output of the OR-gate is logic 1 when either input A or input B is at logic 1.

Kinetic Theory

Pressure

Pressure on a surface is defined as the force per unit area.
Hence :

$$P = \frac{F}{A}$$

Where: P is the pressure measured in Pascals (Pa)
F is the force measured in Newtons
A is the area measure in square metres (m^2)

1 Pascal is equivalent to 1 Newton per square metre;
i.e. 1 Pa = 1 Nm^{-2}

Example

Calculate the pressure exerted on the ground by a truck of weight 16 000 N if each wheel has an area of 0.02 m^2 in contact with the ground.

A = 4 x 0.02 = 0.08 m^2
W = 16 000 N

$$P = \frac{F}{A}$$

$$= \frac{16\,000}{0.08}$$

Kinetic Theory of Gases

The kinetic theory tries to explain the behaviour of gases using a model. The model considers a gas to be made up of a large number of very small particles which are far apart and which move randomly at high speeds, colliding with and bouncing off everything they meet.

Volume

The volume of a gas is taken as the volume of the container. Gas particles move about throughout a container.

Temperature

The temperature of a gas depends on the kinetic energy of the gas particles. The faster the particles move, the greater their kinetic energy and the higher the temperature.

Pressure

The pressure of a gas is caused by the particles colliding with the walls of the container. The more frequent these collisions or the more violent these collisions, the greater the pressure will be.

Gas Laws and the Kinetic Theory of Gases

Pressure and Volume (constant mass and temperature)

Consider a volume, V, of a gas at a pressure, P. If the volume of the container is reduced without a change in temperature, the particles of the gas will hit the walls of the container more often. This will produce a larger force on the container walls. The area of the container walls will also reduce with volume. As volume decreases, then the force increases and area decreases resulting in an increase in pressure.

Pressure and Temperature (constant mass and volume)

Consider a gas at a pressure, P and temperature, T. If the temperature of the gas is increased, the kinetic energy (and the speed) of the particles of the gas will increase. The particles collide with the container walls more violently and more often. This will produce a larger force on the container walls. Thus resulting in an increase in pressure as the temperature increases.

Volume and Temperature (constant mass and pressure)

Consider a volume, V of a gas at a temperature, T. If the temperature of the gas is increased, the kinetic energy (and the speed) of the particles of the gas increases. If the volume was to remain constant, an increase in pressure would result as explained above. If the pressure is to remain constant, then the volume of the gas must increase to increase the area of the container walls that the increased force is acting on. As the temperature increases the volume of the container increases if the pressure remains constant.