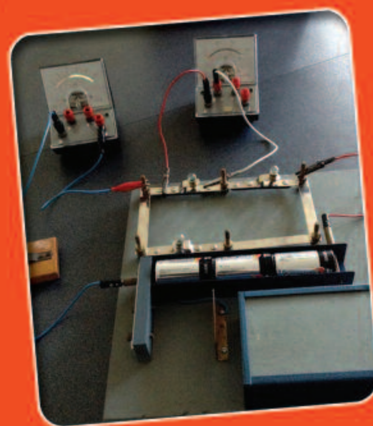
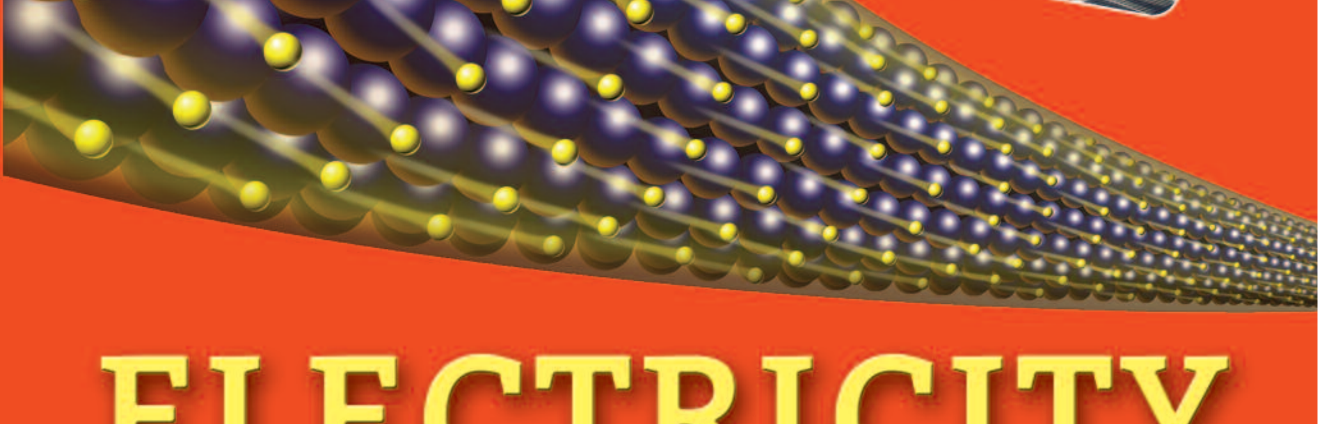
CHILDREN'S SCIENCE ENCYCLOPEDIA

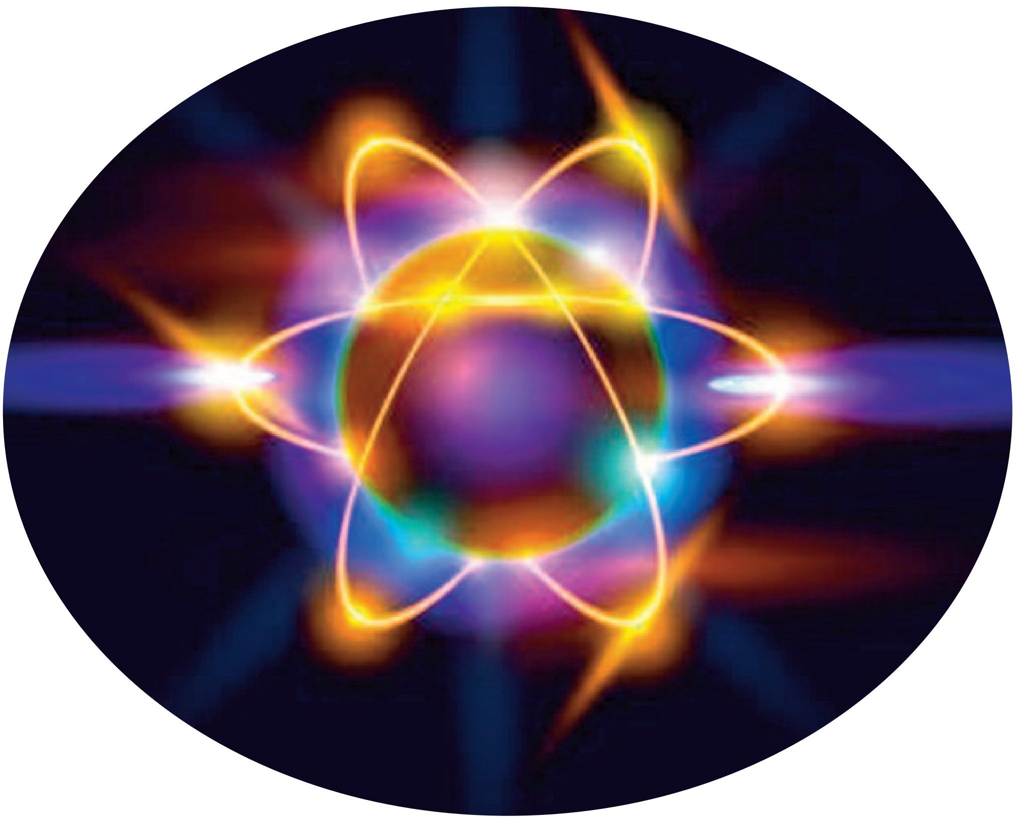




ELECTRICITY

CHILDREN'S SPACE ENCYCLOPEDIA

ELECTRICITY



Orpheus

FACTFILE

Electricity travels through space at the speed of light—about 300,000 kilometres per second. In a coaxial cable, where the conducting wire is surrounded by a polyethylene insulating layer, it travels at about 66% the speed of light.

Electricity

Electricity is a kind of energy stored inside atoms, the minute building blocks of which all things are made. Atoms themselves are made up of particles, including electrons, which have a negative electric charge, and protons, which have a positive electric charge. In normal atoms, there are the same number of electrons and protons, and so the charges cancel each other out. To make electricity, we must either make the atoms lose or gain electrons, or enable free electrons to move.

▼ Different ways electricity is produced or generated: a power station, a wind farm and lightning.

Static electricity

In static electricity, the electrons do not move. It is produced when two objects rub against each other: the electrons rub off from the atoms of one material on to the other.

You can make static electricity by running a comb through your hair. The comb leaves a few of its electrons behind in the hair, so the comb now has a small positive charge. It can pick up small pieces of paper because it attracts the electrons in the paper's atoms. If you comb your hair in a dark room then hold the comb close to your thumb, you will see a tiny spark. The release of electricity heats the air molecules (groups of atoms) between comb and thumb, producing a flash of light.

An electric charge heating air molecules is exactly what happens—but on a much grander scale—when lightning strikes during a thunderstorm. Lightning is static electricity that suddenly leaps between clouds and the ground, or from one cloud to another. Thunder is the noise of the air expanding rapidly in the intense heat.

▲ Static electricity is produced when two objects rub against each other and electrons rub off from the atoms of one material on to the other. On a comb it attracts small pieces of paper.

FACTFILE

The word electricity comes from the Greek electron, meaning amber (fossilized tree resin). This is because static electricity could be produced by rubbing amber.

◀ Lightning, a dramatic release of static electricity

▲ Lightning, an example of plasma, a conductor

Electrical conductors

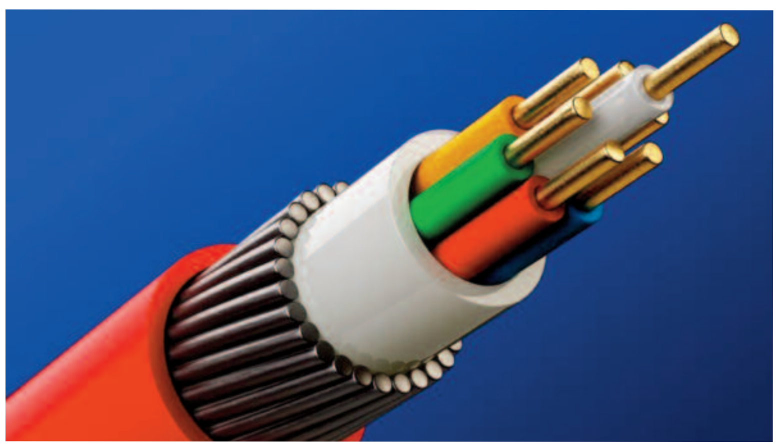
Electricity flows in a current when electrons are free to move through certain materials, known as conductors. Most metals, especially silver and copper, have electrons that can move easily, so metals make particularly good conductors of electricity. Carbon is an example of a non-metallic conductor—but only in certain forms. Graphite is a good conductor, but diamond is not. A substance in liquid form, either molten (melted) or in solution, that can conduct electricity is called an electrolyte.

Insulators

In substances such as rocks, wood, most plastics, rubber and glass, there are no—or very few—electrons free to move. These materials reduce or prevent the flow of electricity and are known as insulators. But they are just as useful: rubber and plastics are used to cover wires and so protect us from electric shocks.

FACTFILE

Pure water cannot conduct electricity, but very small amounts of other substances dissolved in it, such as salt, turn it into a conductor.



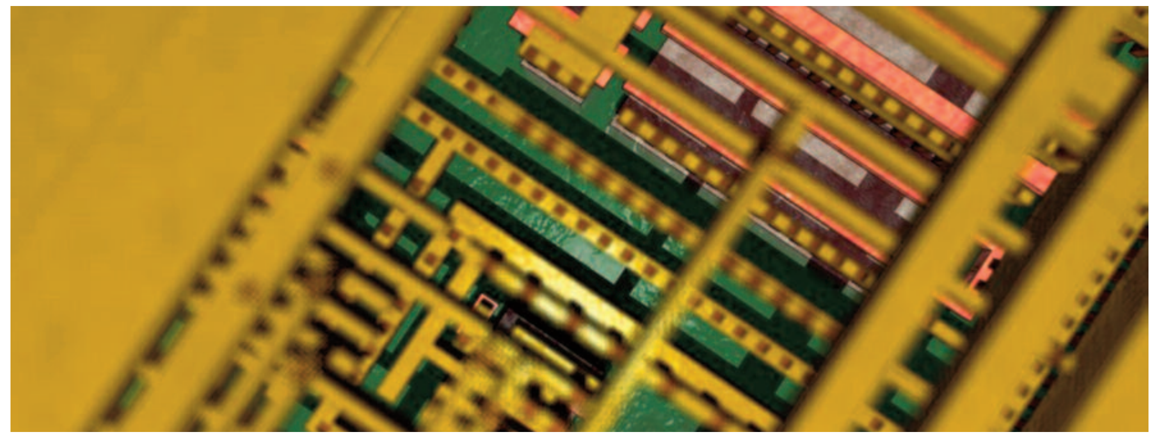
▶ Cross-section through an electric cable. The copper wires are surrounded by sheaths of plastic, a material that does not conduct electricity and so acts as a useful insulator.

Semiconductors

There is a third group of materials, known as semiconductors, which conduct electricity better than insulators but not as well as conductors. These include the elements germanium and, especially, silicon. By adding tiny amounts of impurities to it (a process called "doping"), silicon can be made to carry an electric charge. The addition of boron creates "holes" in silicon's atomic structure, giving it a positive charge (this is called a p-type semiconductor), while the addition of arsenic or phosphorus gives it a negative charge (an n-type semiconductor).

FACTFILE

Copper is one of the best affordable conductors, and is the standard to which other conductors are compared. Silver is an even better conductor, but is too expensive to use for wiring. Aluminium has 62% the conductivity of copper.



▲ A magnified image of an integrated electronic circuit. The different types of silicon—a semiconducting material—appear as pink, grey or green. The rest is copper, a conducting material.

Silicon's semiconducting properties are extremely useful and are fundamental to electronics. Electronic engineers are able to control the electrical properties of a semiconductor in another way: by adjusting the voltage of the electric current passing through it. When linked together in an electronic circuit, transistors—electronic components made from semiconductors—can thus be made to act as switches or amplifiers.

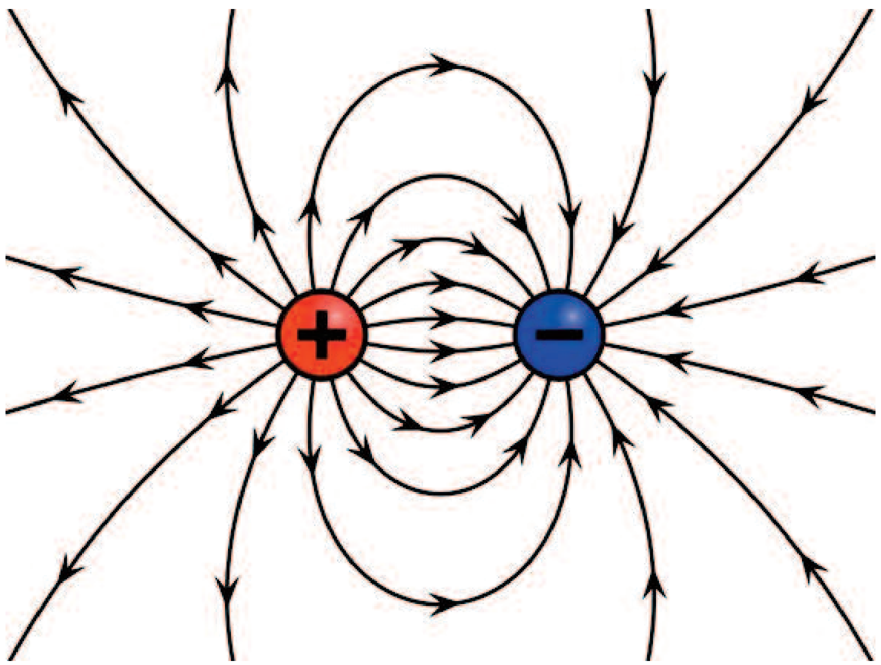
FACTFILE

Typically, lightning may carry an electric current of 10,000 amps at 100 million volts.

Electric charge

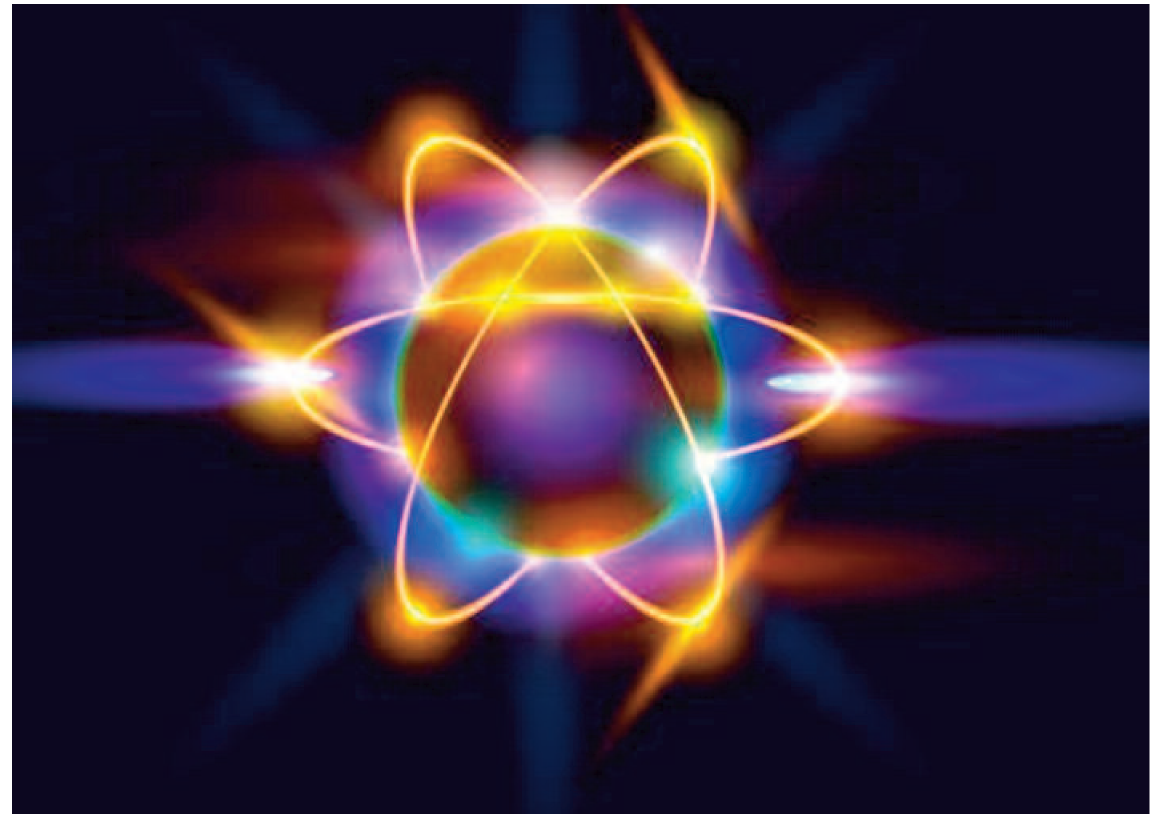
▲ Charles Augustin de Coulomb

Atoms, the building blocks of matter, are made of elementary particles. Most particles carry what is called an electric charge: they are each surrounded by their own electric field and exert (produce) an electric force. The strength of the electric force between two particles depends on the strength of their electric charges and the distance between them. The French engineer, Charles Augustin de Coulomb (1736–1806) proposed an "inverse-square law" called Coulomb's Law, which says that the strength of this electric force decreases with the square of the distance between the particles. The basic unit of electric charge is named after him: the coulomb (C).



▲ Diagram of an electric field surrounding particles with a positive (+) and negative (-) charge

Positive and negative



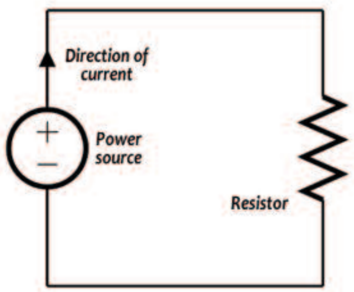
▲ An atom consists of a nucleus of protons and neutrons, with electrons orbiting around.

There are two kinds of electric charge, labelled "positive" and "negative". Two charges of the same kind repel—the force they exert pushes them apart—but two charges of the opposite kind attract—they are pulled together. In an atom, its positively charged nucleus is surrounded by negatively charged electrons, so the atom is electrically neutral: it has no charge. When, however, the atom loses or gains an electron, it becomes electrically charged, either positively (if it loses one) or negatively (if it gains one). The atom is then known as an ion.

FACTFILE

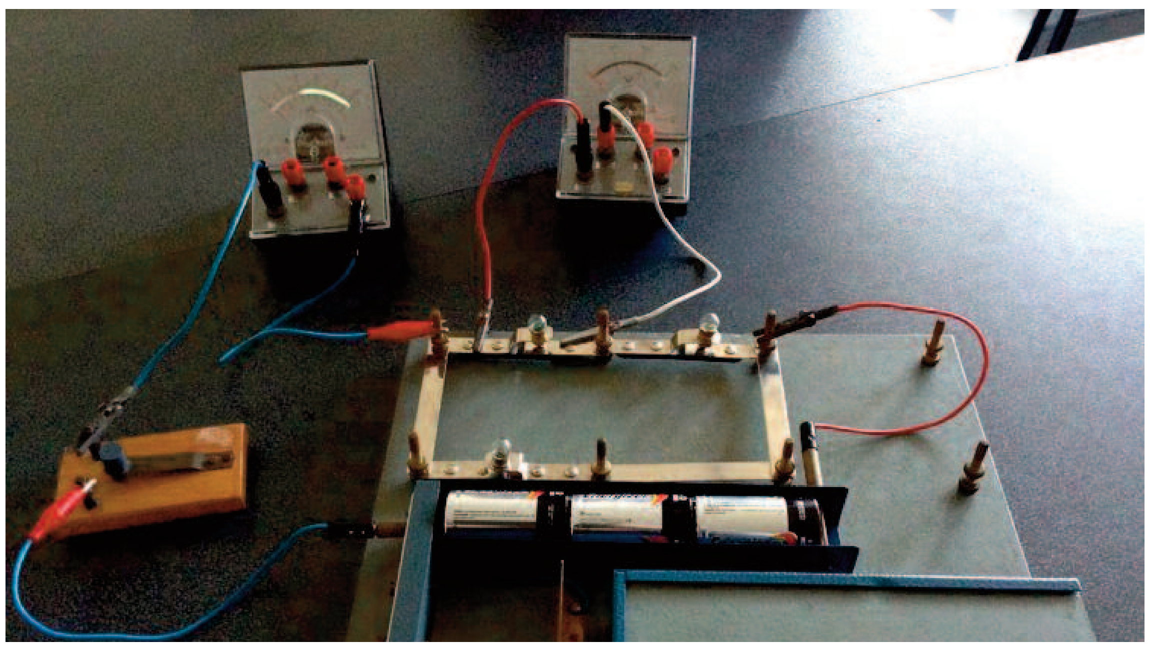
In the 18th century some doctors believed electricity could treat many different medical conditions. So patients with health concerns ranging from sprains to constipation were given mild electric shocks in an attempt to cure them.

Electrical circuits



▲ A simple electric circuit made up of a power source (battery or generator) and a resistor.

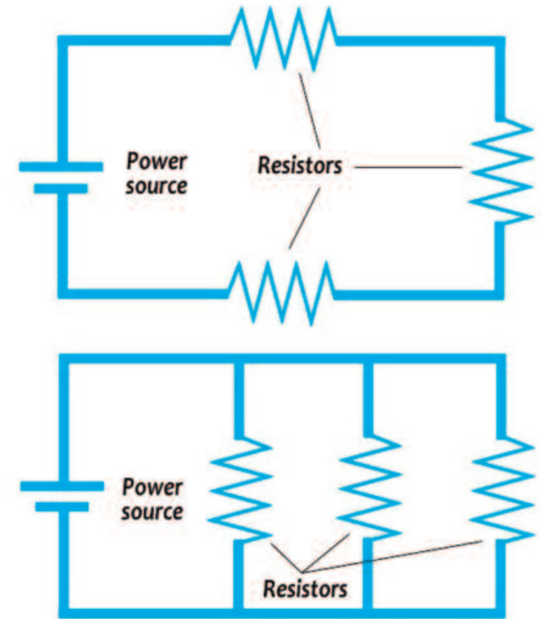
In current electricity, electrons are pushed along a conductor by a battery or generator. When the current is switched on, any electrons free to move in the wire all move in the same direction. They flow only if they have a complete pathway of conductors. This pathway is called a circuit. All parts of a circuit must conduct electricity and must be connected to one another. A circuit may have sections or components connected in a series or in parallel. Electrons flow from the negative terminal of a battery or generator towards the positive one, even though the electric current itself is said, by convention, to travel from positive to negative.



▲ An electric circuit, featuring a series of batteries, a switch, an ammeter (top left, to measure the current flowing through the circuit) and a voltmeter (top right, to measure the voltage across a single bulb)

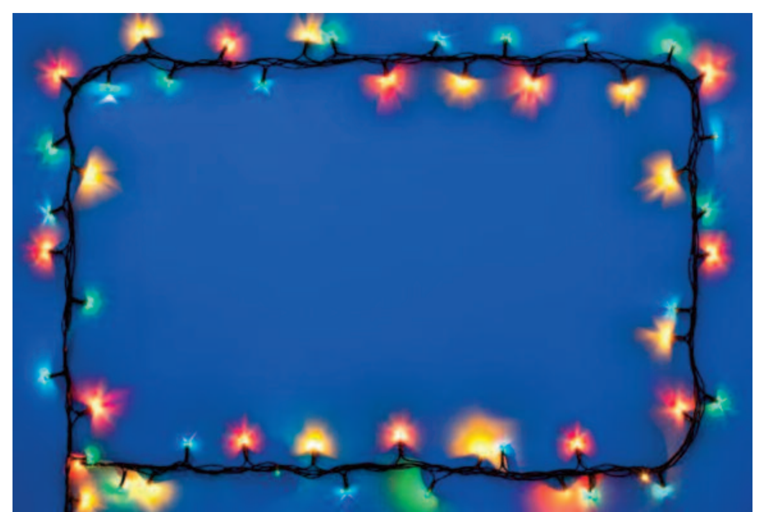
Series or parallel

Components of an electrical circuit are connected in either a series or in parallel. In a series circuit—made up of, say, four light bulbs and a single 6-volt battery—a wire links the battery to the first bulb, from there to the second, then on to the next two in turn before returning to the battery in a continuous loop. In a parallel circuit, each bulb is wired to the battery in a separate loop. When the four light bulbs are connected in series, the same current flows through all of them but the voltage is divided into four: 1.5 V for each bulb. When the light bulbs are connected in parallel, each bulb receives a quarter of the current, but the full 6 V from the battery.



▲ Series circuit (top) and parallel circuit (above). Both have a voltage source (battery) and three resistors.

In a series circuit, every component must function for the circuit to be complete; one bulb burning out in a series would break the circuit. In a parallel circuit, each light has its own circuit, so if one were to burn out, the others would all still function. Many Christmas tree fairy lights are connected as a series circuit, so if one bulb burns out or is removed, the whole string fails.



◀ Christmas tree lights. They are all connected to one another along the "outward" stretch of wire. The rest of the wire, the "inward" portion, doubles back to the power source (plug and socket) to complete the circuit.

FACTFILE

The conventional symbol for an electric current is I, which comes from the French phrase "intensité de courant" (current intensity). The I symbol was used by the French scientist André Marie Ampère (1775–1836) after whom the unit of electric current, the ampere, was named.

Voltage

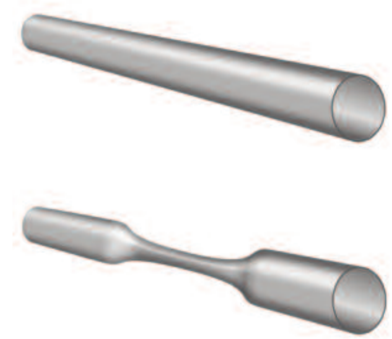
Electric current flowing around a circuit is a bit like water flowing through pipes. In the same way that a pump may be used to drive the water along, a battery or generator provides the pressure, or driving force, to push the electrons along the wire. This electrical pressure, known as the electro-motive force (e.m.f.), is measured in volts (V). As the voltage increases, so does the amount of electric current (I). The rate at which a current flows round a circuit is measured in amperes (A), or amps for short. An amp is the equivalent of one coulomb (the unit of electric charge) per second.

Voltage is sometimes defined as the electric potential difference between two points. Just as the water pressure in a pipe is different between one end of the pipe and the other, so there is a difference in electrical pressure between two points on a circuit. This is known as the potential difference.

▶ High-voltage power lines at a substation. Substations are part of the distribution network for the national grid—a nationwide electric circuit that delivers electricity from power stations. Transformers at a substation reduce the very high voltage (400,000 volts) carried by the grid power lines down to a lower voltage suitable for use in the home (230 volts).

Resistance

Just as the flow of water is slowed down if the pipe it runs through narrows, the electric current is reduced if the electrons have less space in which to flow: there is resistance to the flow. This may happen if the electrons are forced to squeeze along a thinner stretch of wire, for example. A thicker wire has a lower resistance to a thin one; a shorter wire has less resistance than a longer one. Resistance is measured in units called ohms (Ω). Any component in an electric circuit, such as a light bulb or a heater, will have some resistance to the flow of current.



▲ A resistor can be thought of as a thin section of pipe. Just as the flow of water is slowed by being forced through a narrower section, so the flow of electricity will be reduced if a wire is thinner.

◀ The filament of an incandescent light bulb, highly magnified

Thin wires made of metal can be made to have a high resistance if they are coiled round and round to extend their length. The wires become hot as they resist the current flowing through them. Coils of extremely fine wire used as filaments in electric light bulbs glow white hot when the electricity is switched on, giving out light. Coils of thicker wire are used in electric fires, which glow red hot.

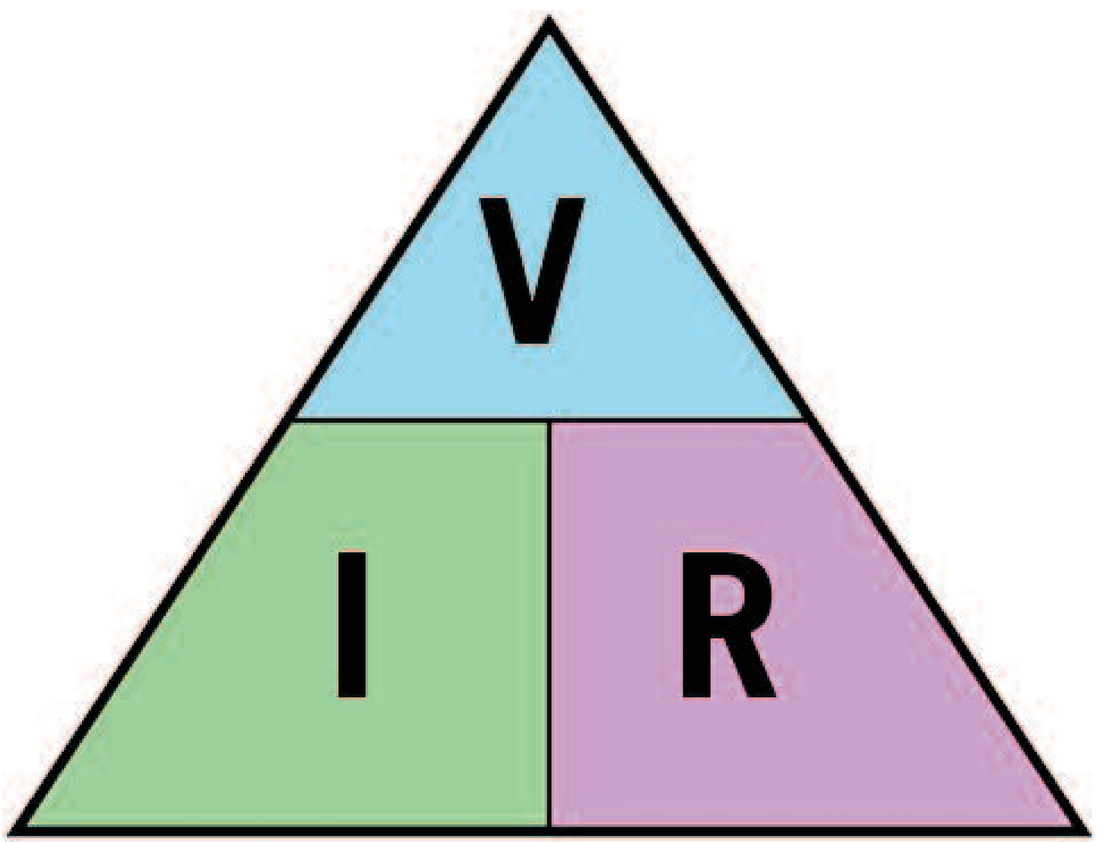
FACTFILE

Your beating heart—and that of every animal—generates tiny electrical currents. These can be amplified and recorded using a technique known as electro-cardiography as an electrocardiogram (ECG). Similarly, the electrical activity in your brain can be recorded via electro-encephalography as an electro-encephalogram (EEG).

Ohm's Law

The amount of current in a circuit depends on both the amount of voltage (the force with which an electric current is pushed along) and the amount of resistance in the circuit (provided by, for example, a thin filament in a bulb) that reduces it. This relationship between current, voltage and resistance is known as Ohm's Law. It states that resistance equals voltage divided by current, or $R = V \div I$

▼ Ohm's Law can be expressed in three different ways: resistance equals voltage divided by current ($R = V \div I$); current equals voltage divided by resistance ($I = V \div R$); voltage = current multiplied by resistance ($V = I \times R$). The equations can be represented by a triangle. The horizontal line represents a division bar; the vertical line represents multiplication. Put your finger over the quantity you want to work out to see how to calculate it.



Energy consumption

▲ Glowing electric stove

The rate at which electricity (or any form of energy) is used is measured in watts. When electricity flows through a component, such as a ring on a cooker, the energy used is equal to the voltage multiplied by the current. So a 240-volt ring receiving a current of 4 amps uses 960 watts of energy. The total energy consumed by the ring can be calculated by multiplying that figure by the length of time the ring is turned on. In three hours, for example, the ring consumes 2880 watt-hours or 2.88 kilowatt-hours (kWh,1000 watts = 1 kilowatt) of electricity.

FACTFILE

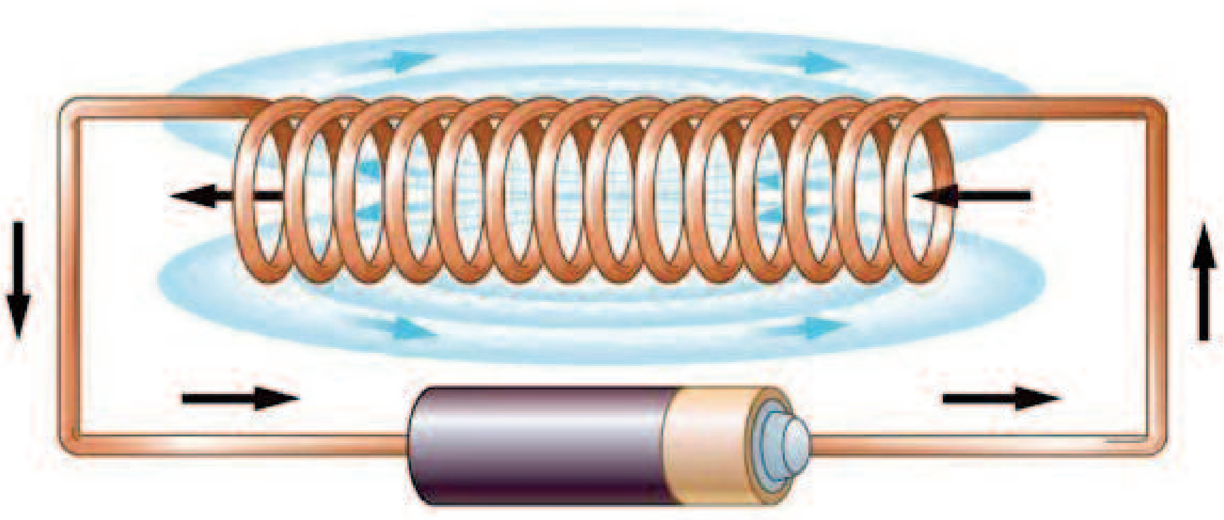
The direction of an electric current is, by convention, the direction in which a positive electric charge would move, i.e. from the positive terminal of a battery towards the negative one. But electrons actually move through the wire in the opposite direction, from negative to positive. But the convention has stuck and is used today worldwide.

FACTFILE

To work out the direction of motion in an electric motor, use Fleming's left hand rule. Raise your left thumb, point straight ahead with your first finger (index finger) while using your second finger to point at right angles to that. The thuMb indicates Motion; the First finger indicates the direction of the magnetic Field; the seCond finger indicates the direction of the electrical Current.

Electric generators and motors

Electricity and magnetism are so closely linked that one can produce the other. An electric current flowing in a cable produces a magnetic field around the cable. A magnetic field moving near a wire causes electricity to flow along the wire. Electromagnetism is the basis of how both generators and electric motors work.

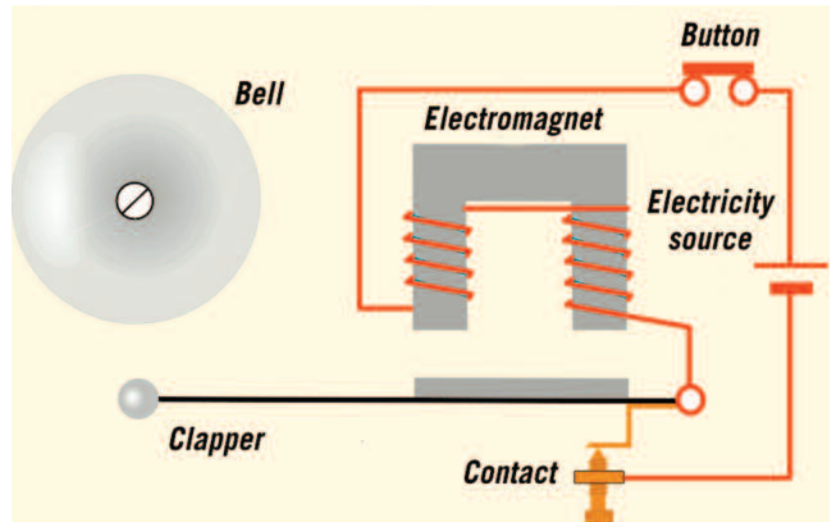


▲ An electric current flowing in a wire produces a magnetic field around the wire.

Electromagnetism

In 1820, the Danish scientist Hans Christian Ørsted (1777–1851) observed that when he passed an electric current through a wire, a magnetic compass needle nearby was slightly deflected. He realised that the electric current had produced magnetism: he had discovered electromagnetism.

▲ Ørsted demonstrates his discovery that a magnetic compass needle is deflected by an electric current flowing through a wire.



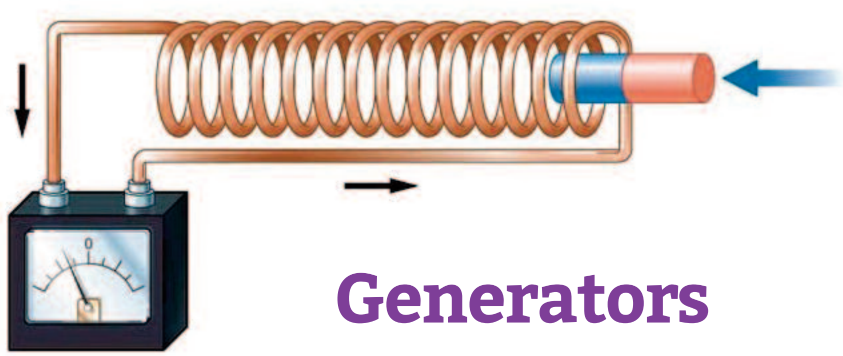
◀ The filament of an incandescent light bulb, highly magnified

If the wire is wound around a core of iron to form a long coil, or solenoid, and an electric current passed through it, the strength of the magnetism increases. When current is flowing, the core of this electromagnet is magnetized and both the core and wire produce a magnetic field. Switch off the electricity and the field disappears, because the core loses its magnetization and the wire no longer carries a current. Electromagnets have many uses, including magnetic cranes to lift heavy pieces of metal or, on a smaller scale, inside electric doorbells.

Using movement to produce electricity

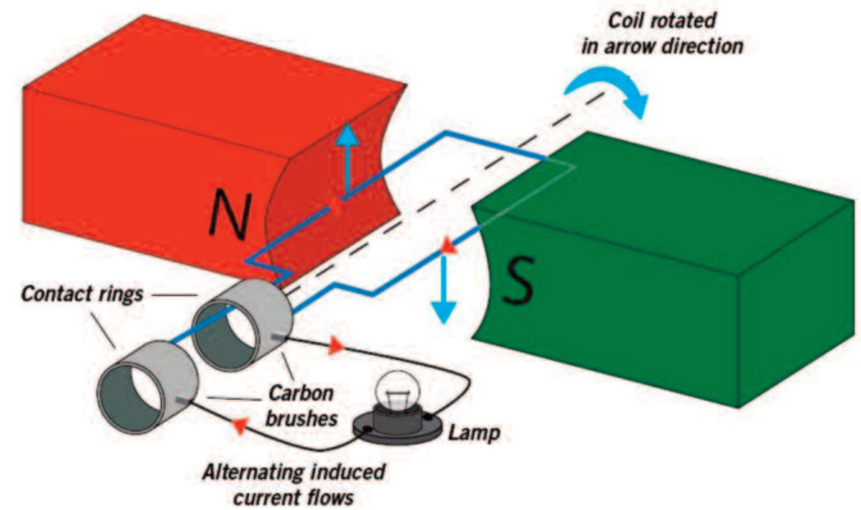
After Ørsted discovered that electricity could produce magnetism, the English scientist Michael Faraday (1791–1867) investigated whether the reverse effect—that magnetism could produce electricity—was possible. In an experiment he carried out in 1831, he found that an electric current was produced in a coil of wire when a magnet was moved in and out of it. The faster the magnet moved, the greater the current produced.

▼An illustration of Faraday's experiment. Moving a magnet in and out of a coil of wire induces (creates) electricity in the coil. The flow of electricity is detected on a galvanometer. The current flows only when the magnet is moving, and its direction, detected by the galvanometer, depends on the direction in which the magnet moves.



Generators

This principle established a way of generating electricity: a means of converting motion, or kinetic energy, into electrical energy. The same effect that Faraday had discovered could be achieved by moving a wire while keeping the magnet stationary. Inside a simple generator, a coil of wire is made to spin between the poles of a magnet, which induces (creates) an electric current in the wire. The first half of each turn of the coil produces a current flowing in one direction; the second half produces one flowing in the opposite direction. So the current varies, or alternates, from zero to a maximum and back again. This is known as an alternating current (a.c.). The number of times this cycle is completed in one second is called the frequency.

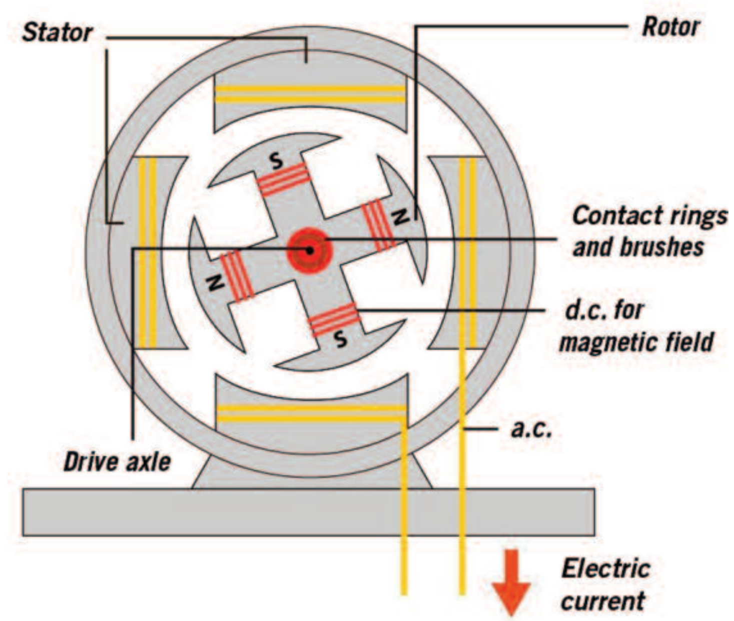


◀ A simple a.c. generator, also known as an alternator. The generator is linked to an electrical circuit via a pair of contact rings and carbon brushes.

Power station generator

In a generator at a modern power station, the coil that produces the electric current, sometimes called the armature, is kept stationary: it is known as the stator. The changing magnetic field is produced by a rotating electromagnet: the rotor. The rotor is connected to a turbine, driven by a power source such as the steam from water heated by burning fuel or nuclear reactions, or simply the movement of water itself. A current flows when the generator is connected to a circuit.

▼Cross-section through a generator in a power station



Glossary

Alternating current (a.c.) An electric current where the flow of electrons regularly reverses direction. This type of current is produced in power stations.

Ammeter An instrument used to measure electric current in amperes.

Ampere (A) The unit used to measure the strength of an electric current. Amperes, or amps, measure how many electrons pass a certain point in one second.

Battery A device that converts chemical energy into electrical energy. When a battery is connected to a circuit, a chemical reactions inside it creates an electric current that flows out of one end, around the circuit, and back to the other end of the battery.

Circuit A pathway along which an electric current can flow, for example, a wire joining a battery and a light bulb. If there is a gap in the wire, the circuit will be broken and the current will stop flowing. Switches turn electrical appliances off by breaking a connection in a circuit.

Current electricity Electricity that flows from one point to another.

Direct current (d.c.) An electric current that always flows in one direction. Batteries produce direct current.

Electric charge Atoms are made up of subatomic particles called protons, neutrons and electrons. Electrons have a negative (-) electric charge and protons have a positive (+) electric charge. Neutrons have no charge at all.

Electric conductor A substance that electricity can easily flow through. Metals are good conductors because metal atoms contain electrons that are free to move.

Electric current The flow of electric charge through a conductor.

Electric insulator A material that reduces or stops the flow of electricity. Substances such as wood, most plastics, rubber and glass are good insulators because they have no, or very few, electrons that are free to move.

Electricity A form of energy made by the movement of electrons, the negatively charged particles found inside atoms. Electricity flows when electrons are free to move through a material. It is easily changed into other forms of energy and is easy to use because it can be directed along wires.

Electromagnet A temporary magnet produced by sending an electric current along a coil of wire that surrounds a piece of magnetic metal. The magnet can be turned on and off by switching the electricity on and off.

Electromagnetism The link between electricity and magnetism.

Generator A machine that uses a rotating wire coil to generate electricity. There are two main types of generator - a dynamo, which produces direct current (d.c.) and an alternator, which produces alternating current (a.c.).

Lightning A visible spark of electricity produced during a thunderstorm. Static electricity builds up inside clouds when ice and water molecules bump against each other and become electrically charged. If enough charge builds up in the cloud, it discharges as a lightning flash. The light we see is a strip of air being suddenly heated by the electricity.

Magnet An object that has two ends, called poles, and produces a magnetic force field around itself. Most magnets are made of the metals iron or steel and attract other objects made of these materials. The Earth itself has a magnetic field, as if it had a magnet inside it. Most magnets have no noticeable effect on wood, plastic, or nonmagnetic metals.

Magnetic compass An instrument that has a small needle-shaped magnet balanced inside it. The ends of the needle are attracted to the Earth's magnetic poles, so that one end always points due north.

Magnetic field The region surrounding a magnet where the effects of the magnet can be felt.

Magnetic poles The two arcas at either end of a magnet, called the north and south poles. Lines of magnetic force run between opposite poles.

Magnetism The invisible force of attraction or repulsion between magnetic materials. Electricity can produce magnetism and magnetism can produce electricity.

Resistance A measure of how easily electrons can flow through a material. Good conductors have low resistance, meaning that electrons can pass along them quickly and easily. Resistance is measured in units called ohms.

Semiconductor A substance whose resistance lies inbetween that of a conductor and that of an insulator.

Solenoid A long coil of wire that acts as a magnet when electricity is passed through it.

Static electricity Electricity that does not move. Static electricity is produced when two objects rub against each other and electrons rub off from one material on to the other. The material that has lost electrons becomes positively charged; the material that has gained them becomes negatively charged.

Volt (V) The unit used to measure the voltage in an electric circuit. The voltage can be thought of as the force needed to push electrons around a circuit. An instrument used to measure voltage is a voltmeter.