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INTRODUCTION

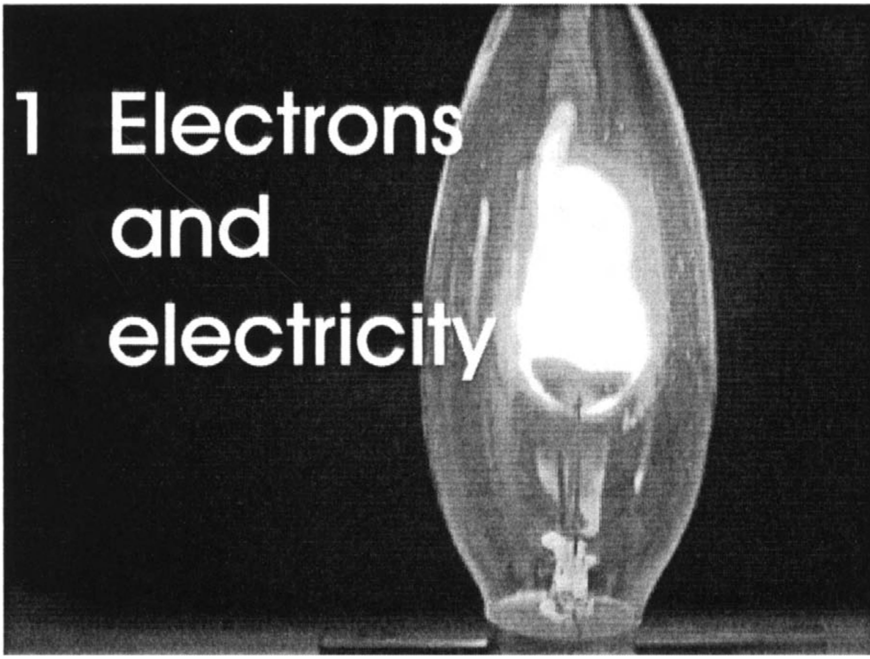
This is a book for anyone who wants to get to know about electronics. It requires no previous knowledge of the subject, or of electrical theory, and the treatment is entirely non-mathematical. It begins with an outline of electricity and the laws that govern its behaviour in circuits. Then it describes the basic electronic components and how they are used in simple electronic circuits. Semiconductors are given a full treatment since they are at the heart of almost all modern electronic devices. In the next few chapters we examine a range of electronic sensors, seeing how they work and how they are used to put electronic circuits in contact with the world around them.

The methods used for constructing electronic circuits from individual components and the techniques of manufacturing complex integrated circuits on single silicon chips are covered in sufficient detail to allow the reader to understand the steps taken in the production of an item of electronic equipment. This is followed by an account of the test equipment used to check the finished product.

The next few chapters deal with the electronic circuits that are used in special fields and serves as an introduction to amplifiers, logic circuits, audio equipment, computing, telecommunications (including TV and video equipment) and microwave technology. Then we look at the ways in which electronics plays an ever-increasing role in measurement, detection and control in industry and other fields. Throughout, the descriptions are intentionally aimed at the non-technical reader.

Finally, we outline some of the current research in electronics and point the way to future developments in this technology.

All the photographic illustrations in this book were taken by the author.

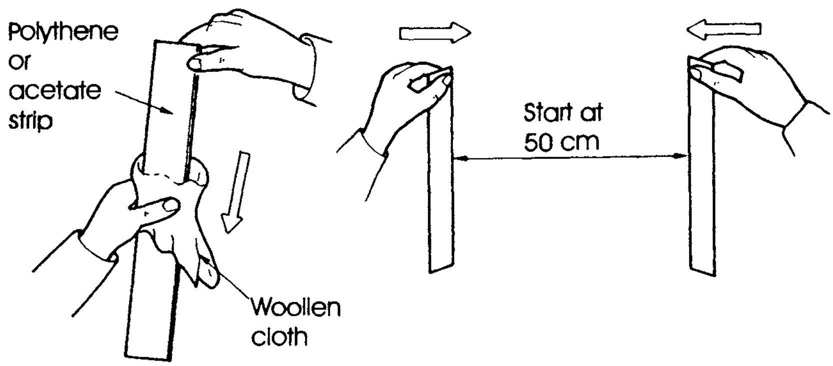


1 Electrons and electricity

Electricity consists of electric charge. Though electricity has been the subject of scientific investigations for thousands of years, the nature of electric charge is not fully understood, even at the present day. But we do know enough about it to be able to use it in many ways. Using electric charge is what this book is about.

Electric charge is a property of matter and, since matter consists of atoms, we need to look closely at atoms to find out more about electricity. But, even without studying atoms as such, we are easily able to discover some of the properties of electricity for ourselves.

The simplest way to demonstrate electric charge is to take a plastic ruler and rub it with a dry cloth. If you hold the ruler over a table on which there are some small scraps of thin paper or scraps of plastic film, the pieces jump up and down repeatedly. If you rub an inflated rubber balloon against the sleeve of your clothing then place it against the wall or ceiling, for a while, the balloon remains attracted to the wall or ceiling, defying the force of gravity. The electric charge on the plastic ruler or wall is creating a force, an **electric force**. In effect, the energy of your rubbing appears in another form which moves the pieces of paper, or prevents the balloon from falling.



The nature of electric charge is easy to demonstrate.

You can also charge a strip of polythene sheet (cut from a plastic food-bag) by rubbing it. If you charge two strips, then hold them apart and then try to bring them together, they are repelled by each other. As you try to push them together, their lower ends diverge, spreading away from each other.

A similar experiment is to charge a strip of acetate sheet (cut from a shirt-box) by rubbing it and bring it toward a charged polythene strip, the two strips attract each other. If they are allowed to, their lower ends come together and touch. From this behaviour, we reason that the charge on an acetate strip must be of a different kind from that on a polythene strip. Simple demonstrations such as these show that:

- There are two kinds of electric charge.
- Like kinds of charge repel each other.
- Opposite kinds of charge attract each other.

The discovery of electricity

Electricity takes its name from the Greek word *elektron*, the name of the resinous solid known as amber. The ancient Greeks had discovered that, when a piece of amber is rubbed with a soft cloth, it becomes able to attract small, light objects to it. We say that it has an electric charge.

More electric attraction

You may have noticed this effect in the shower. The fine spray of water droplets charges your body and the shower curtain, but the charges are opposite. There is an attractive force between your body and the curtain. The curtain billows inward and clings to your body.

Electric charge and atoms

Now we are ready to link the basic facts about electric charge to what is known about the structure of matter.

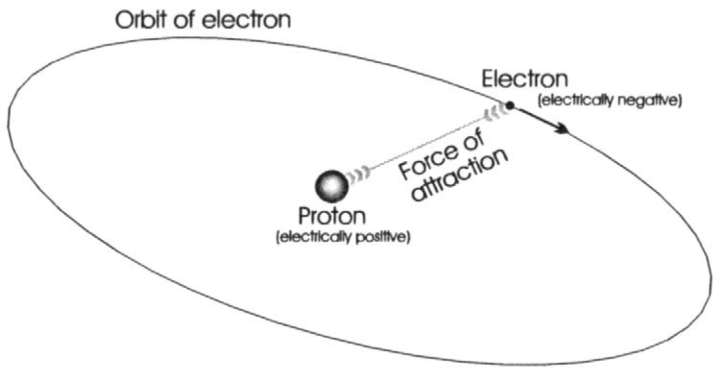
Research has shown that atoms are built up of several different kinds of atomic particle. Most of these occur only rarely in atoms but two kinds are very common. These are electrons and protons. Although protons are about 2000 times more massive than electrons, protons and electrons have equal electric charges. The charge on an electron is opposite in its nature to the charge on a proton; these are the two kinds of electric charge mentioned above. The charge on an electron is said to be negative and that on a proton to be positive, but this is simply a convention. There is nothing positive on a proton which is 'missing' or 'absent' from an electron. The two terms merely imply that positive and negative charges are opposite.

We have said that electrons and protons carry equal but opposite charges. If an electron combines with a proton, their charges cancel out exactly and an uncharged particle is formed — a neutron. Since neutrons have no charge, they are of little interest in electronics.

Atomic structure

All atoms are composed of electrons and protons (ignoring the other rare kinds of particle). The simplest possible atom, the atom of hydrogen, consists of one electron and one proton. The proton is at the centre of the atom and the electron is circling around it in orbit. With one unit of negative charge and one of positive charge, the atom as a whole is uncharged.

Since the electron is moving at high speed around the proton, there must be a force to keep it in orbit, to prevent it from flying off into space. The force that holds the electron in the atom is the attractive electrical force between oppositely charged particles, which we demonstrated earlier. It acts in a similar way to the attractive force of gravity, which keeps the Moon circling round the Earth, and the planets of the solar system circling round the Sun.



A hydrogen atom consists of two particles that are oppositely charged.

Other atoms

There are more than a hundred different elements in nature, including hydrogen, helium, copper, iron, mercury and oxygen, to name only a few. Each element has its own distinctive atomic structure, but all are based on the same plan as the hydrogen atom. That is to say, there is a central part, the nucleus, where most of the mass is concentrated, which is surrounded by a cloud of circling electrons. However, atoms other than hydrogen have more than one proton and also some neutrons in the nucleus at the centre of the atom. The positive charge on the nucleus is due to the protons it contains. The electron cloud contains a number of electrons to equal the number of protons in the nucleus. In this way the positive charge on the nucleus is exactly balanced by the negative charges on the electrons and the atom as a whole has no electric charge.

The electrons are in orbits at different distances from the nucleus. These orbits are at definite fixed distances from the nucleus and there is room for only a fixed number of electrons in each orbit.

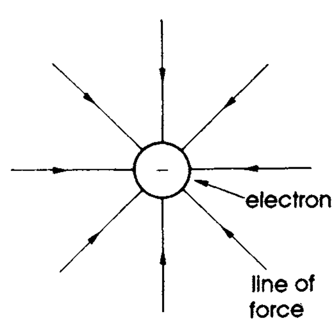
Atomic dimensions

The orbit of the electron of a hydrogen atom is about one ten-millionth of a millimetre in diameter. If the atom was scaled up so that its nucleus (the proton) was 1 mm in diameter, the orbiting electron would be a tiny speck about 120 m away. The interesting point is that the electron and proton take up very little room in the atom. So-called 'solid' matter is mostly empty space. The tangible nature of matter is not due to it consisting mostly of firm particles. Instead, it is due to the strong electrical forces between atomic particles and the forces between adjacent atoms, which hold the atoms more-or-less firmly together. There is more about the structure of matter on page 8.

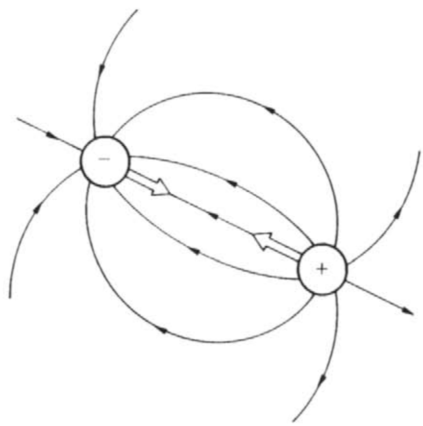
Electric fields

When an object is charged there is an electric field around it. This is a **force field** which makes charged objects move when they are in the field. Another more familiar force field is gravity, which affects us everywhere and at all times; but gravity is only attractive, it does not repel.

The drawing shows how we imagine the field around an electron. The lines of force show the way a positive charge moves when placed in the field; it moves towards the electron. Although lines of force are strictly imaginary (just as the lines of latitude and longitude on the Earth are imaginary) it helps to think of them as if they are like rubber bands under tension. This gives them two properties:



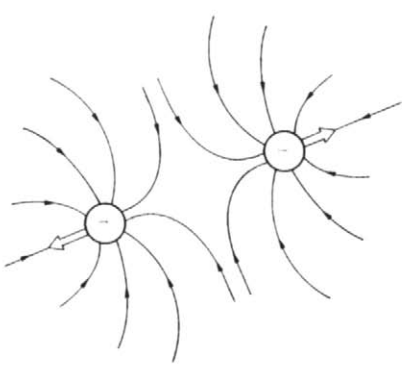
- They tend to be as short as possible.
- They tend to be as straight as possible.



Unlike charges attract

When there is a proton in the vicinity of an electron, we see the fields of the electron and proton combining to give lines running from the proton to the electron. Making the lines as short as possible creates forces acting on the electron and proton, drawing them together until they meet. They are *attracted* to each other.

The field between two electrons is very different. The lines of force of one electron do not join with those of the other electron. Each electron maintains its own field.



Like charges repel

Another property of lines of force is that they can not cross. So the fields become distorted, as shown. But lines of force tend to become straight and, for this to happen, the electrons are forced to move further apart. They are *repelled* by each other.

For the same reason, two positive charges repel each other.

Charge and energy

We can now begin to understand what happens when we charge a strip of plastic by rubbing it with a cloth. Although there is normally a fixed number of electrons circling around the nucleus of an atom, the electrons in the outer orbits are less strongly attracted to the nucleus than those closer to it. Rubbing the plastic with a cloth provides energy (derived from our muscles) to overcome the attractive forces between the nucleus and the outer electrons. Depending on the nature of the plastic, we may remove electrons from some of the atoms in the molecules of the plastic and attach them to the atoms in the molecules of the cloth.

Removing electrons leaves the plastic with excess positive charge; collecting electrons on the cloth gives it negative charge. When we pull the cloth away from the plastic at the end of the rubbing process, the strip and cloth are oppositely charged, so they are attracted to each other. We need to use more muscular energy to pull them apart now than if they were uncharged.

When the strip and cloth have been separated, they remain charged until charged molecules in the air are attracted to them. The plastic which, lacking electrons, is positively charged, attracts any negatively charged molecules that happen to be in the surrounding air. The electrons on these are passed across to the charged atoms of the plastic, so gradually discharging them. A similar process discharges the cloth.

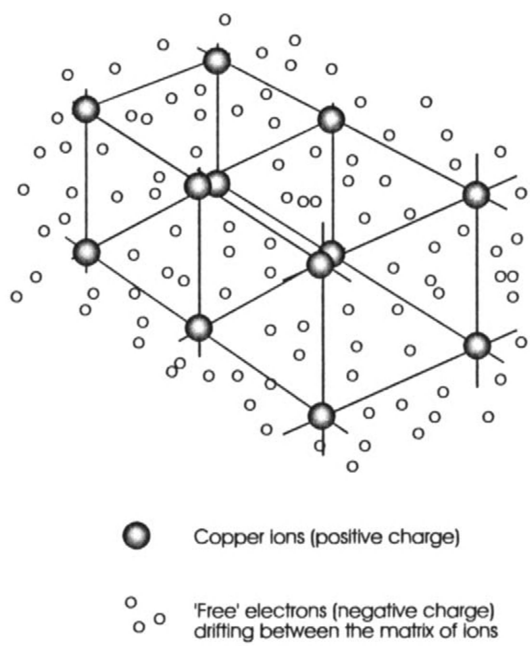
Charging other substances

Many kinds of substance are charged when rubbed with a cloth: possible substances include different kinds of plastic, rubber, and glass. Exactly what happens depends on which substance is rubbed with which kind of cloth. On this page, we described how the substance becomes negatively charged and the cloth becomes positively charged. But with a different substance or a different kind of cloth, charging may occur in the opposite direction.

Conduction

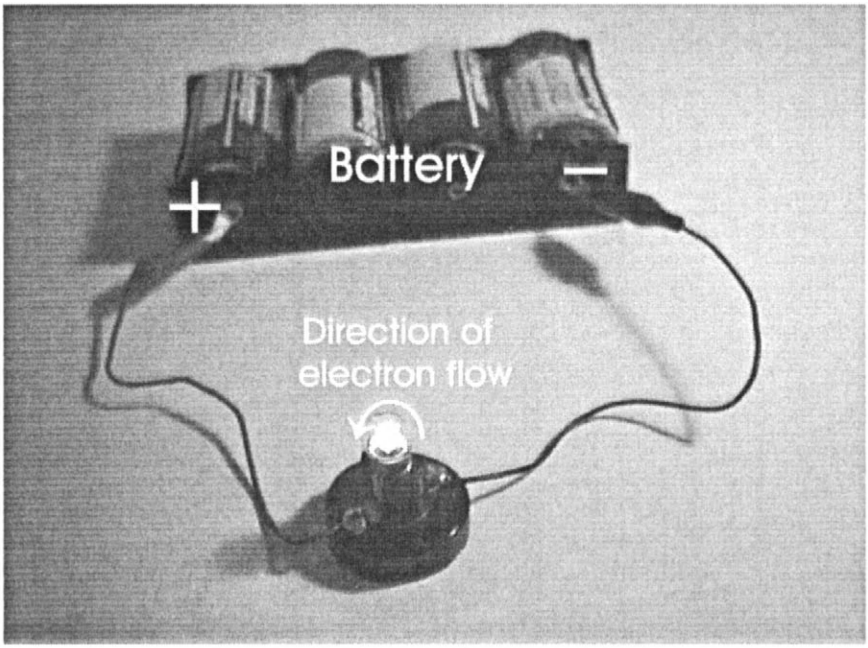
Substances such as plastic, wool, glass, and rubber can be charged because there is no quick way that electrons removed from an atom can be replaced or that excess electrons can be got rid of. The charged atoms are isolated from each other and from the surroundings, except when, for example, a charged molecule is attracted from the air, or the substance is brought into contact with an oppositely charged surface. Substances of this kind, in which charges stay in a fixed place, are known as **non-conductors** or **insulators**. As well as those mentioned above, this class of substance includes dry wood, paper, ceramics, pure water, asbestos and dry air. The other major class of substance comprises the **conductors,** in which electrons can move freely. These are mostly elements such as silver, gold, copper, lead, and carbon. The majority of them are metals. Conductors also include alloys of metals (such as brass) and solution of salts.

Metals have the structure of crystals, the individual atoms are arranged in a regular three-dimensional array known as a **matrix** or **lattice**. They are held in position by forces (not electric) existing between each atom and its neighbours. These are indicated by the 3D grid of lines in the diagram. Each atom has electrons circling its nucleus but, in metals, the outer electrons are only weakly attracted to the nucleus. They are able to leave the atom and wander off at random into the spaces within the lattice, not being attached to any particular atom. When these electrons move, negative charge moves from one part of the copper block to another. We say that the electrons are **charge carriers**.



The arrangement of copper atoms in the lattice of metallic copper. A cloud of 'free electrons' permeates the lattice. These electrons are available for conducting charge.

The photograph shows one way in which the electrons may be made to move in an orderly fashion. The filament lamp is connected to an electric battery by copper wires. There is an electric field between the positive and negative terminals of the battery. The way this field is generated is described later but, for the moment, consider there to be lines of force running from the positive terminal (+) to the negative terminal (–). Before the battery is connected to the lamp, the field lines run directly between the terminals, through the air. When the battery is connected by wires to the lamp, the field lines mostly become bunched together, and run through the wires and the filament of the lamp, instead of running through the air. Thus there is an electric field running from the positive terminal, through the wire on the left, through the lamp, through the wire on the right and back to the battery at its negative terminal. Any charged particles in that field will move, provided that they are free to do so.



This is a simple example of an electric circuit. Current flows from the battery, through the various conductors and returns to the battery.

If the wires and filament of the lamp were made of plastic or some other non-conductor, charged particles would not be free to move. However, in a conductor such as copper the electrons wandering between the atoms are very free to move. As long as there is no field within the conductors the electrons wander randomly in the space within the lattice. Once a field has been applied to the conductors the electrons all flow in one direction. They flow through the wires and lamp repelled by the negative terminal of the battery and attracted toward its positive terminal. We have an **electric current**. This is just what an electric current is – a mass flow of electric charge from one place to another.

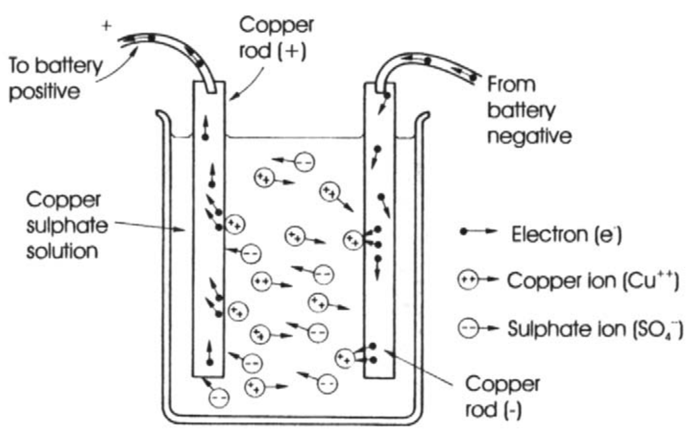
As electrons move through the circuit, those reaching the positive terminal of the battery pass into it. They are replaced by electrons coming from the negative terminal. Most of electronics deals with the flow of electric currents. We are not much interested in the stationary (or static) charges built up by rubbing non-conductors, but there is one instance in which static charges are really important and we must take special precautions to eliminate them, as explained on page 83.

Electromotive force

When a charged particle is in an electric field it is subject to a force, which makes it move if it is free to do so. This force is known as electromotive force, often referred to briefly as e.m.f.

Current through a solution

Electrons are not the only particles that can carry an electric charge. The charge carriers in a solution in water are the **ions** of the dissolved substance. For example, when copper sulphate ($CuSO_4$) is dissolved in water, its molecules break up into two ions: copper (Cu) and sulphate (SO_4). When they break up, or **ionize**, the sulphate ion takes two electrons from the copper atom, leaving it positively charged (Cu^{++}). This makes the sulphate ion negatively charged (SO_4^{--}).



There is a two-way flow of charge through a solution.

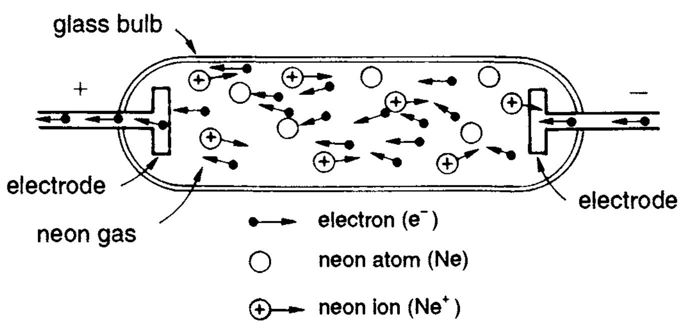
Consider the flow of charge carriers between two copper rods immersed in a solution of copper sulphate and connected externally to a battery. The copper ions are attracted toward the negative rod and are there discharged by electrons which have come from the negative terminal of the battery. The discharged copper ions are deposited on the rod as a bright reddish layer of copper.

Copper *atoms* of the positive rod dissolve in the water, becoming copper *ions*, each losing two electrons. The electrons flow to the positive terminal of the battery. This copper rod gradually becomes thinner. The sulphate ions are attracted toward the positive supply but do not become discharged, so they are not charge carriers.

Although salts form ions when dissolved in water, making the salt solution a conductor, pure water does not form ions, and so it is a non-conductor.

Current through a gas

Gases under low pressure can conduct electric charge. As in the case of a solution, there is two-way conduction.



Neon, argon, krypton, and some other gases conduct electric charge when they are at low pressure.

Electrons flow from the negative plate (negative electrode) to the positive plate (positive electrode). On their way, they strike neon atoms and knock electrons out of them. This creates more electrons to act as negative charge carriers. The neon atoms which have lost electrons become positive ions, and act as positive charge carriers. The energy from the moving carriers excites many of the neon atoms. Excited atoms later lose this energy, which then appears in another form, that of reddish light. An example is the 'flicker flame' lamp shown in the title photograph of this chapter.