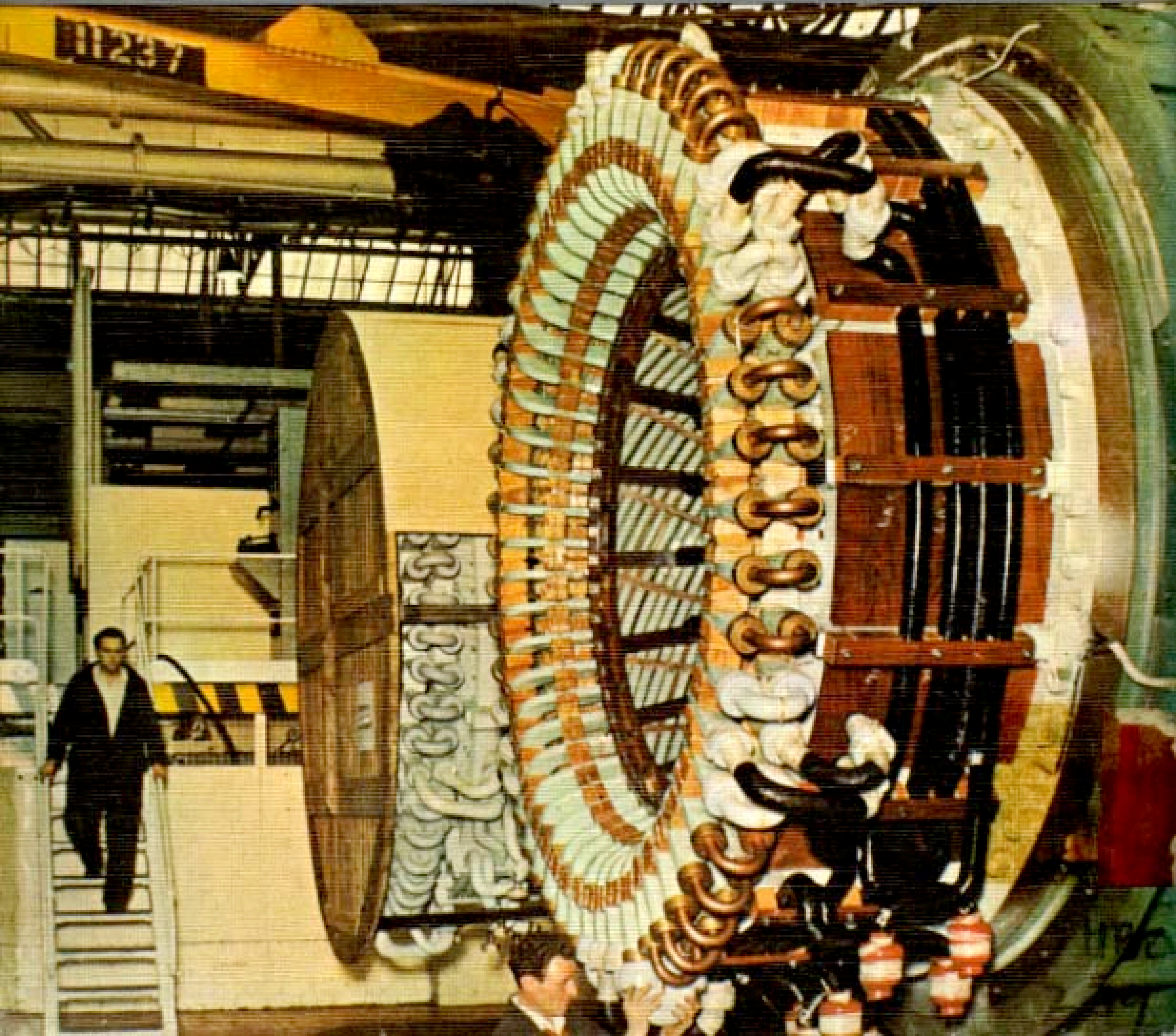
Electromagnetism

JOHN M. OSBORNE

LONGMAN PHYSICS TOPICS

General Editor J. L. Lewis, Malvern College; formerly Associate Organiser, Nuffield O-level Physics Project

This series provides background material for modern courses in physics. The authors were closely associated with the Nuffield Foundation Physics Project, and thus have an intimate knowledge of its spirit. These books are not textbooks in the conventional sense, nor do they give the answers to investigations that pupils will be carrying out in the laboratory. Instead they show the relevance and application in the outside world of the principles studied in school.



LONGMAN PHYSICS TOPICS *General Editor:* John L. Lewis

ELECTROMAGNETISM

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NOTE TO THE TEACHER

This book is one in the series of Physics background books intended primarily for use with the Nuffield O-level Physics Project. Most of the team of writers who have contributed to the series were associated with that project. It was always intended that the Nuffield teachers' materials should be accompanied by background books for pupils to read, and a number of such books is being produced under the Foundation's auspices. This series is intended as a supplement to the Nuffield materials – not books giving the answers to all the investigations pupils will be doing in the laboratory, certainly not textbooks in the conventional sense, but books, easy to read and copiously illustrated, which show how the principles studied in school are applied in the outside world.

The books are such that they can be used with conventional courses as well as with the new programmes. Whatever course the pupils are following, they often need straightforward books to help clarify their knowledge, sometimes to help them catch up on any topic they have missed in their school course. It is hoped that this series will meet that need.

This background series will provide suitable material for reading in homework. This volume is divided into sections, and a teacher may feel that one section at a time is suitable for each homework session.

This particular book is written as a background book for the electromagnetism in Year III of the Nuffield course, though it should be useful for pupils studying later years to remind them of earlier work. It presupposes a knowledge of the work on electric currents done in Year II of the Nuffield course and for which there is a separate background book in this series – Electric Currents.

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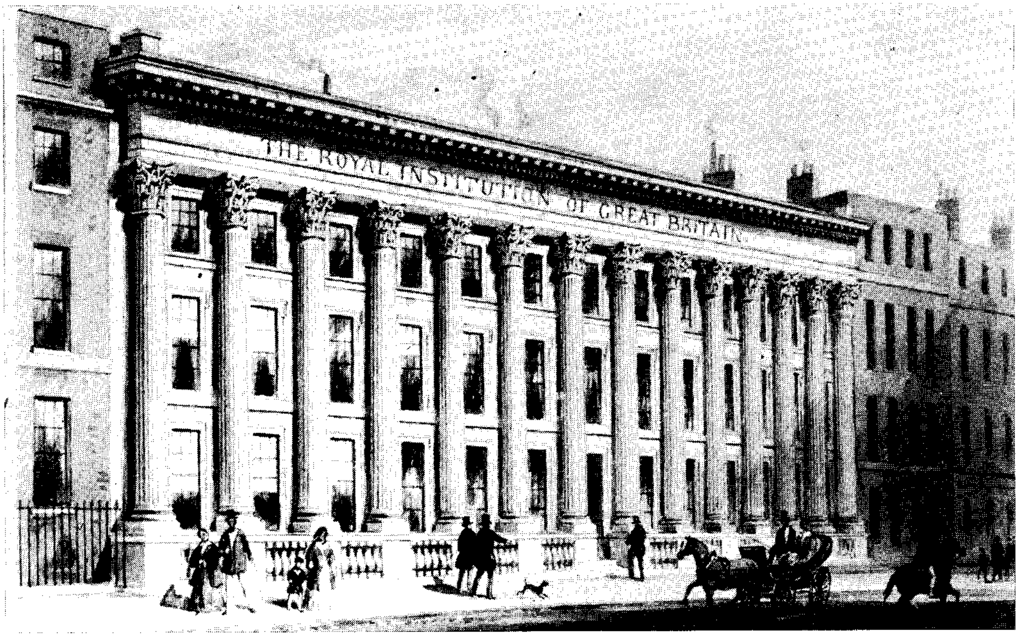
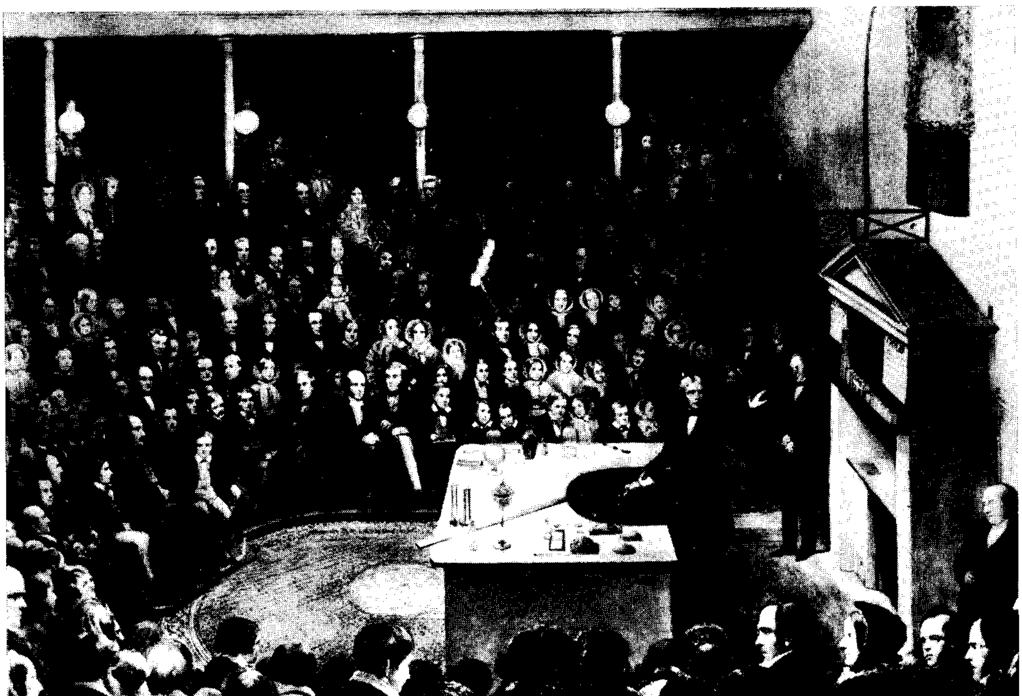

THE ROYAL INSTITUTION of GREAT BRITAIN



ELECTRO-MAGNETISM

Michael Faraday

Above opposite: the Royal Institution in Albemarle Street, London, where Faraday worked for the larger part of his life. The building has changed very little since his time.

Below opposite: Michael Faraday giving one of the Royal Institution's Christmas Lectures

Michael Faraday has been described as the father of electromagnetism. It was his work which laid the foundation for the electrical world in which we live today. He was born in 1791, the son of a blacksmith. At the age of thirteen, he went to work in a bookshop, where he began by delivering newspapers. Four years later, he started bookbinding and many books on science passed through his hands. He was fascinated by what he read and eventually a customer arranged for him to attend lectures at the Royal Institution.

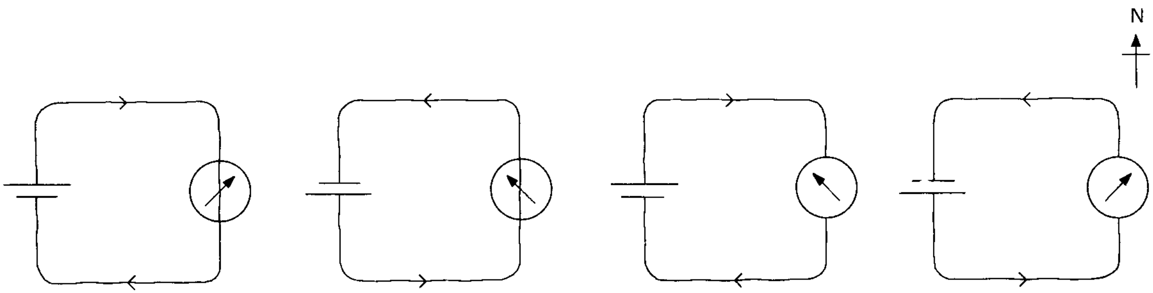
The Royal Institution had been started not many years before, in 1799, by Count Rumford and others who felt the need to provide the public with instruction in science. They acquired a building in Albermarle Street in London, which was extended to provide the lecture theatre which has been famous ever since. Many of London's schoolchildren have been to lectures there. They were first made popular for children by Faraday himself when he started the famous Christmas lectures.

So great was the impression made on him by the books he read and the lectures he attended that Faraday decided to devote all his efforts to science. He wrote to Sir Humphry Davy, who was the Director of the Royal Institution asking for employment. As a bookbinder's apprentice, he could put forward no qualifications to justify his application for a post, so he included with his request neatly written lecture-notes, illustrated with drawings, which he had made when listening to Sir Humphry at the Royal Institution. The Director was most impressed and obtained permission from the governors to employ Michael Faraday, then aged twenty-two. He started by washing bottles, but soon began helping Davy in the preparation of his experiments. Under the guidance of Sir Humphry, Michael Faraday rapidly matured into a brilliant experimental scientist. Finally, he succeeded him as Director of the Royal Institution.

While still an assistant, Faraday started making independent investigations on his own and he turned his attention to, amongst other things, the behaviour of electric currents. Very little was understood about electricity by the scientists of that time. So great, however, were Faraday's powers of observation and deduction, so great was his ability to contrive experiments to verify or disprove new theories, that in a remarkably short space of time he had clarified existing knowledge and added his own invaluable contributions, laying a sound foundation of electrical knowledge which has changed little since that time.

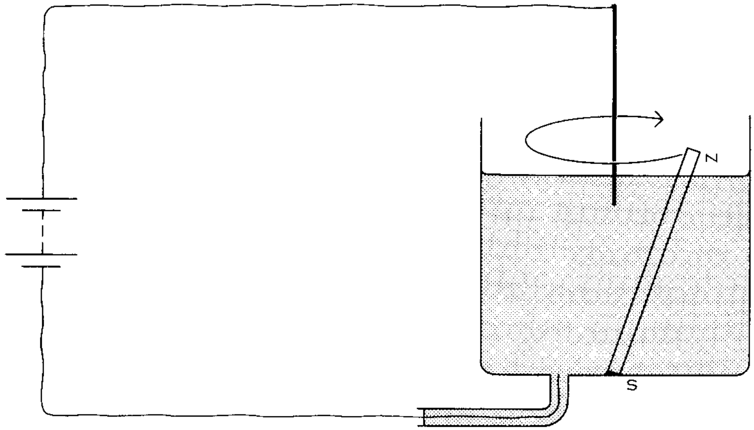
OERSTED'S EXPERIMENTS

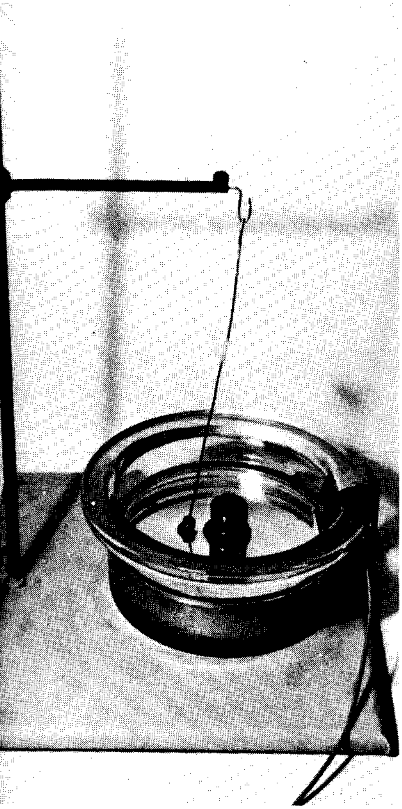
The most important piece of knowledge on which Faraday had to build in establishing his theory of electromagnetism was provided by Oersted. In 1819 Oersted had discovered that a wire connected across a voltaic pile (a battery) had a strong effect on a compass needle. This effect is shown diagrammatically in the figure below.



A wire passing North and South above a compass needle caused the needle to be deflected either towards the East or the West according to which way the current was flowing in the wire. The needle was deflected in the opposite directions when the wire was below the compass needle.

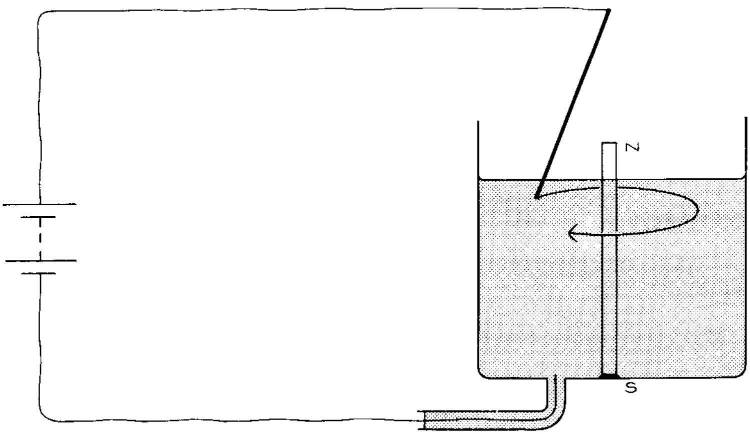
Faraday repeated Oersted's experiments and realised that it might be possible to use this effect, in some way, to produce continuous rotation. He suspended a rigid vertical copper wire so that the bottom end was immersed in a pool of mercury, which is a good conductor. An electric current was passed through the mercury and the wire. He put a magnet in the pool of mercury with its bottom end tethered. When the current flowed, the pole of the magnet rotated round the wire (see top diagram opposite).





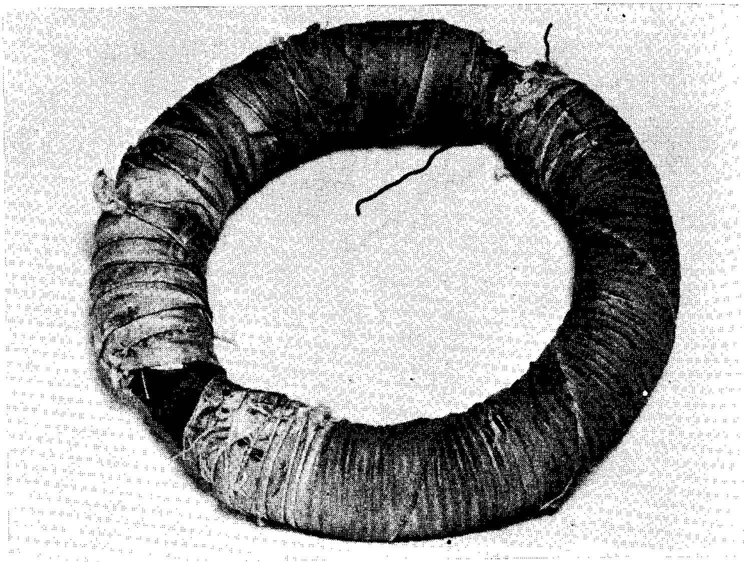
This showed that when a current flowed, there was a force on the magnet. He also tried keeping the magnet still in order to see if there was a force on the wire. For this he fixed a magnet vertical in the pool of mercury. A copper wire was freely suspended over the centre of the magnet so that it dipped into the mercury beside the pole of the magnet. Connections were made to a battery. When the current flowed, there was a force on the wire which caused it to move continuously in a circle around the magnet. This simple piece of equipment was really the first electric motor.

The photograph shows a copy of Faraday's apparatus.



ELECTROMAGNETIC INDUCTION

It was in 1831 that perhaps Faraday's most far reaching discovery was made. His diary of August 29, 1831 reads:



Faraday's original iron ring from the Royal Institution

'2 Have had an iron ring made (soft iron) 6 inches in diameter. Wound many coils of copper wire round one half, the coils being supported by twine and calico. Will call this side of the ring A. On the other side was wound wire amounting to 60 feet in length; this side called B.'

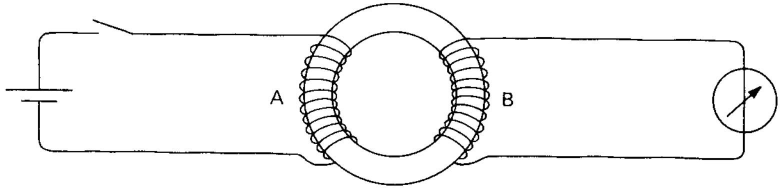
Faraday wound twine between the turns of the copper coil to insulate adjacent turns from each other. He also separated the layers of the coil with a cloth called Calico. Why did Faraday not use insulated wire?

'3 Connected the B side coil by a copper wire passing to a distance and just over a magnetic needle 3 feet from iron ring. Then connected its ends on A side with battery; immediately a sensible effect on the needle. It oscillated and settled at last in original position. On breaking connection of A side with battery, again a disturbance of the needle.'

Faraday next improved the current detecting arrangement by putting a flat coil (helix) beside one pole of the magnetic needle. A current in the coil produced a much greater magnetic field than in the wire passing over the needle; the deflection of the needle was much greater.

'7 When all was ready, the moment the battery was communicated with both ends of wire at A side, the helix strongly *attracted* the needle. After a few vibrations, it came to a state of rest in its original and natural position; and then on *breaking* the battery connection, the needle was as strongly *repelled*, and after a few oscillations came to rest in the same place as before.'

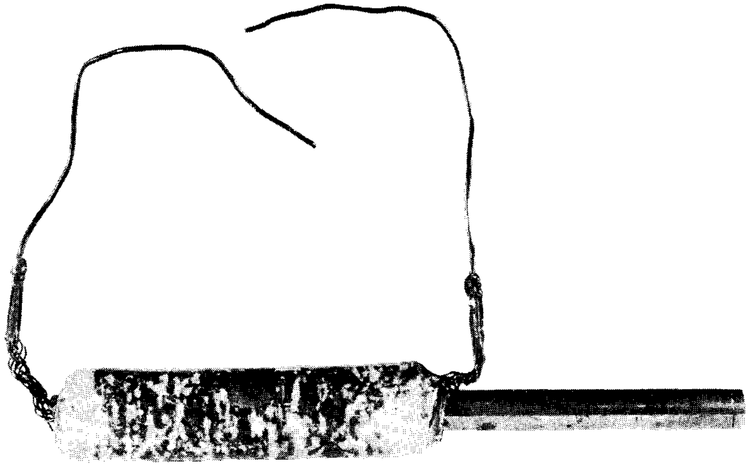
Thus Faraday had shown that an effect was produced in the second circuit (coil B) when the current in the first circuit (coil A) was switched on or when it was switched off. A steady current in coil A had no effect on coil B. The most remarkable fact he noticed was that the breaking of the circuit A produced as great an effect, although in the opposite direction, as that obtained on making (closing) the circuit. He had discovered the phenomena of electromagnetic induction on which all our dynamos and generators are based.



A few weeks later Faraday did another very important, though simple, experiment. A length of copper wire (about 200 ft) was wound on a paper cylinder about one inch in diameter and 6 inches long. The ends were connected to a galvanometer, using long leads. Why did Faraday use long leads? Try to answer this when you have read the rest of the paragraph. A cylindrical bar magnet about 8 inches long was inserted into the cylinder. Faraday's diary of October 1st, 1831 reads:

'57 Then it was quickly thrust in the whole length and the galvanometer needle moved – then pulled out and again the needle moved, but in the opposite direction. This effect was repeated every time the magnet was put in or out. . . .

'58 The needle did not remain deflected, but returned to its place each time.'



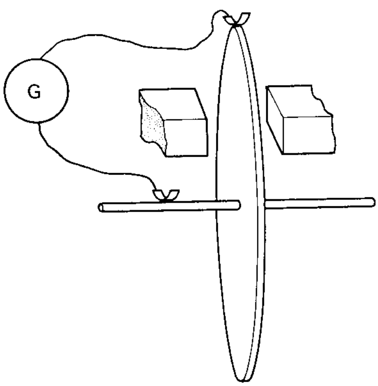
The original coil and bar magnet with which Faraday showed that magnetism could be used to produce electricity

What Faraday has shown may be briefly summarised as follows. If a magnetic field through a coil is *altered*, a voltage is induced across the coil which will cause a current to flow in the circuit connected to it.

FURTHER EXPERIMENTS BY FARADAY

Just as Faraday produced the forerunner of the electric motor and the transformer (the iron ring is very like a transformer), so he also produced the first elementary dynamo. His diary reads:

'99 Made many experiments with a copper revolving plate about 12 inches in diameter and about $\frac{1}{5}$ inch thick, mounted on a brass axle.'



Faraday discovered that, if this plate was rotated between the poles of a magnet, a current was made to flow through a galvanometer which was connected between the spindle and a contact brushing the edge of the ring on the other side of the magnet.

Faraday tried all possible combinations of connections to the disc and arrangements of the magnets. He showed that the motion of a conductor moving through a magnetic field can cause an electric current to flow and that by making this conductor in the form of a disc which could be continuously rotated, a continuous source of electricity was available for as long as the disc was kept in motion.

Such a dynamo would be of little practical use since even with a very strong magnetic field it would only produce a few millivolts. Nevertheless, this instrument is the forerunner of the modern dynamo.

THE PURPOSE OF THIS BOOK

The discovery that a magnetic field was produced when a current flowed in a wire has led to many devices in use today: the electromagnet, the electric bell and the electric buzzer, the relay and the reed switch, and the motor horn.

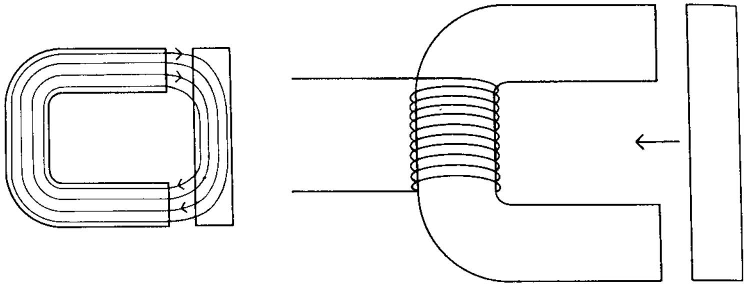
The fact that a force is exerted on a conductor in a magnetic field when a current flows through it is the basis of the electric motor. It is this force which is put to use in the moving coil meter.

Electromagnetic induction is used in large electric generators and in small dynamos. It makes possible the manufacture of transformers, both small ones for hearing aids and large ones to be used in transmitting electric power round the country.

The purpose of this book is to enlarge on some of the above and to show how the principles you have studied in the school laboratory, most of which originate from the work of Faraday, are applied in the world today. The final chapter will explain how many of the devices discussed elsewhere are put to practical use in the motorcar.

THE ELECTRO-MAGNET

The electromagnet is a very useful device for producing small movements in electromechanical applications. You are already familiar with the fact that, if a coil of wire is wrapped round a soft iron core and connected to a suitable battery, the core will become magnetised and attract a bar of iron near it.



The smaller the gap between the magnet and the iron, the bigger the force of attraction. It is important to realise that if one needs a big force, the design of the device should keep this gap as small as possible.

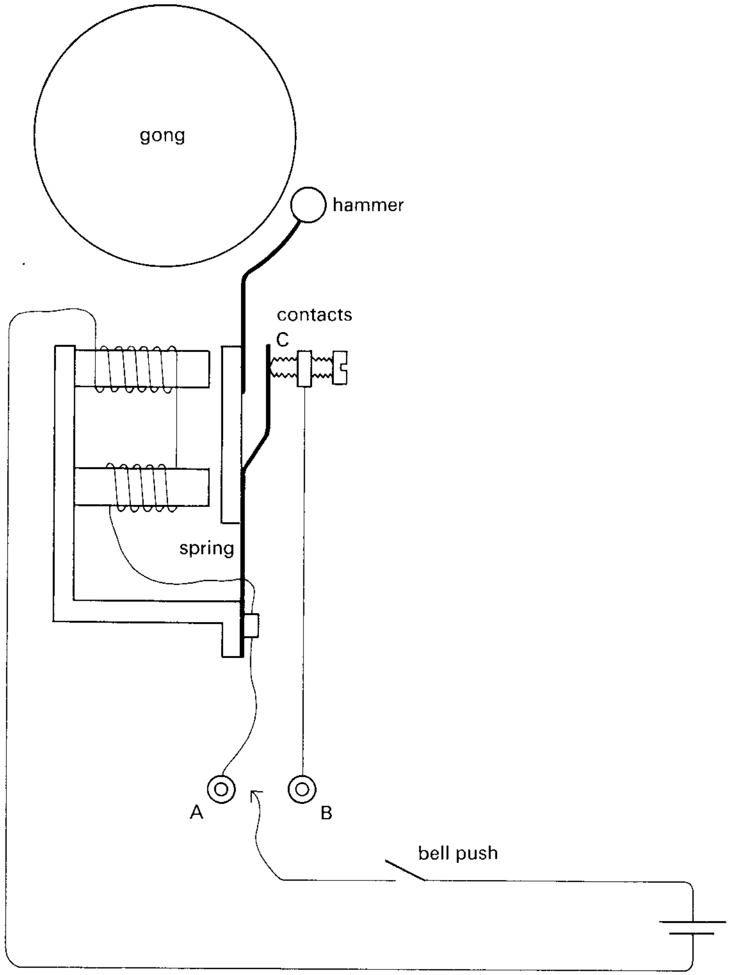
Can you think what the left-hand diagram shows?

THE ELECTRIC BELL

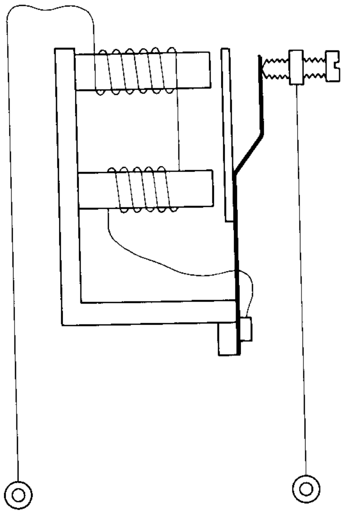
One application is the electric bell, which is illustrated opposite. In this a piece of iron is mounted on a springy bit of steel so that it can vibrate. On the end is a hammer which hits the gong. This moving part is called the armature.

When a battery is connected to the coil of the electromagnet through terminal A, the armature will be attracted to the electromagnet and the gong will be struck. This will occur once every time the current is switched on.

If, instead, the connection is made through terminal B, the circuit is completed through a pair of contacts C. One of these contacts is attached to the armature through another small piece of steel spring. As the armature is attracted, contact is maintained by this spring pushing against the fixed contact. The fixed contact is adjustable and set so that the contact opens just before the hammer



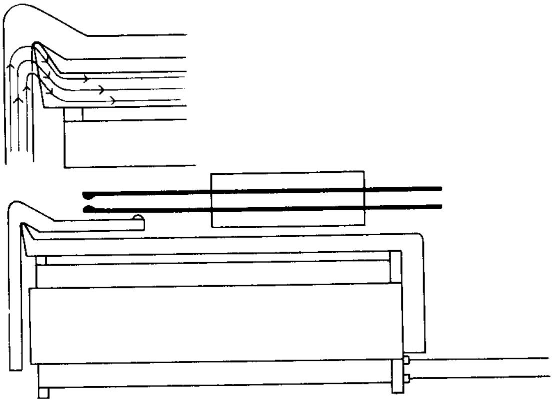
hits the gong. As soon as contact is broken, the electromagnet ceases and there is no longer a pull on the armature. It continues under its own inertia to strike the gong, after which it falls back under the action of its main spring until contact is again established and again the electromagnet pulls the armature towards the gong. The bell thus goes on ringing as long as the battery is connected. This arrangement is used for the domestic doorbell. The first arrangement (when the bell only strikes once) is used for the starting-stopping bell on buses.

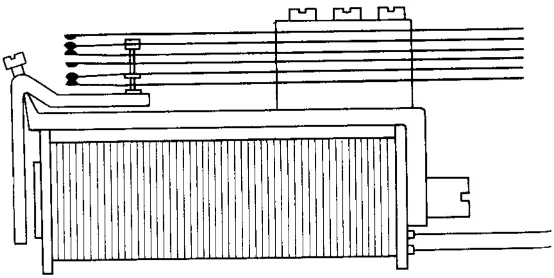


The illustration here shows the buzzer. Electrically this is identical to the bell, but it has no gong and the armature has a very much smaller mass so that it can move backwards and forwards at a much greater rate. The sound it produces is that of the armature buzzing backwards and forwards.

THE RELAY

A very important application is the relay. This is an electromagnetically operated switch used in signalling and telephone exchanges. In the diagram below, the armature is extended to form a right angle and is hinged as shown. There is a very small gap between it and the core.

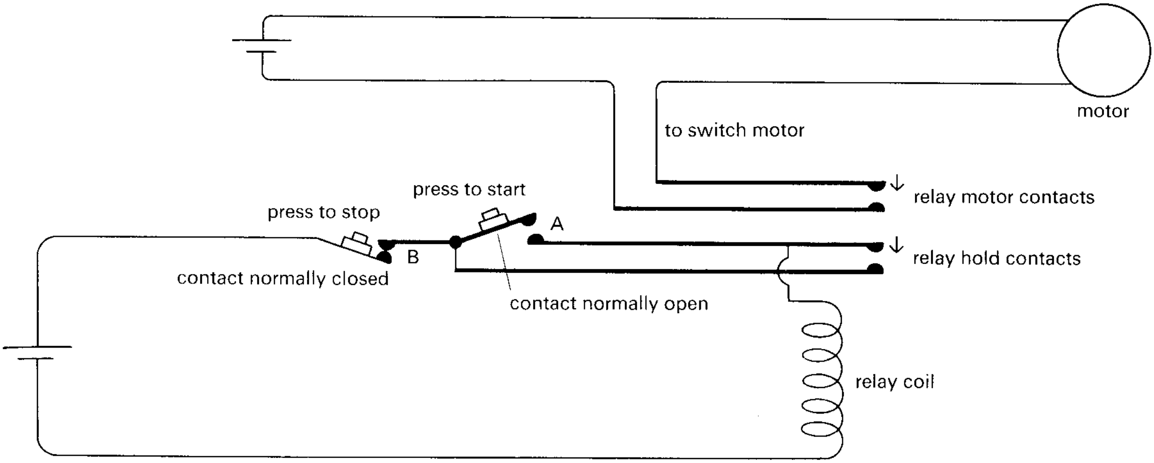




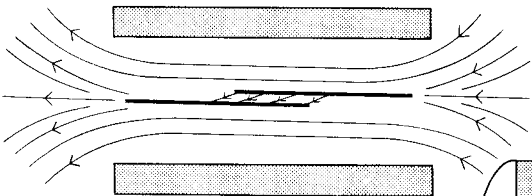
When the current flows through the coil, it magnetises the iron core and attracts the armature. The top end of the armature is raised and closes the switch contacts by pressing against them. Thus a current in the coil can switch on a current in another circuit.

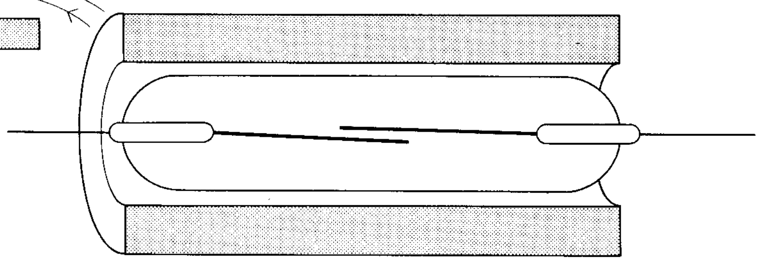
In some relays, the armature is arranged to switch on or off many contacts at once. Such a multiple relay is illustrated above.

A typical application is shown opposite, in which an electric motor is started by a single push on the button A and will continue to run until button B is pushed.



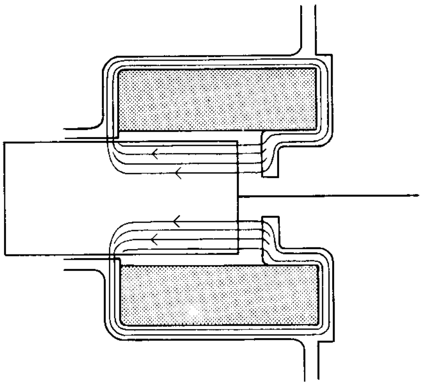
When the button A is pushed, a current passes through the coil of the relay, thus *making* the contacts which start the motor. At the same time, other contacts short-circuit the starter button and so keep the current flowing through the relay even when button A is released. Pressing button B interrupts the current through the coil so that the contacts open and the motor is switched off. Such an arrangement enables a large motor requiring heavy switches to be operated by small push buttons situated conveniently for the operator.

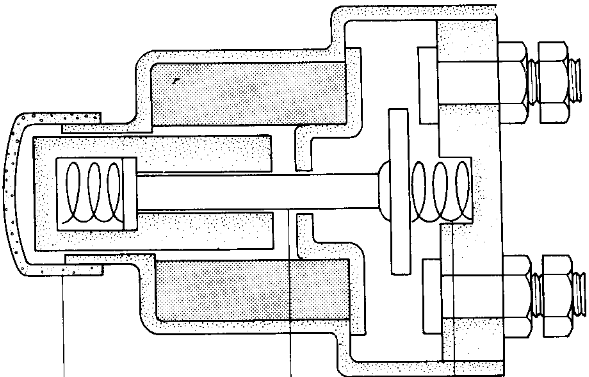




An attractive type of relay for switching small currents very quickly and reliably is the reed relay. It consists of two iron reeds inside a sealed tube, usually filled with an inert gas to avoid corrosion of the contacts. The tube is put inside a coil. When a current is passed through the coil, the reeds become magnetised and attract each other making contact, thereby switching on another circuit. What happens if the current through the coil is reversed? Such a switch is useful in a radio-controlled model boat. A current of a few milliamps through the coil from a transistor receiver could switch on or off an electric motor taking, say, $\frac{1}{5}$ ampere. The electric motor might be propelling the boat or perhaps operating the rudder.

Relays are used in starting a car. A turn of the starting switch on the driving panel of the car operates a relay which in turn connects the battery to the starter motor. The very heavy wiring, which may carry 100 amps, from the battery to the motor is kept as short as possible by having the relay on the motor itself, whilst the leads to the switch on the driving panel carry a relatively small current.



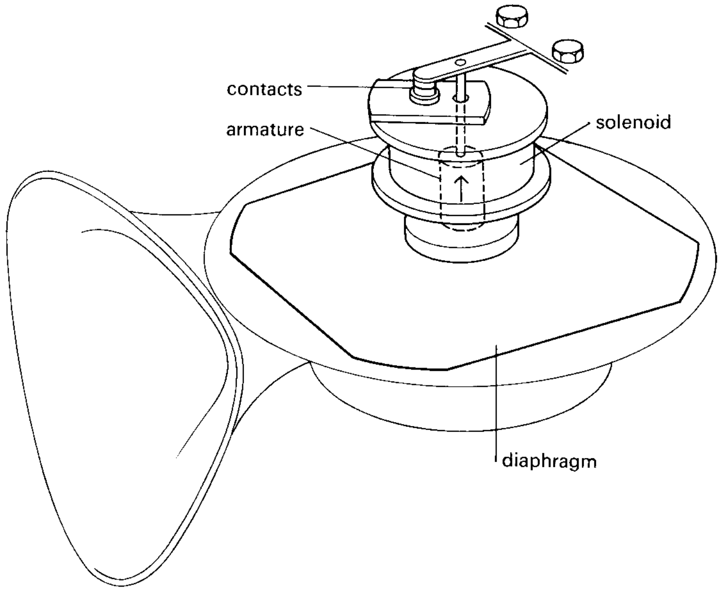


The illustration above shows yet another arrangement: the armature this time is the iron rod inside the coil. It is spring loaded so that normally there is a very small gap, but, when a current is passed through the coil, the armature moves, thereby engaging the moving contact with the fixed contacts.

Notice the very large terminals and the substantial contacts necessary to carry the large current for the starter motor. The rubber cap on the end makes it possible to operate the armature manually: a garage mechanic, working under the bonnet of a car, can turn the engine by pressing the armature in by hand.

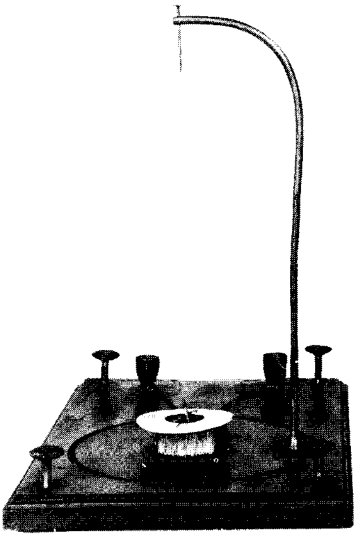
THE MOTOR HORN

Another application is the car horn. The principle is similar to that of the electric bell, but the armature is placed inside the coil in a somewhat similar fashion to the starter relay. The armature moves backwards and forwards rapidly and in doing so drives a diaphragm backwards and forwards at a high frequency – and this sends out sound waves from the horn.



You can see in the diagram that, as the armature is attracted in to close the gap, it simultaneously presses open the contacts, thus switching off the coil current. The armature falls back, contact is again made and the process is repeated just as in the electric bell, but at a very much higher frequency.

METERS



Faraday's galvanometer from the Royal Institution

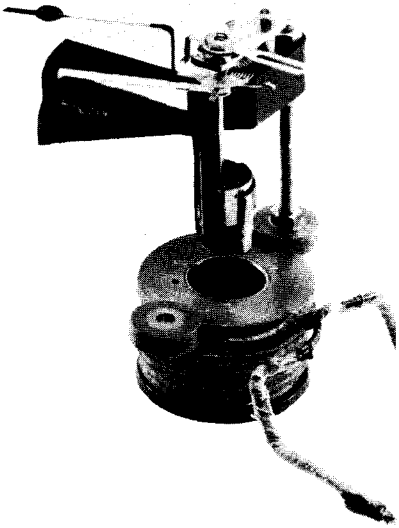
In the early days of electricity, experimenters used various devices which would indicate the existence of an electric current. One of Faraday's galvanometers is shown here. As an electric current passes round the coil, the magnetic field produced in the coil combines with the earth's magnetic field and alters the direction in which the little magnet points.

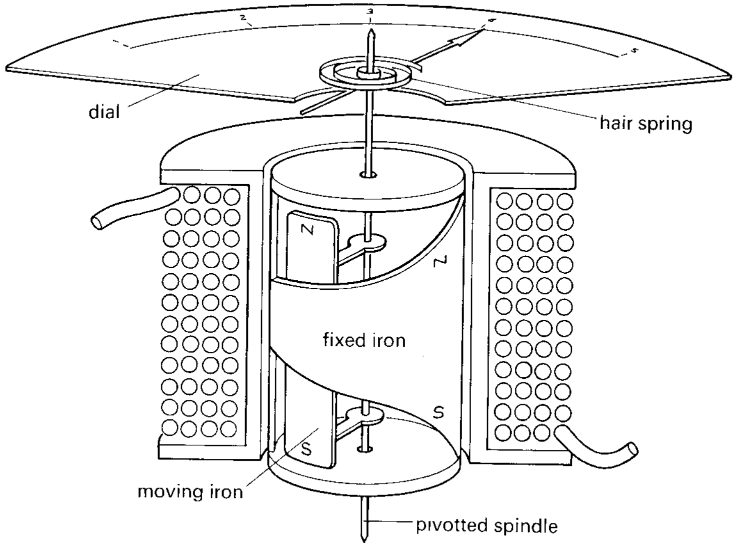
By measuring the angle through which the small magnet turns, one can compare the strength of the magnetic field due to the coil with that of the earth's magnetic field, and so in turn compare the strength of the current in the coil against an unchanging field. For example, suppose the coil is set up pointing North-South, and if the compass points North West or North East, the magnetic field due to the coil must be equal to the earth's magnetic field to produce this 45° deflection. The scale, however, would be very awkward to use because doubling the current does not double the angle of deflection. For many years, however, meters based on this principle were used. These *tangent galvanometers* are now extinct.

A much more robust and convenient instrument for measuring electric currents is the modern moving iron ammeter. It can be used in any position since it is independent of the earth's magnetic field. The operation of this instrument depends on (a) the fact that two pieces of soft iron inside a coil will both be magnetised the same way by a current and (b) the fact that magnets with like poles together will repel each other. Inside the coil of the instrument are two pieces of soft iron, one fixed and the other suspended on a pivot so that it can move. A current through the coil makes both of these pieces of iron magnets. The one on the pivot being repelled from the fixed one, moves and, in doing so, it winds up a very fine spring like the hair spring of a wrist watch. It also moves a needle across a dial.

Now the stronger the current, the stronger the magnetism induced both in the fixed and the moving pieces of iron, the stronger they will be repelled from each other, the further the spring will be wound up and the further round the dial the pointer will move.

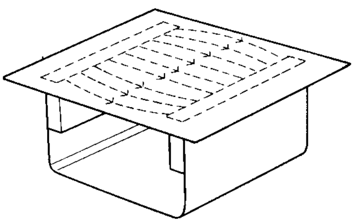
An instrument of this sort often takes some time to

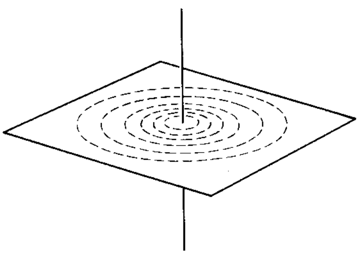




record the current after it is switched on, since it overshoots the mark and moves backwards and forwards many times before finally coming to rest. Better instruments have some form of 'damping' to reduce these oscillations: for example, a light vane can be attached to the moving part to increase air resistance.

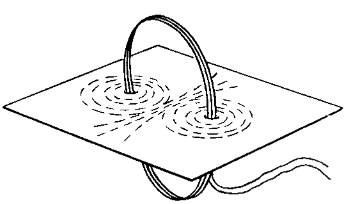
By far the most common measuring device is the moving coil instrument. It has many advantages over all other meters. To explain how the instrument works, we must first look in detail at the magnetic fields due to currents.



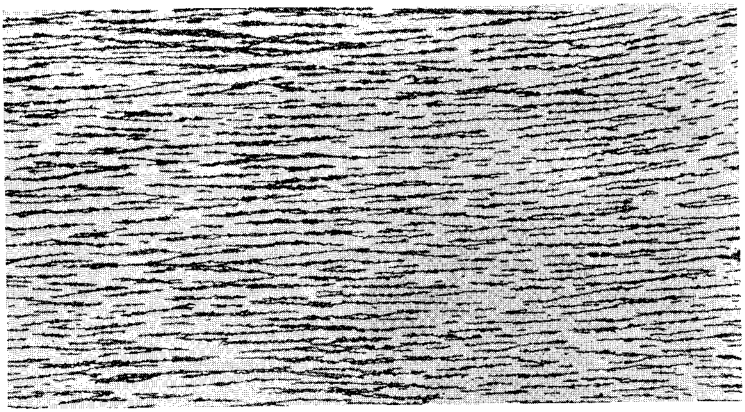


MAGNETIC FIELDS

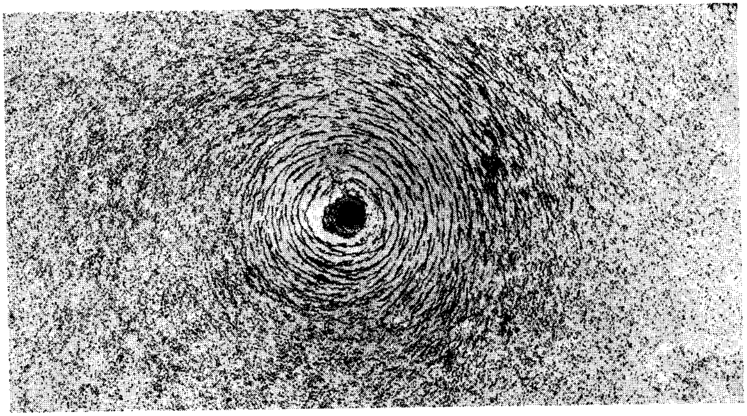
In your experiments in the school laboratory, you found the magnetic field between two Magnadur magnets was as illustrated on the left. The arrows in the drawings represent the direction in which a small exploring compass would sit.



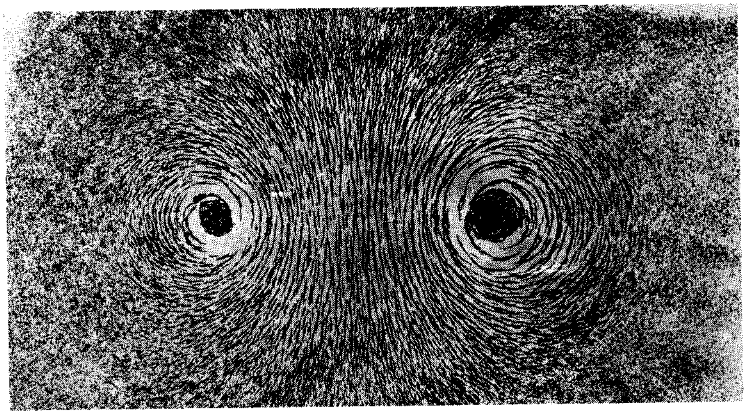
You also investigated the field due to a long straight wire and due to a coil. The drawings on the left show what those fields were like and the photographs on the next page show typical iron-filing patterns.



Field due to Magnadur magnets

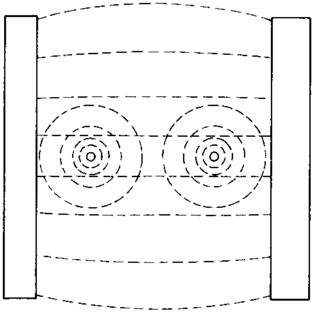


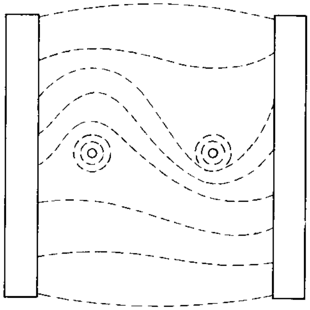
Field due to a current in a long straight wire

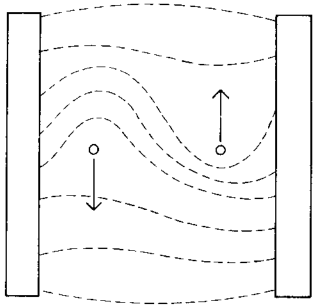


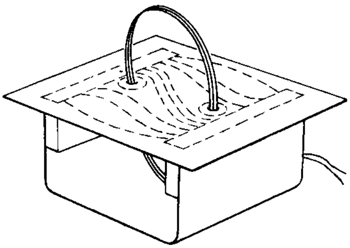
Field due to a coil

An interesting case arises when a coil is put in between the Magnadur magnets. What will the field be like when a current passes through the coil? The first drawing shows

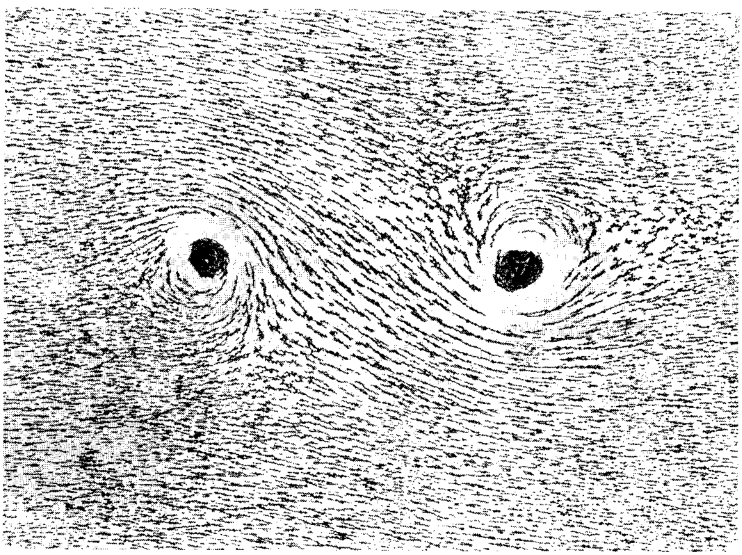




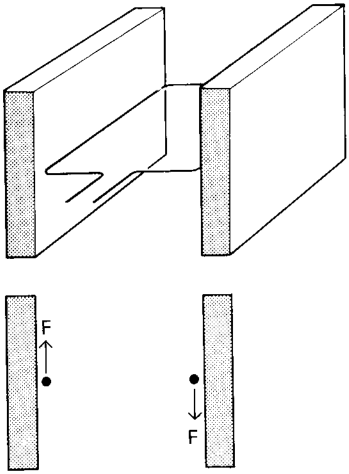




the field due to the Magnadur magnets, and the field due to the coil superimposed on each other. But a search compass cannot point in two directions at once. There can be only one field, a combined one and this you will have seen is like that in the second drawing – a field we often call a *catapult field*. The result of such a field is that there are forces acting on the coil in a field, tending to turn it round as illustrated in the third diagram. A photograph of a catapult field is shown below.

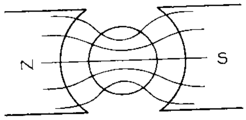


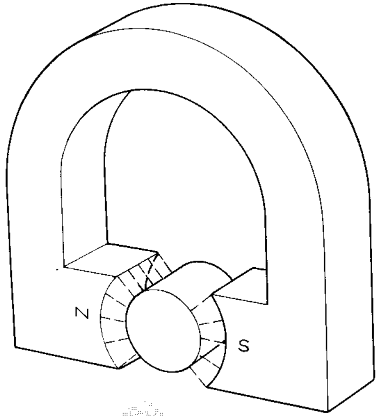
Catapult field

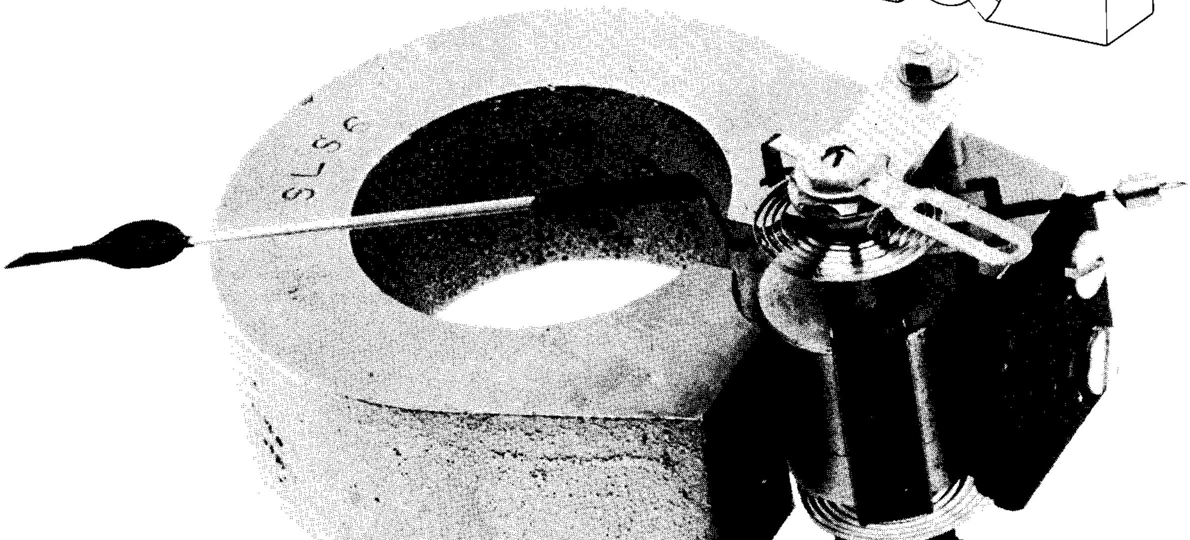


MOVING COIL METER

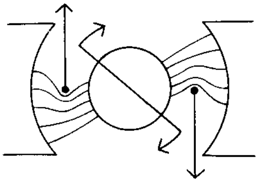
It is this force which causes the coil to move in a typical moving galvanometer. In commercial instruments, the pole pieces are usually given a special shape and a soft iron cylinder is put between them, so that the magnetic field lines cross the gap directly towards, or directly away from, the centre of the cylinder.

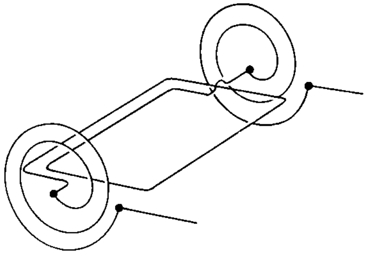


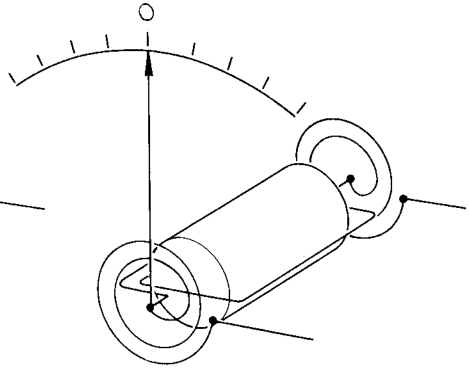




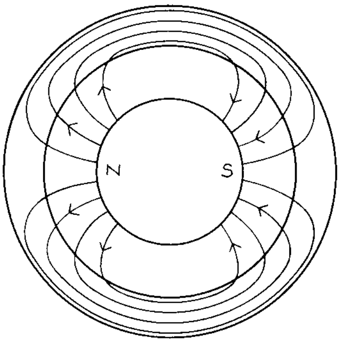
A coil is arranged on pivots so that it can be rotated about the cylinder with the sides of the coil in the gaps. Connections to the coil are made through the hair springs which keep it in the zero position when there is no current flowing.



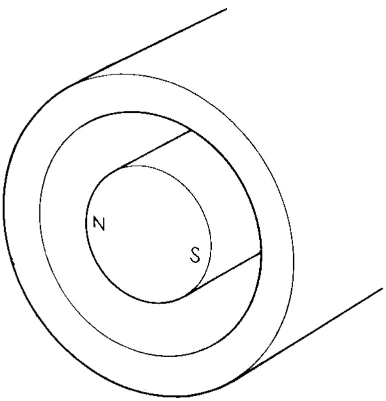




When the current flows, catapult fields will be produced and there will be forces on the coil as shown. It will rotate until the hair springs have been wound up enough to balance the forces due to the current. The greater the current, the greater the force, the more the coil moves and hence the more the pointer moves. With the poles shaped in this way, the moving coil meter has a very useful feature in that the deflection of the pointer is exactly proportional to the current in the coil: doubling the current, doubles the deflection, until the end of the scale is reached.



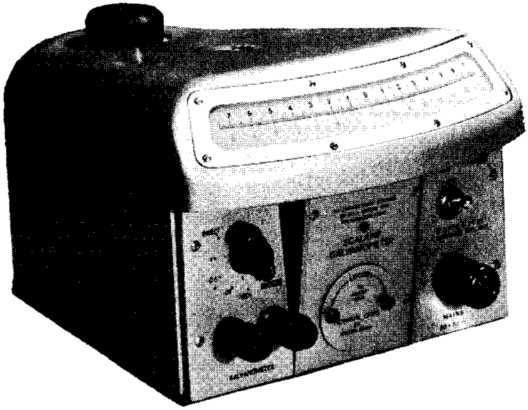
A cheaper and more convenient magnetic field for such instruments which is becoming increasingly popular is shown on the left. In this the core is a permanent magnet in the form of a cylinder, magnetised across a diameter. This is surrounded by a cylinder of iron which is such that the magnetic field in the gap is very similar to that shown on the left.



SPOT LAMP GALVANOMETERS

The most sensitive instruments use a taut suspension instead of hair springs. In these the coil is suspended vertically by a piece of very thin phosphor bronze strip at each end. These strips not only support the coil, but they also provide electrical connections to it and, furthermore, they have the restoring effect that the hair springs had in the moving coil instruments.

Scalamp galvanometer

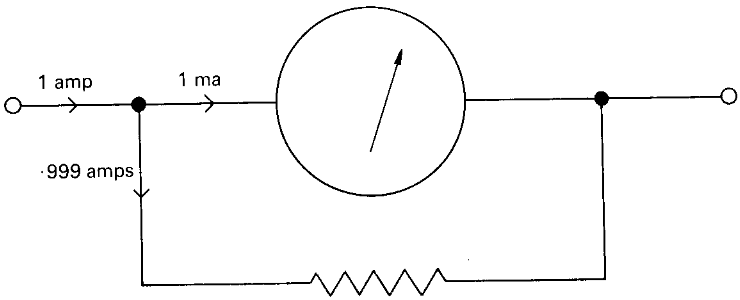


As the suspension is very weak, it is impracticable for it to support a pointer. Instead, a small mirror is fixed to the coil. A beam of light falling on the mirror is reflected on to a scale. As the coil rotates (winding up the phosphor bronze strip) the spot is deflected to a new position on the scale. Because of the distance the beam of light travels, it is equivalent to having a very long pointer.

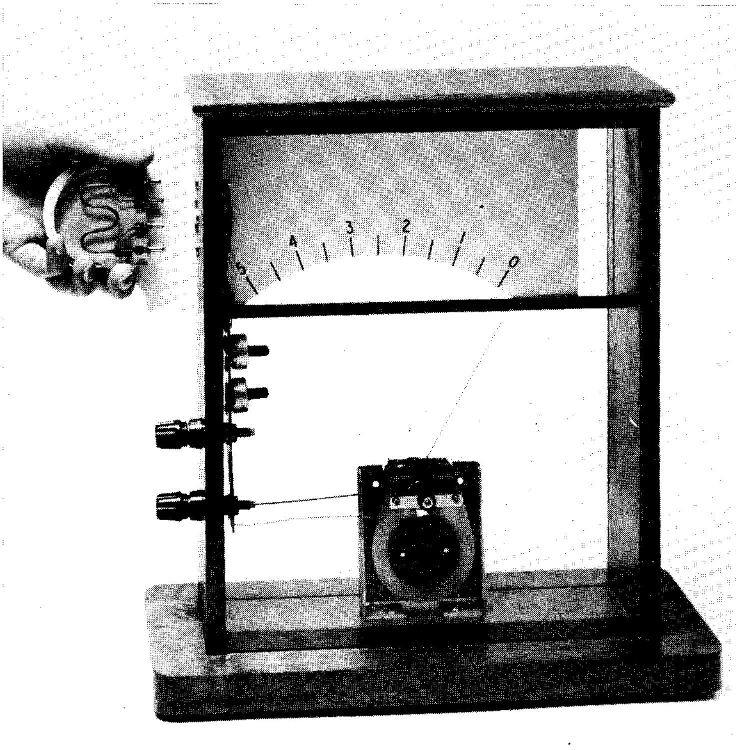
AMMETERS

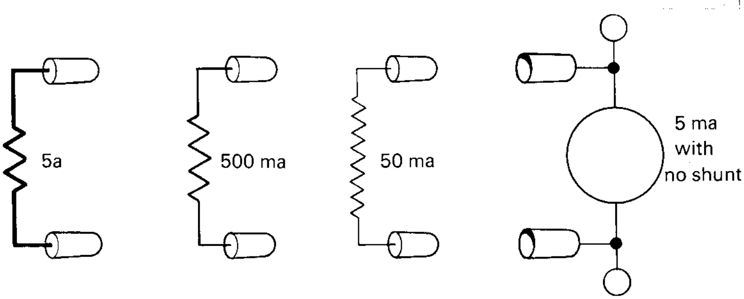
It would be uneconomic if each moving coil instrument could be used for only one current range. There are often arrangements for altering the range.

Suppose a certain instrument requires 1/1000 ampere to move the pointer right the way across the scale. It could be used to indicate currents up to an ampere if there were a way of diverting 999 parts of the current around another circuit while allowing 1 part to pass through the coil of the instrument. Such an arrangement is shown below.

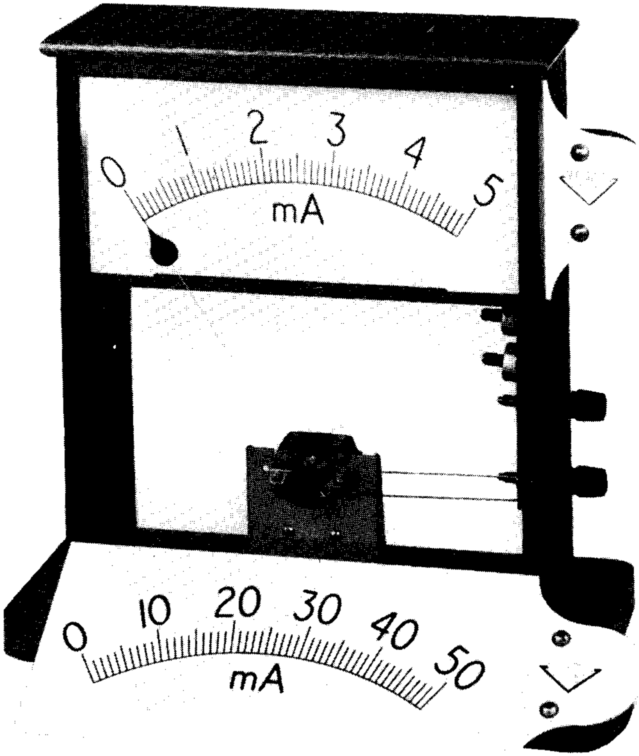


The resistance put in parallel with the moving coil meter is called a *shunt*. As one amp flows in the circuit, only a thousandth of this goes through the meter, the rest goes through the shunt. We interpret the needle position as indicating 1 amp in the main circuit, although only 1 mA is in fact passing through the moving coil. If the current drops to half an ampere, the current divides in the same ratio as before: half a milliampere passes through the meter so that it indicates half what it did before, in other words, $\frac{1}{2}$ amp.



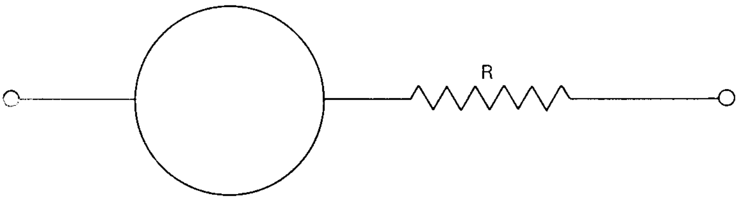


The figure on the page before shows how different shunts can be used to make an instrument which reads from zero to 5 mA, also read up to 50 mA, 500 mA, 5A and so on. The photographs below show an instrument of this type in which the whole scale is changed with the shunt, thus making it quite clear which range is in use.

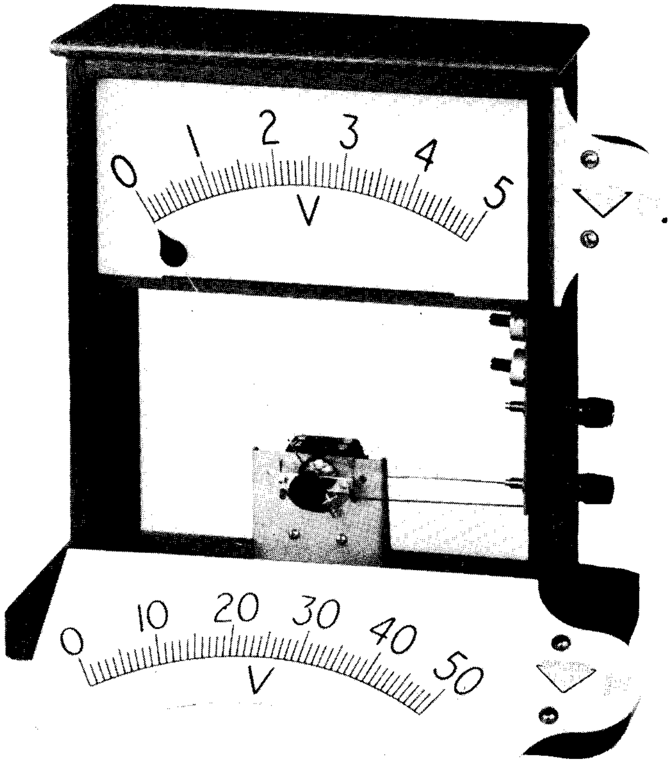


VOLTMETERS

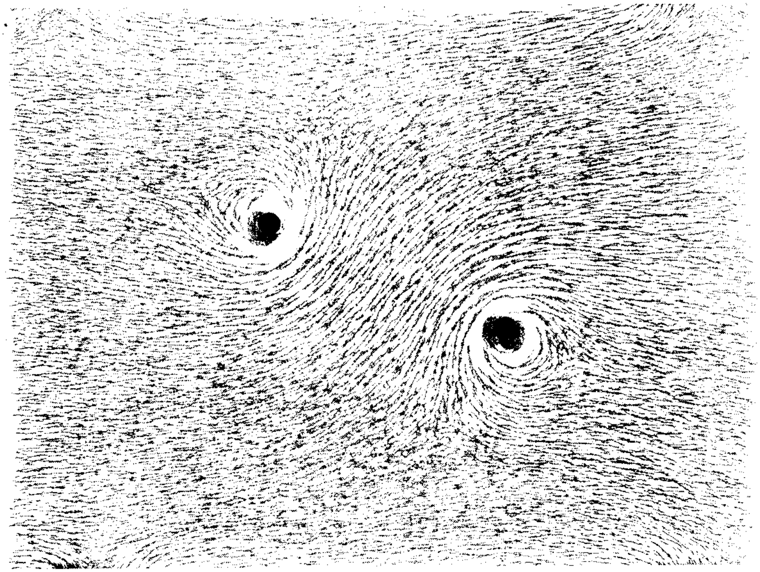
Moving coil instruments can be used to measure voltage by measuring the current which the voltage causes to flow



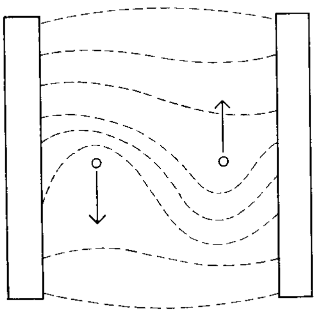
through a resistance. The greater the voltage applied to the terminals, the greater the current through the resistance R and so the greater the reading on the moving coil meter. By having appropriate resistances attached to the scales, the instruments below can indicate different voltage ranges.



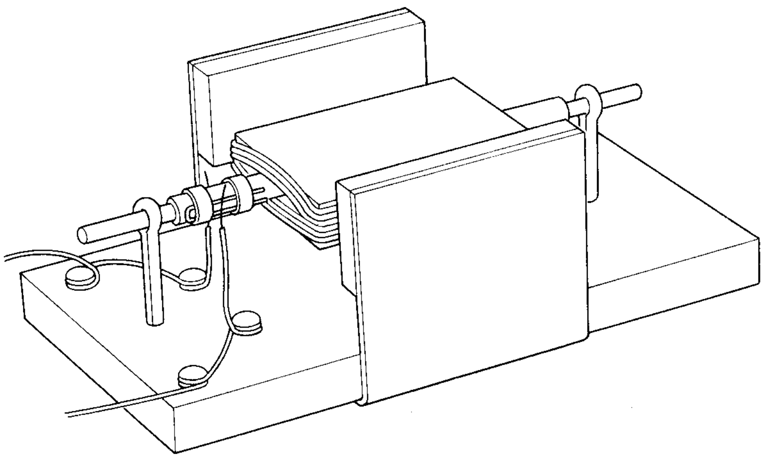
THE ELECTRIC MOTOR AND DYNAMO



This photograph is similar to that on page 21. It shows a catapult field, but the coil has now turned through 30°



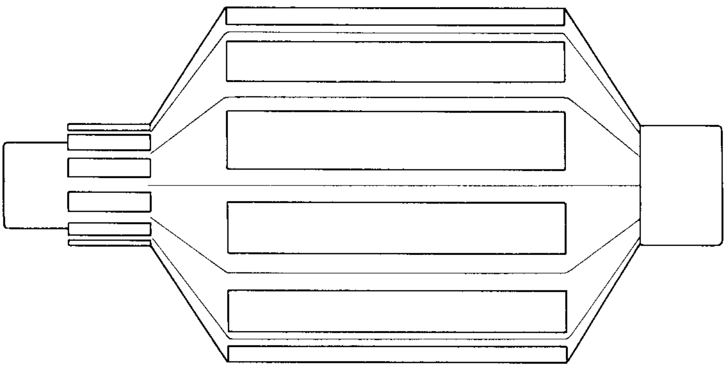
On page 21 we discussed the catapult field which is produced when a current flows through a wire in a magnetic field. This results in a turning effect on a coil carrying a current in a magnetic field. The coil can only turn through half a revolution. Such an arrangement would not make a very good motor. How can this difficulty be overcome?

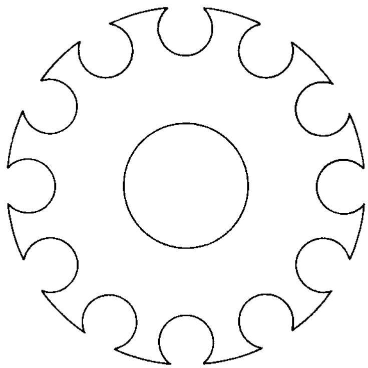


You had an arrangement in the laboratory when you reversed the direction of the current in the coil every 180° so that the forces continued to make the coil move in one direction. Such an agreement for reversing the direction of the current is called a *commutator*. The conductors which make contact with the commutator are usually called the *brushes*.

You probably found that the weakness in your motor was bad contact between the brushes and the commutator. The same problems exist in commercial motors and the brushes are usually kept in spring loaded holders in order to make good contact.

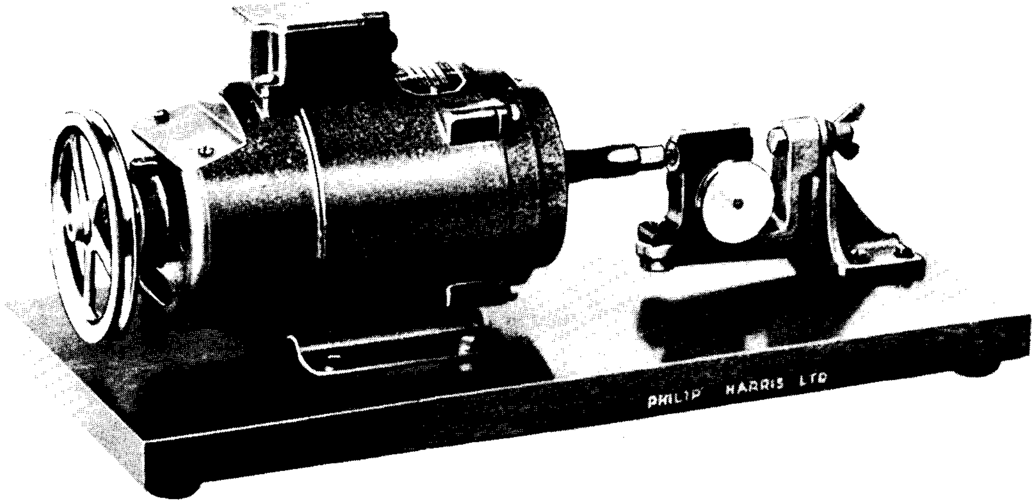
There was not much power in your motor: it could not lift a very heavy load. One reason is that there is only a force acting for the small part of the cycle during which contact is made between the brushes and the commutator and a current flows. A much steadier force would be obtained if there were a whole series of coils wound round the armature in a series of slots, each set of coils being connected with a multiple commutator at the end. The





photograph above shows spring loaded brushes in contact with such a multiple commutator.

In small motors it is possible to use permanent magnets to provide the magnetic field, but this would not be easy in large motors for which an electromagnet is usually used. You will have seen such a motor in your school laboratory, similar to the one on the next page, which is a *fractional horse power motor* providing about $\frac{1}{8}$ horse power.

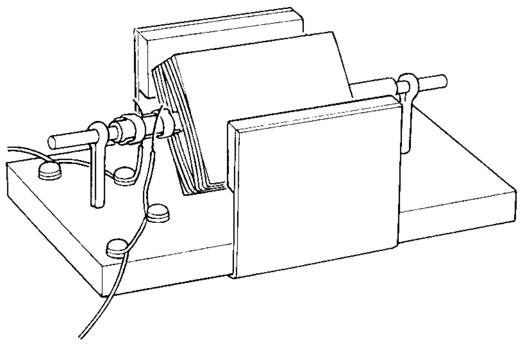


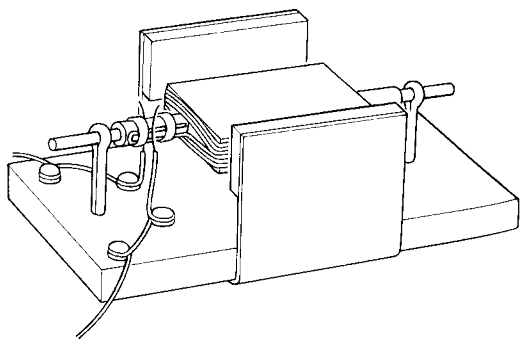
Fractional horsepower motor

In the model above, 12 volts has to be supplied to the field terminals in order to provide the magnetic field. A separate supply may be used to provide the armature current: the force exerted (and hence the speed of rotation) will increase as the current increases. The same supply can of course provide both the field current and the armature current. If the field winding and the armature are connected in series with the supply, we have a *series wound motor*; if it is in parallel to the field and armature windings, we have a *shunt wound motor*.

THE DYNAMO

Compare the two different positions of the armature in the two drawings below. In the first the magnetic field passes





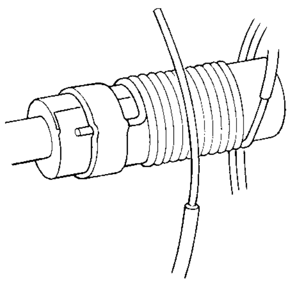
through the coil, in the second no magnetic field passes through it. The effect of turning the coil from the first position to the second is equivalent to taking a magnet out of the coil. You will remember Faraday's experiment, discussed on page 9. This leads to electromagnetic induction and a voltage is produced across the terminals.

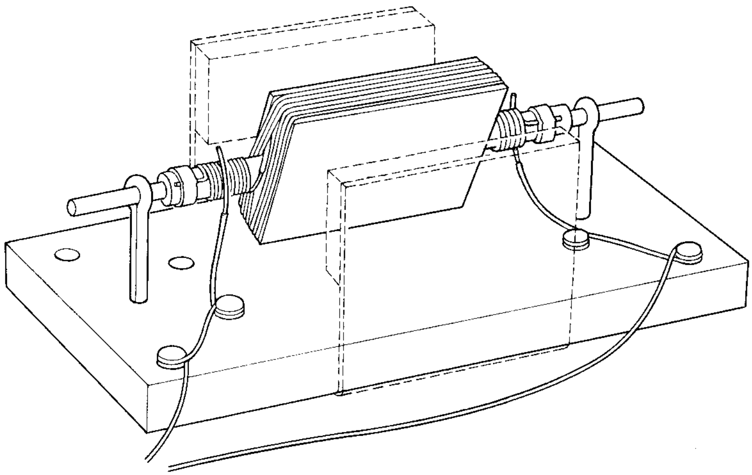
If you connect your simple motor to a galvonometer and spin it, you will observe the current flowing. You will be using your motor as a *dynamo*.

The same thing can be shown with the fractional horse power motor. First supply 12 volts to the field terminals to provide the magnetic field. Connect a meter to the armature terminals, then turn the armature by hand. A current will flow. (What would happen if you reversed the direction in which you were turning?)

A.C. GENERATOR

What would be the difference in the voltage output if there were no commutator and the coil was wound as shown below?





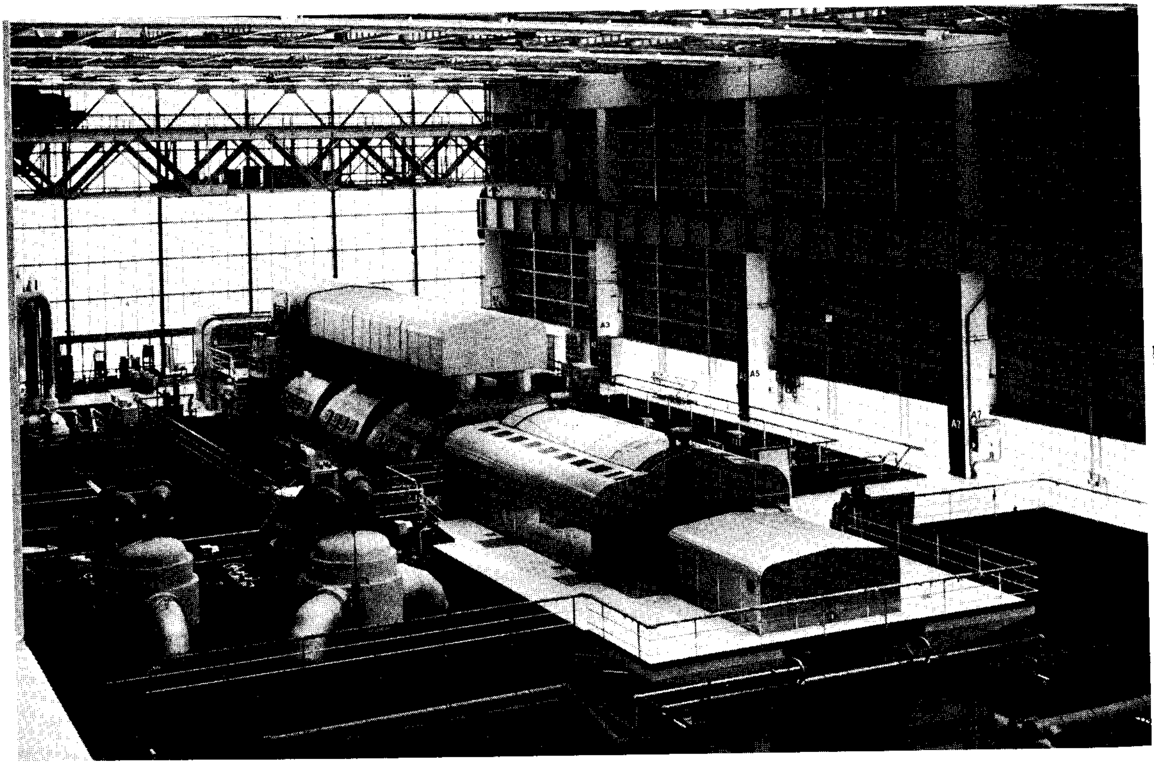
The large-scale production of electric power is usually by means of an a.c. generator, usually driven by a steam turbine, the steam being produced by burning coal, gas or oil, or from atomic power. The combination of a turbine and generator in one machine is called a *turbo-generator*.

BACK E.M.F.

The fact that a motor can be operated in reverse as a generator has important consequences which should be mentioned before concluding this section.

A motor may require, say, 5 amps to start it moving. But once it is turning in the magnetic field, electromagnetic induction begins to be effective and a *back voltage* (back e.m.f.) is produced. This reduces the current to 1 or 2 amps. Thus there is always an extra surge of current when the motor is switched on.

The turbine hall at West Burton power station showing one of the turbo-generators.

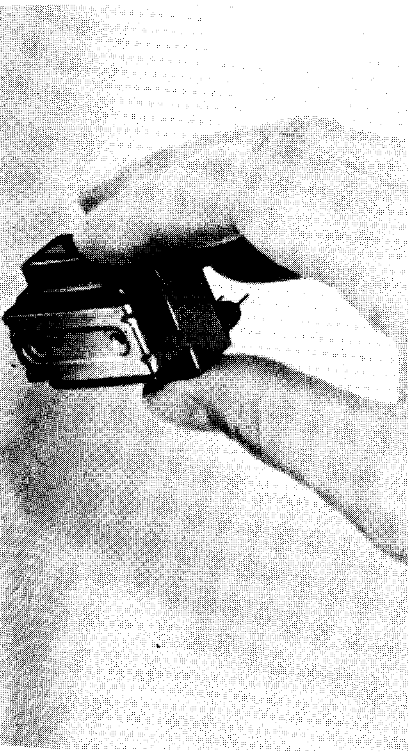


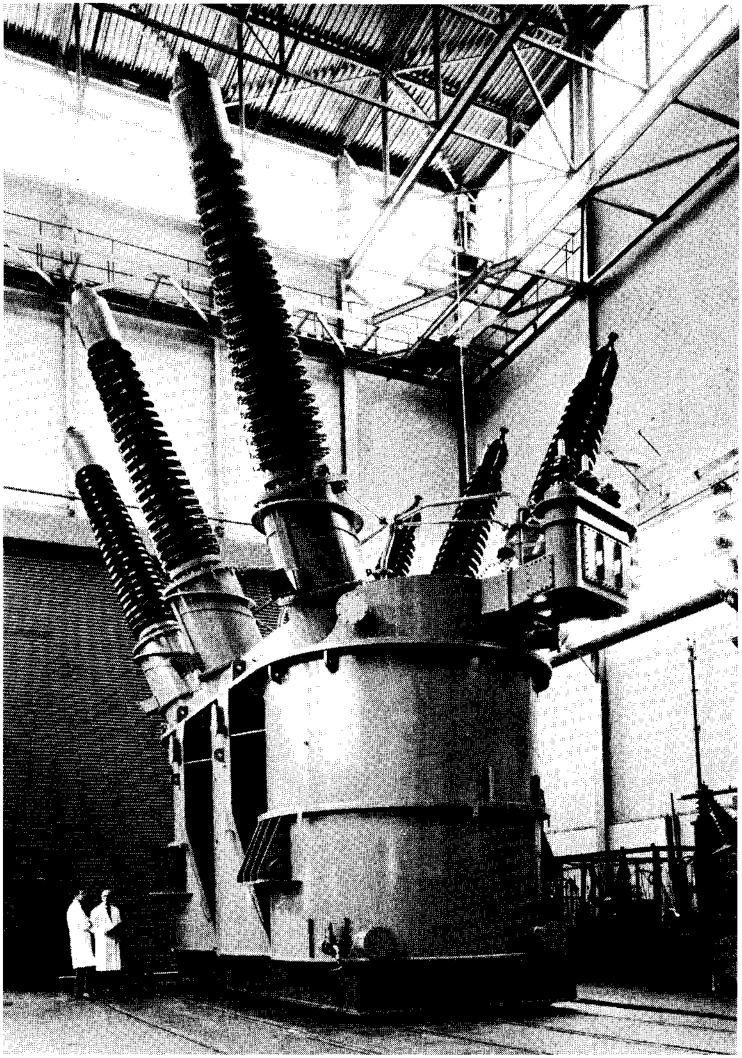
THE TRANSFORMER

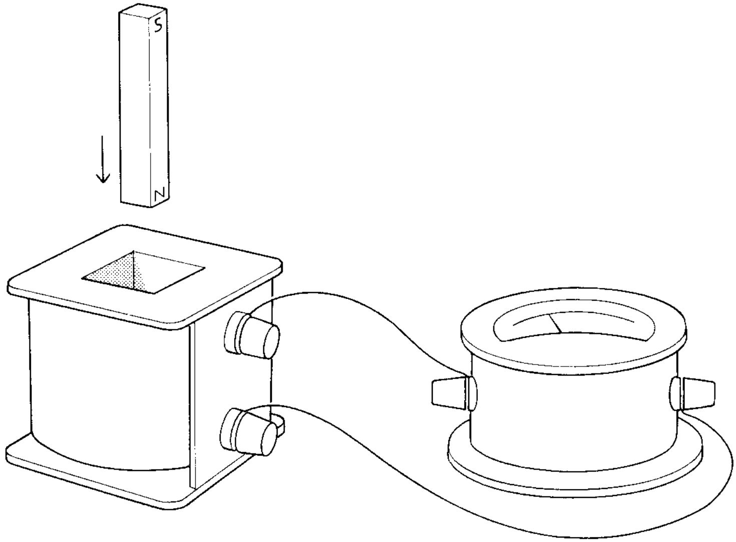
One of the most important devices based on electromagnetic induction is the transformer. Transformers vary from small ones a fraction of a cubic centimetre in size, as used in deaf aids, to large ones weighing hundreds of tons, as used in power stations.

We have already described, on page 9, Faraday's experiment when a magnet was inserted in a coil. You have doubtless seen a similar experiment in your school laboratory, in which a coil is connected to a galvanometer.

Large and small transformers

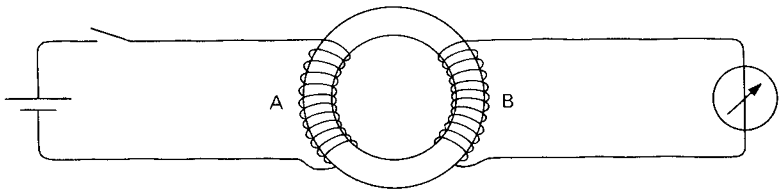






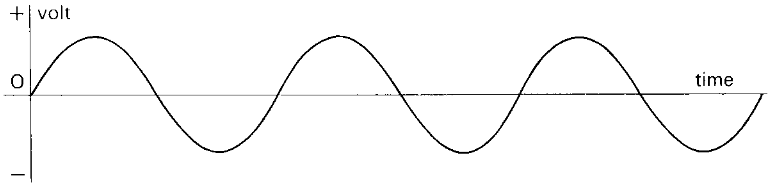
No current flows in the galvanometer. But if a magnet is put into the coil, the galvanometer needle moves. The current ceases once the magnet is inside. When the magnet is pulled out, a current flows momentarily in the opposite direction. You probably also noticed that the faster the movement, the greater the deflection.

Instead of a bar magnet, an electromagnet could be used. Faraday's experiment, described on page 8, did that. When the battery is switched on, coil A makes the iron core into a

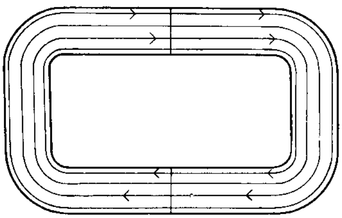


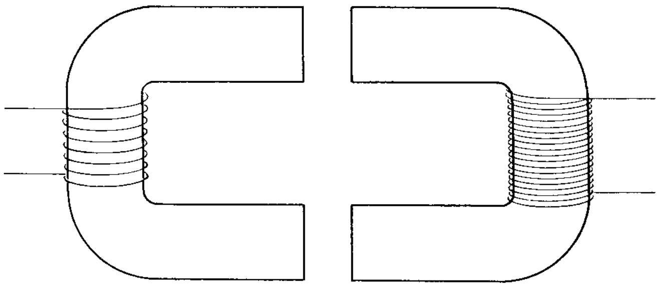
magnet: it is equivalent to putting a magnet into coil B; a burst of current flows in the second circuit. When the first circuit (the primary circuit) is switched off, it is equivalent to removing the magnet from coil B; a burst of current flows in the opposite direction. A current could be made to flow backwards and forwards in the secondary circuit by switching on or off the current in the primary.

What a business it is, switching on and off the primary circuit. How much easier it would be if one had an automatic way of doing it – and this is provided by using an alternating current. The current rises to a maximum, then falls to zero, then rises to a maximum in the reverse direction, then back to zero. The mains voltage goes through such a cycle 50 times a second.

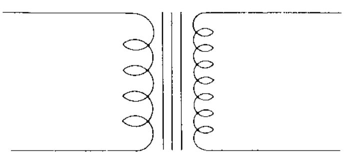


You have probably made in school a simple transformer using C cores, as shown below. The lines of magnetic flux are shown in one direction: the direction is reversed 100 times a second if it is used at the mains frequency.



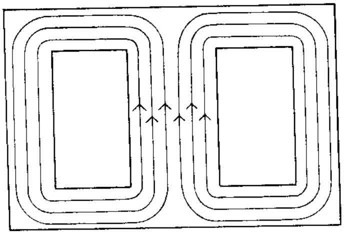


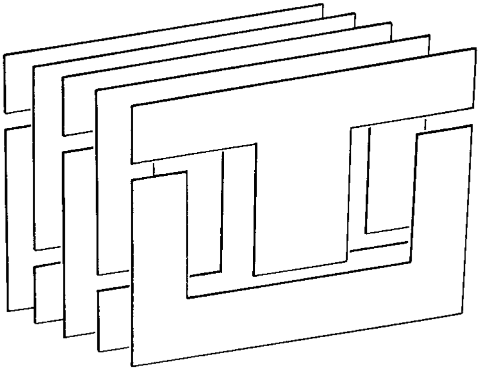
Suppose there were ten turns wound on the left-hand C-core and twenty-five turns on the right-hand C-core. If the left-hand coil is connected to a 1 volt a.c. supply, then $2\frac{1}{2}$ volts output will be produced, sufficient to light a $2\frac{1}{2}$ volt lamp which will not light at 1 volt. Such a transformer is a *step-up* transformer. The left-hand coil is called the *primary* and the right-hand one the *secondary*. A step-down transformer will have fewer turns in the secondary than in the primary, and the output voltage is then less than the input voltage.



The usual electrical symbol for a transformer is shown on the left, the primary and secondary coils and the iron core being symbolically represented.

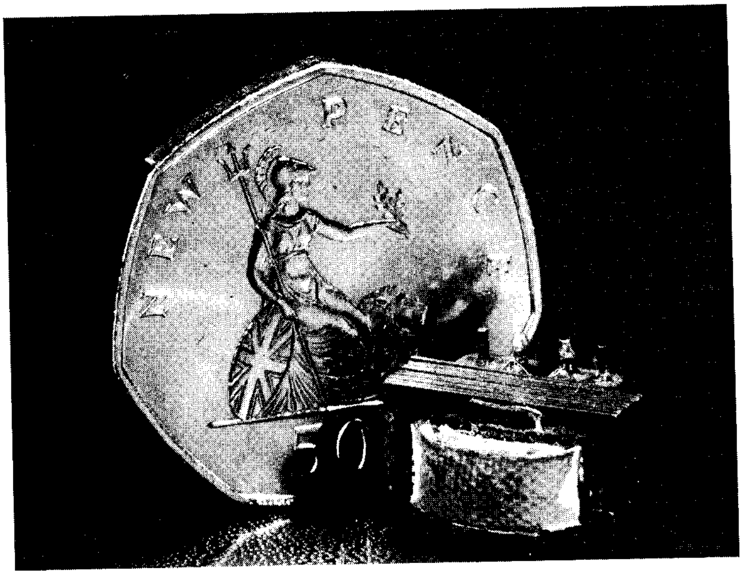
Another common form of transformer construction is shown below. A stack of iron sheets, shaped as Ts and Us is placed together as illustrated, the primary and secondary coils both being wound round the centre limb of the T.



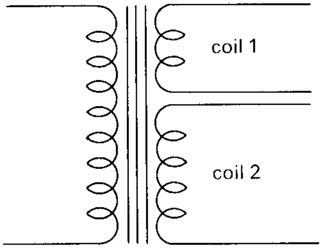


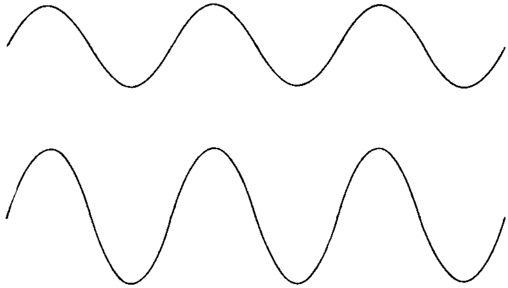
Something to think about

Why is the centre limb twice the width of the outside?

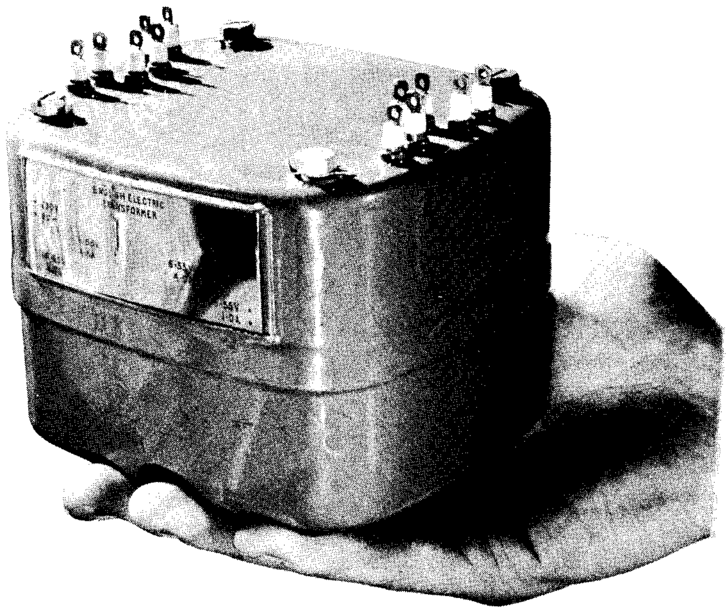


It is very often desirable to have more than one secondary. This is shown diagrammatically on the next page. Coil 2 may, for example, have twice as many turns as coil 1 and so have twice the voltage output.



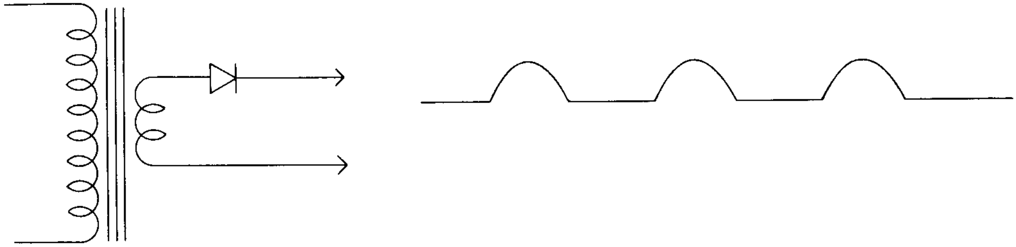


In electronic apparatus it is frequently necessary to have several different voltages available for different parts of the apparatus. These can all be obtained from a single transformer which has the appropriate number and type of secondary windings.



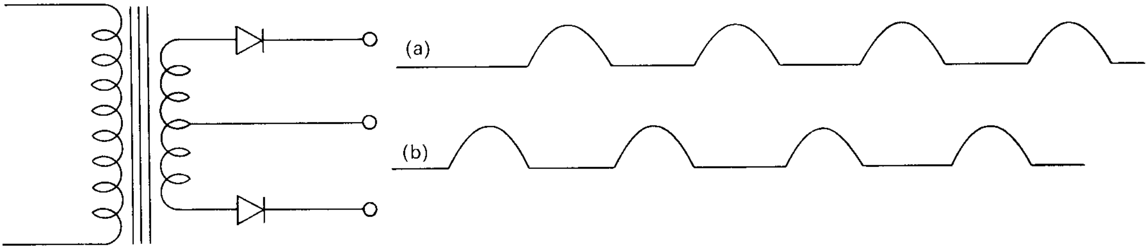
D.C. FROM A.C.

It is often necessary to produce a d.c. supply from an a.c. one. This can be done using a transformer to change the a.c. supply to the right voltage and then *rectifying* it, that is allowing it to go in one direction only.

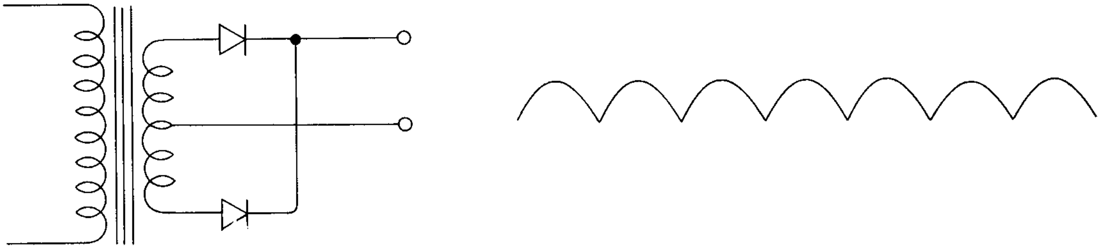


In the arrangement above the transformer steps down the voltage from 240 volts to 1 volt. The secondary coil is connected through a rectifier to the output terminals. The output voltage varies with time as shown: the negative half of the alternating voltage being cut off by the rectifier which conducts in one direction only.

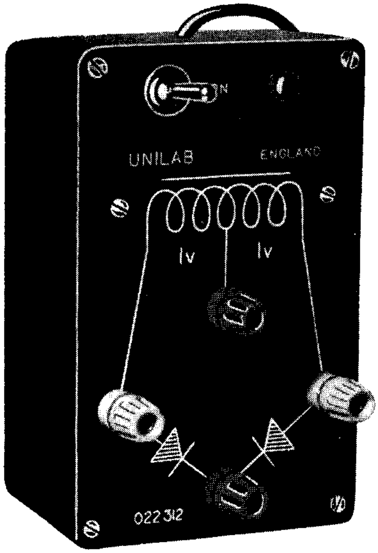
A more useful arrangement uses two secondary windings and two rectifiers. The first secondary winding gives the output (a), while the second produces the output (b).



If the two outputs are connected in parallel, the combined output is as shown below. Such an arrangement is known as *full wave rectification*.



Devices of this sort are used whenever direct current is needed and the normal a.c. mains is available. Such a voltage supply used in schools is shown on the opposite page. You may also use one for supplying a toy electric rail-

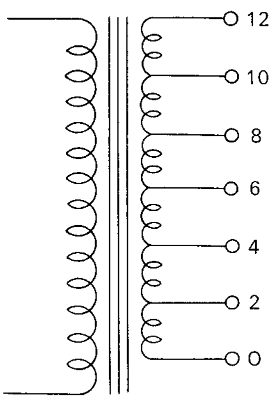


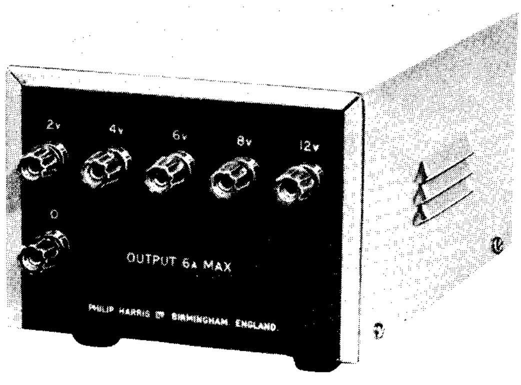
way. The combined transformer and rectifiers are sometimes wrongly described as 'a transformer': a transformer on its own can only work on a.c. and can only give out a.c.

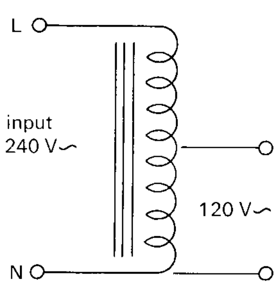
TAPPED TRANSFORMER

Another very useful type of transformer is the tapped transformer. By having connections made to various points on the secondary coil, various output voltages can be selected.

In the circuit shown below, 2, 4, 6, 8, 10, 12 volts are available at the output. (In the transformer shown below, the 10 volt tapping has been omitted. Can you see how the transformer can still provide a 10 volt output without it?)







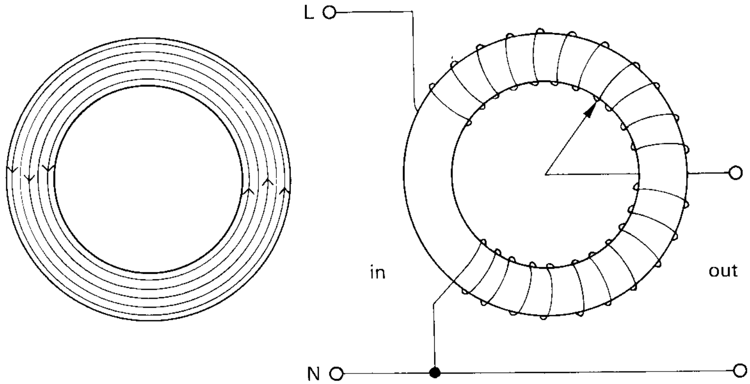
THE AUTO-TRANSFORMER

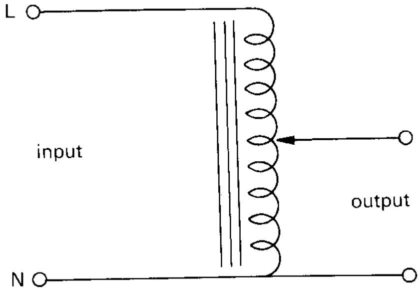
Sometimes the primary and secondary coils are combined. In the case shown on the left, a centre tap on the primary coil produces an output of half the primary input voltage. A transformer of this type is called an auto-transformer. It is very useful for running 110/120 volt foreign equipment from the 240 volt mains.

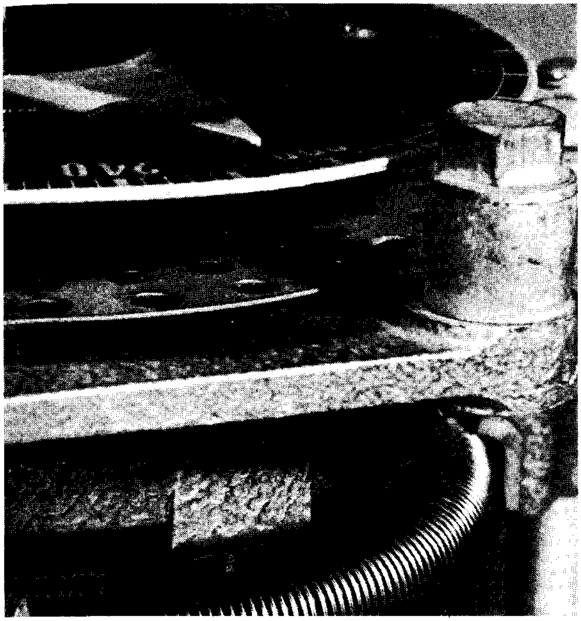
Sometimes transformers have a current marked on the case, as well as the voltage. This is the maximum current which it will safely take. The current supplied depends not on the transformer but on what is connected to it. If nothing is connected no current flows. If a small lamp is connected, only a small current flows. If several lamps are connected in parallel a correspondingly larger current flows.

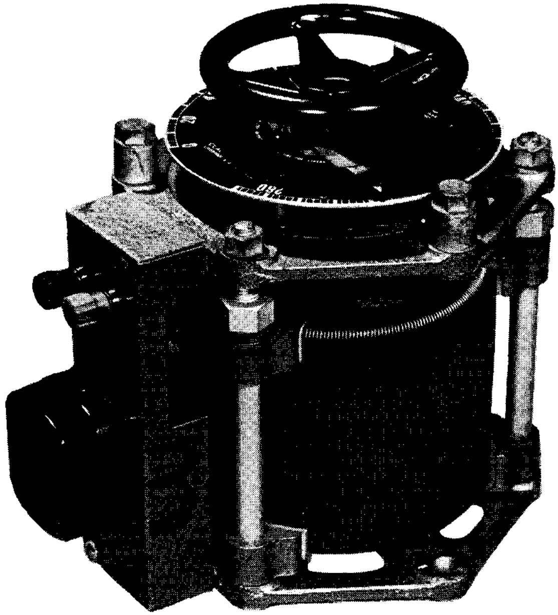
THE VARIABLE TRANSFORMER

If we combine the ideas of both the tapped transformer and the auto-transformer, we have a variable transformer.









The primary coil is wound round an iron ring: the form of winding is called a *toroid.* A brush moves round, making contact with this coil so making a variable tapping similar to that in the auto-transformer, but enabling the output voltage to be adjusted between 0 and the full mains voltage.

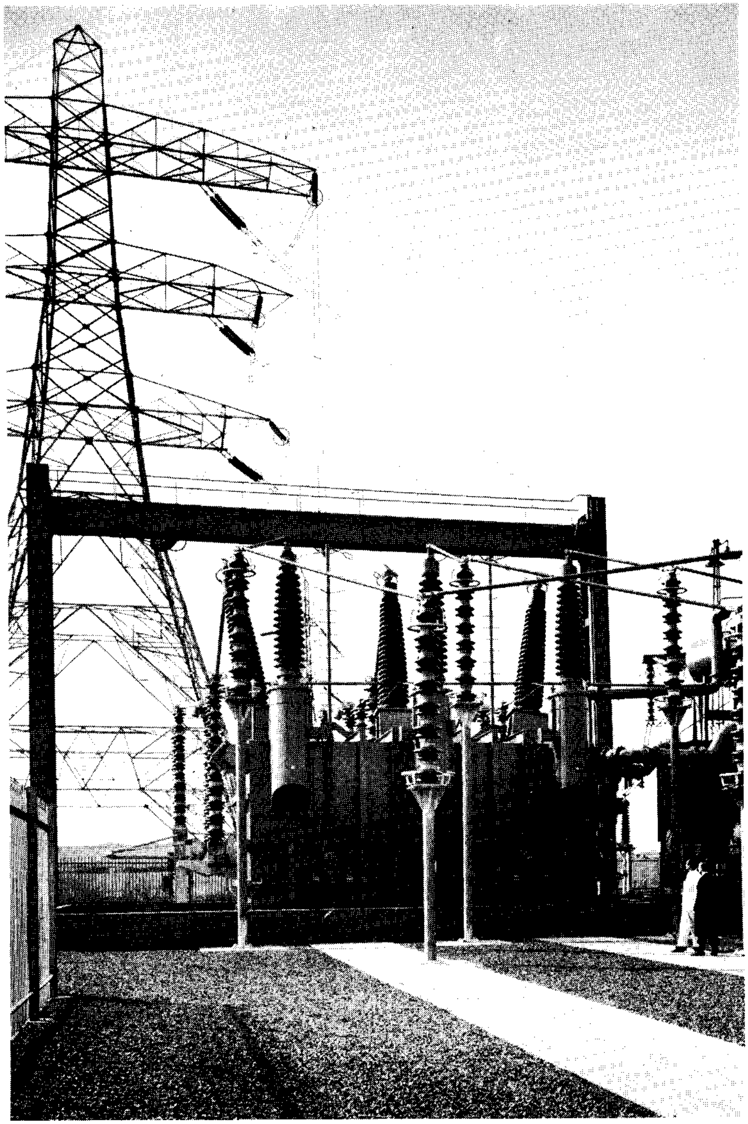
This type of transformer is very useful whenever any sort of control is required, for example in stage lighting, control of motor speed and so on. Unlike a variable resistance (a rheostat) in which heat is invariably generated and energy is wasted, the variable transformer gives efficient control with very little waste of energy.

POWER TRANSFORMERS

Finally, brief reference must be made to the power transformers, the basic principles of which are the same as those we have discussed already. Electrical power is generated at power stations, producing a.c. at 11 000 volts. It is more economic to distribute it around the country by the national grid at 132 000 volts (or the supergrid at 275 000 volts) and therefore transformers are necessary to step-up the voltage.

Step-down transformers will be necessary to bring the voltage to 33 000 volts, and then to lower voltages down to 240 volts.

There is inevitably some energy loss in a transformer and this becomes very significant in these large power transformers. They are usually oil cooled and cooling radiators in which oil circulates can be seen in one of the transformers illustrated below.



COMMUNICATION

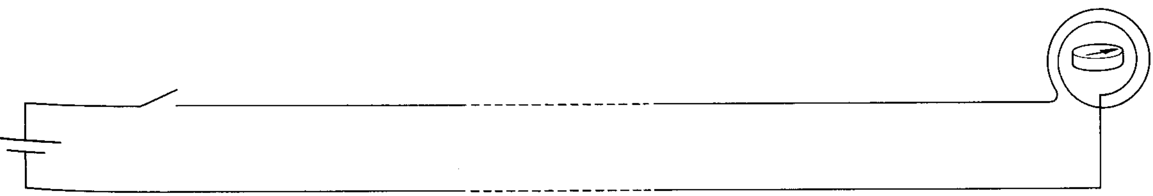
One of the most important uses of electricity is in communication. Much of our modern world depends upon electrical communications-radio, landline, submarine cable, high frequency transmitters, low frequency transmitters as well as communication via Telstar, Intelsat and other satellites.

A century or so ago, it may have taken a week to get news from Edinburgh to London. Now you can listen to the news from Australia, if you so wish, at eight o'clock in the morning, a minute fraction of a second later than when it was spoken. Even messages via a satellite which have to go 40 000 kilometres and back produce an almost imperceptible delay. Do you know how much this delay is?

This very rapid communication has probably contributed as much, if not more, to the changes in our world in the past 50 years than any other scientific development. Not only can a dictator control a whole state with the power of broadcasting, but politicians can exchange views and influence each other's decisions almost as rapidly as they can think. The *hot line* from Washington to Moscow is an example of this.

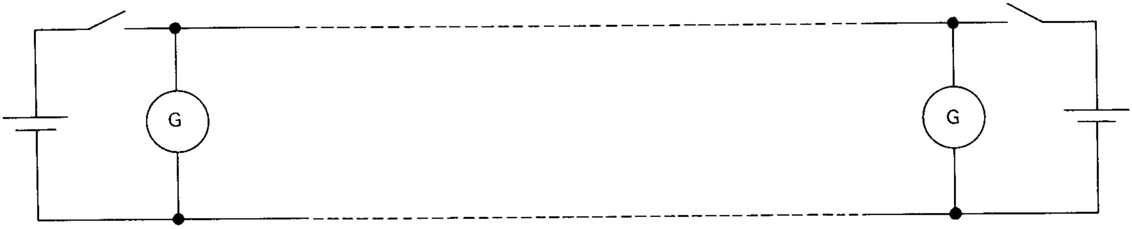
ELECTRIC SIGNALLING

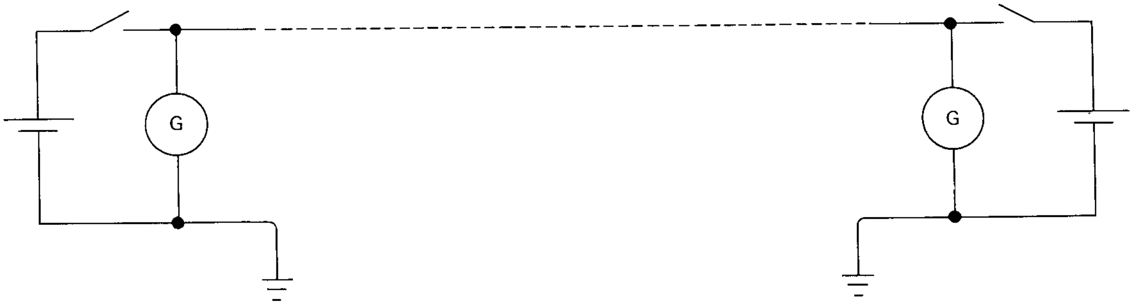
Electric signalling developed naturally once the elementary properties of electric currents were understood. If you have a source of electricity and a detector (for example, a galvanometer) separated by a length of wire, then you have the basic requirements for a signalling system.



The circuit of such an elementary system is shown above. When someone at the source switches on or off, the galvanometer at the distant point indicates this fact.

It is not difficult to make such communications two-way. The first circuit below shows how this can be done. The second circuit shows how the same thing can be done using the earth as a conductor (an earth return) so that only one wire is needed.

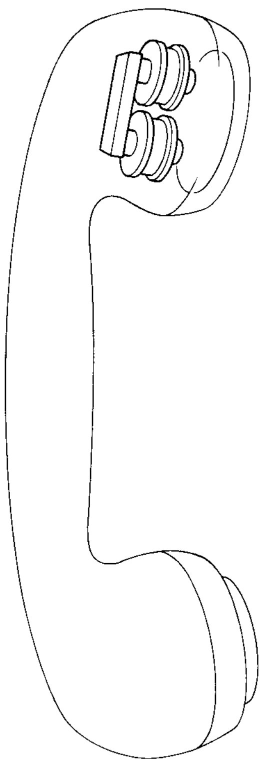




Of course the detectors at both ends in the above circuit will operate together. Can you think of a way of switching in which only the distant detector works when the switch or key at the home station is pressed? In the circuits above, the detectors were galvanometers, but they could be replaced by buzzers if the current is great enough.

You probably know how information can be transmitted over such a signalling system by means of a code. The best known is a series of dots and dashes, or longs and shorts, to represent the alphabet. Morse invented his code in such a way that the maximum information can be transmitted in the minimum of time by using the shortest combinations for the commonest letters. Thus, for example, a short push on the key followed by a long push would indicate to the observer at the distant station the letter A. A single short push the commonest letter E, or a long, single push the next commonest letter T. So what would • •– – – represent?

On-off signalling can be used to send binary numbers as well. Deep space probes on journeys to other planets return their information in this form.

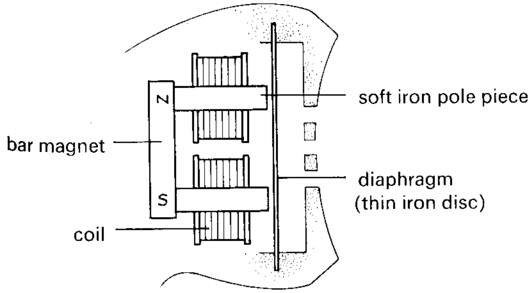


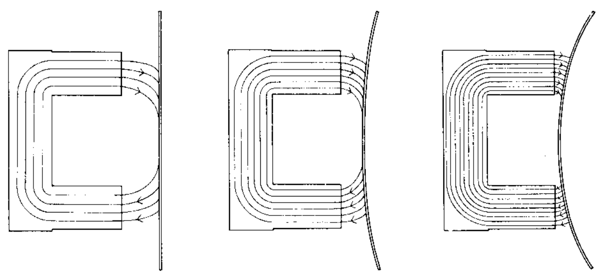
THE TELEPHONE

The most common communication system is the domestic telephone. In this, sound waves generate changes in an electric current which travel to an earpiece where they are turned back to sound waves.

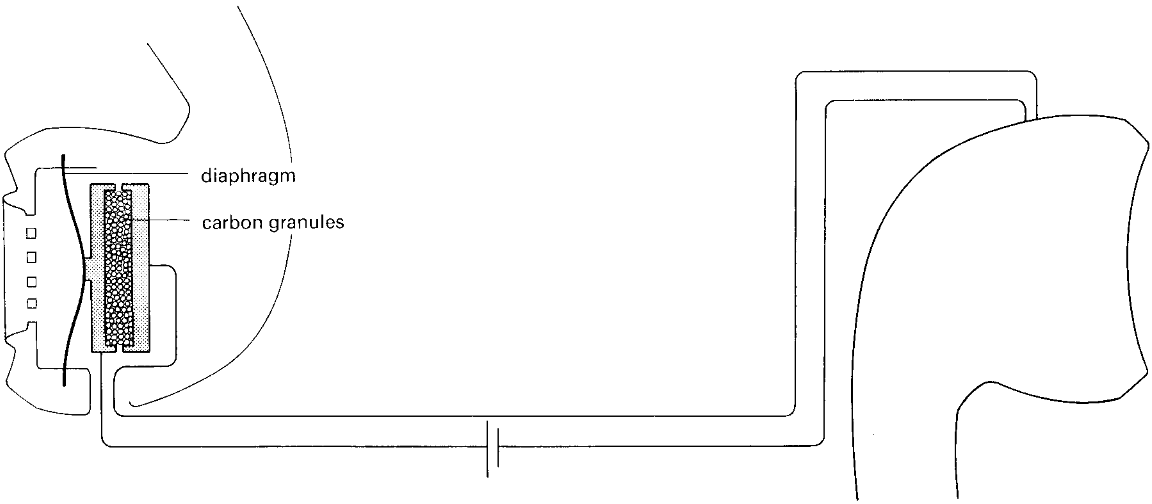
Inside the earpiece is a bar magnet with two soft iron pole pieces, around each of which is wound a coil of many turns of wire. Close to the pole piece is a thin disc of iron about 5 cm in diameter. The thin disc or diaphragm is attracted to the pole pieces by the bar magnet, but it is prevented from touching the pole pieces by being supported at the edge by the case of the instrument.

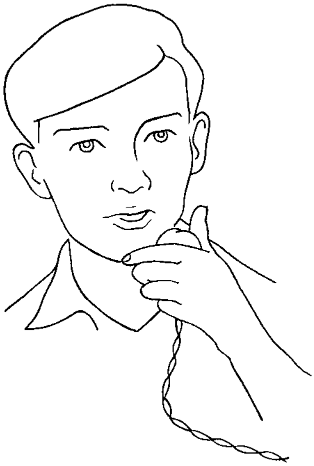
If an electric current passes through the coils on the pole pieces, something will be added to or subtracted from the magnetic field of the bar magnet according to the direction of the current. Being thin the diaphragm is flexible. Either it will be pulled in even closer to the pole pieces if the current strengthens the field, or it will not be pulled in so close if the current weakens the field. If an alternating current flows through the coils, the diaphragm will vibrate in sympathy. If the current alternates 256 times a second, so will the diaphragm vibrate and the note of middle C will issue forth from the earphone.





The most common form of mouthpiece in a telephone system is a carbon microphone. In this two small carbon discs are separated by carbon granules. If the discs are pushed together, the granules will be more tightly packed and the electrical resistance of the carbon granules goes down. If the discs come apart, the granules will be less tightly packed and the resistance goes up. One of the discs is connected to a diaphragm, so that sound waves in front of the diaphragm will cause it to vibrate and as it moves in and out will correspondingly alter the electrical resistance between the carbon discs.



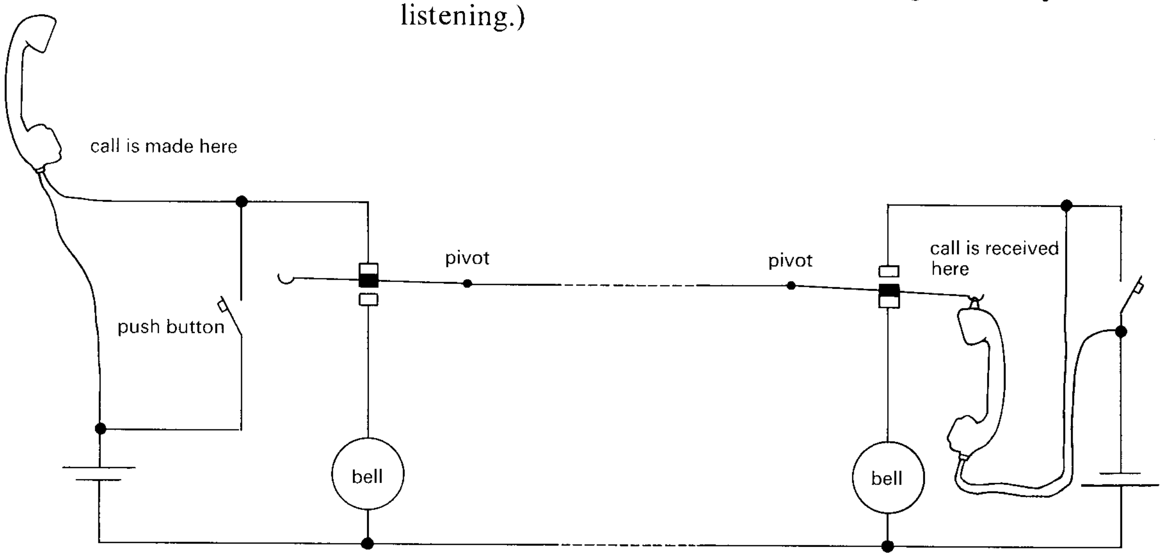


In the circuit above the battery drives the current through the carbon microphone and back through the earpiece. Sound waves hitting the diaphragm change the resistance and hence the current through the circuit. These changes in current will cause the diaphragm in the earpiece to vibrate in sympathy and so produce sound waves again similar to those hitting the mouthpiece diaphragm.

Something to do

A very simple telephone can be made from two earpieces and a long piece of twin flex, connected as shown. If a person shouts into one earphone, the sound can be heard at the other. Can you explain why this works? This system does not give very strong signals. After all, where does the energy come from?

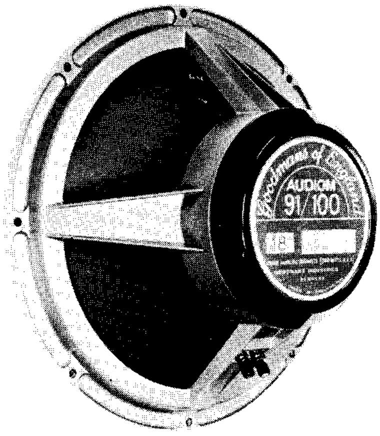
The circuit below shows a possible telephone system. Suppose at the distant end of the telephone line the caller pushes a button which connects the battery to the line. The bell will ring. On hearing the bell the person called will pick up his handset which houses both carbon microphone and earpiece. Doing this actuates the switch mechanism, disconnecting the bell and connecting the handset to the telephone line. With a similar instrument at the far end, the caller and the called can converse. (You can of course hear your own voice through the earpiece as well as the distant caller. If you are in noisy surroundings you can hear the caller better by covering your microphone with your hand to stop the noise getting in while you are listening.)

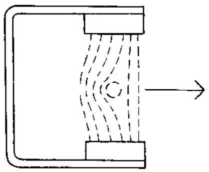


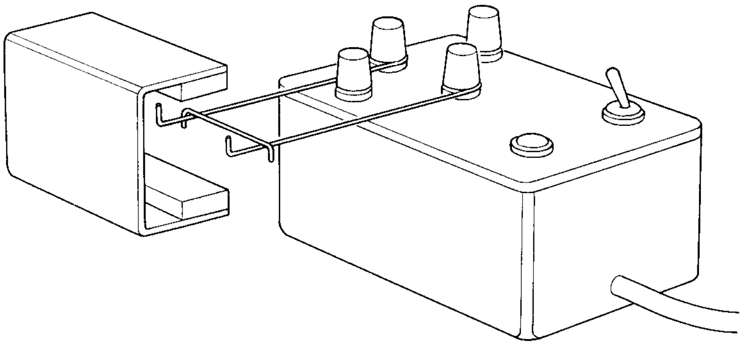
THE LOUDSPEAKER

An earphone produces very little sound. Where more is required, as for a radio or public address system, a loudspeaker is used. To understand its working, it helps to remember an experiment you will have done in your laboratory.

An 18 inch diameter speaker capable of handling 100W

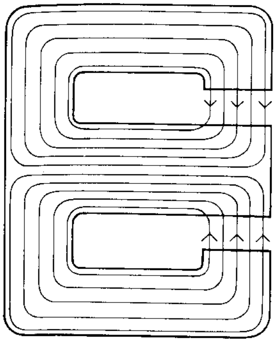


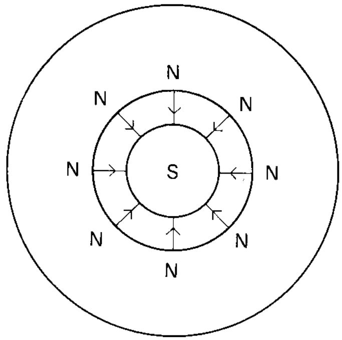


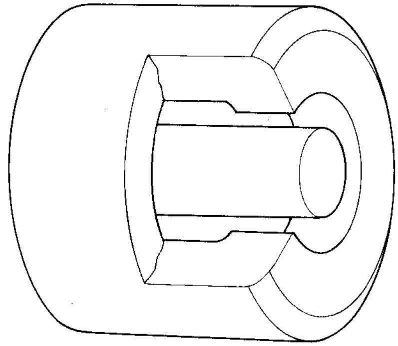


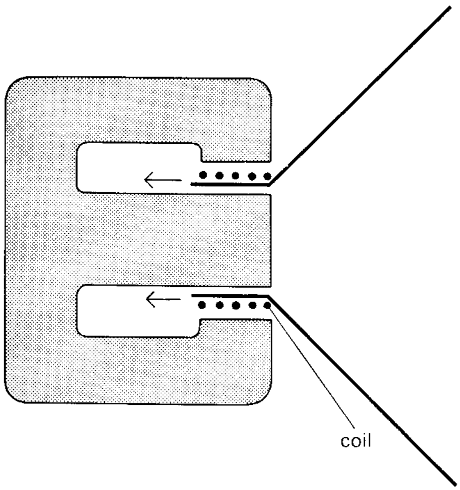
A wire was put between the poles of a magnet. When a current flowed through the wire, there was a force on the wire at right angles to both the current and the magnetic field. The wire was not attracted to the poles: it was pushed in or out depending on the direction of the current.

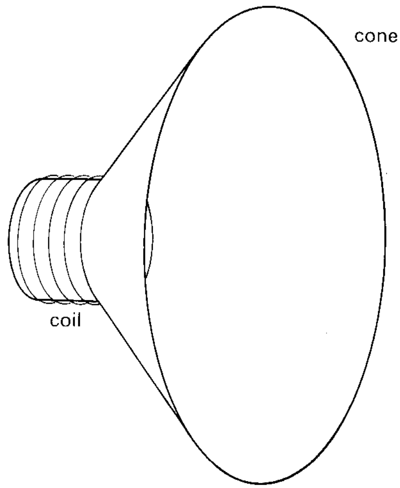
In a loudspeaker a special magnet is used as shown on the next page. This gives a north pole all the way round the outside of the south pole with a circular gap between. A coil of wire is inserted into this gap. If an electric current flows round the coil, it will be pushed in or out just as was the wire in your experiment at the top of the page.











The coil is attached to a cone several inches in diameter. An alternating current through the coil will drive the coil and cone in and out. This will set into vibration a large mass of air because of the size of the cone. Thus, if the electric current has a frequency of 256 Hz, the loudspeaker cone will vibrate 256 times per second and a middle C will be heard.

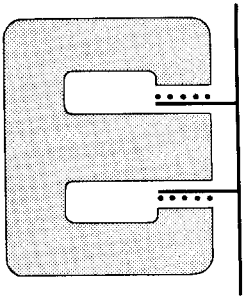
Something to do

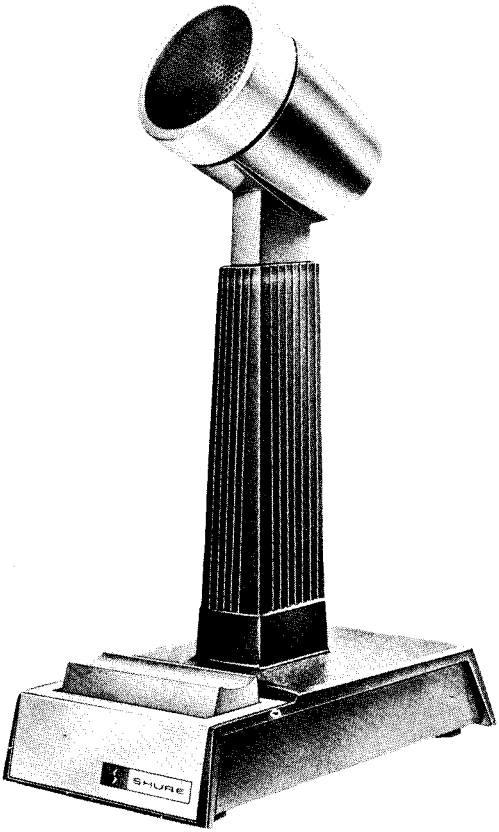
1. If you can find an old broken wireless or television set, try taking a loudspeaker to pieces to see how it is made.
2. If you can find two loudspeakers, you might try the arrangement suggested on page 46 when two earpieces were joined together by flex. Speak into one and get someone at listen to the other end.

MOVING COIL MICROPHONE

The telephone mouthpiece using carbon granules is relatively inexpensive and it is very robust. But it has the disadvantage that it leads to a certain amount of distortion. Far less distortion is obtained when a moving-coil microphone is used.

This works like the loudspeaker in reverse. The cone is replaced by a diaphragm, which vibrates when the sound reaches it. The coil, attached to the diaphragm, vibrates in the magnetic field and this induces an alternating voltage at exactly the same frequencies as the sound wave.



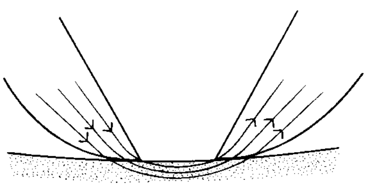


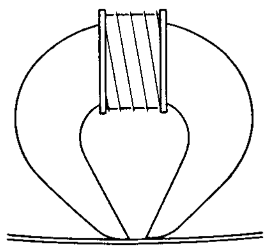
In all these devices described already the signal at the receiving end may be very weak because of the long distance it has travelled and the consequent resistance in the leads, and an amplifier is necessary.

TAPE RECORDING

A very convenient way of storing information is to use a tape recorder. Like the previous devices, this also uses the principles of electromagnetism.

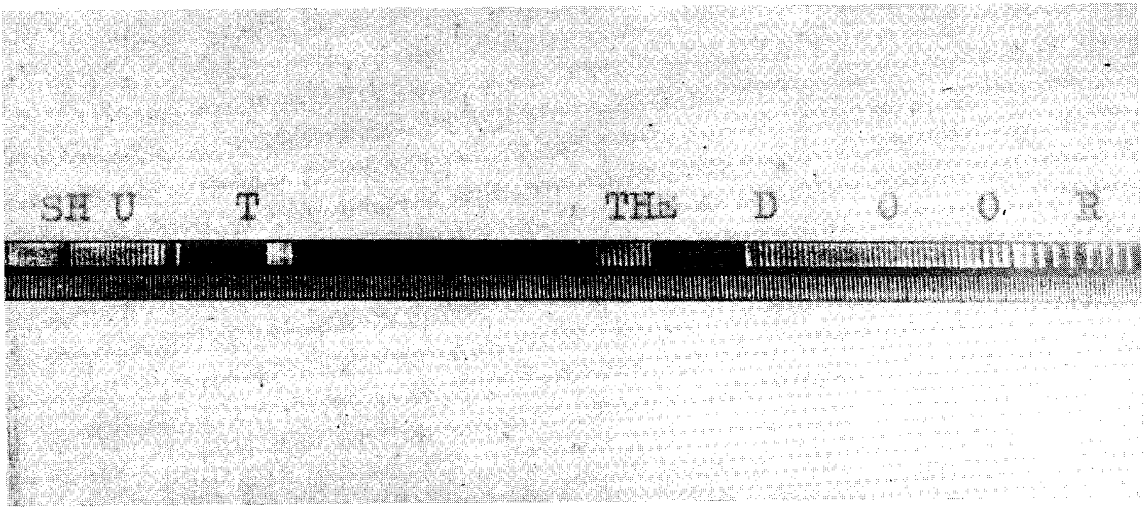
The tape is usually several hundred feet of plastic material impregnated on one side with a very fine magnetic powder. This powder can be magnetised, de-magnetised and re-magnetised like any other magnet such as a piece of steel. Illustrated below is the record/play-back head of a tape recorder passing over the impregnated tape.





Notice that there is a very small gap. A piece of the tape resting across this gap would be magnetised, one way or the other, when a current passes through the coil. Suppose the tape was moving and an alternating current is passed through the coil. Alternating pieces of the tape will be magnetised north/south, then south/north. These will be magnetised strong or weakly, close together or far apart, according to the strength of the current and the frequency of the alternations.

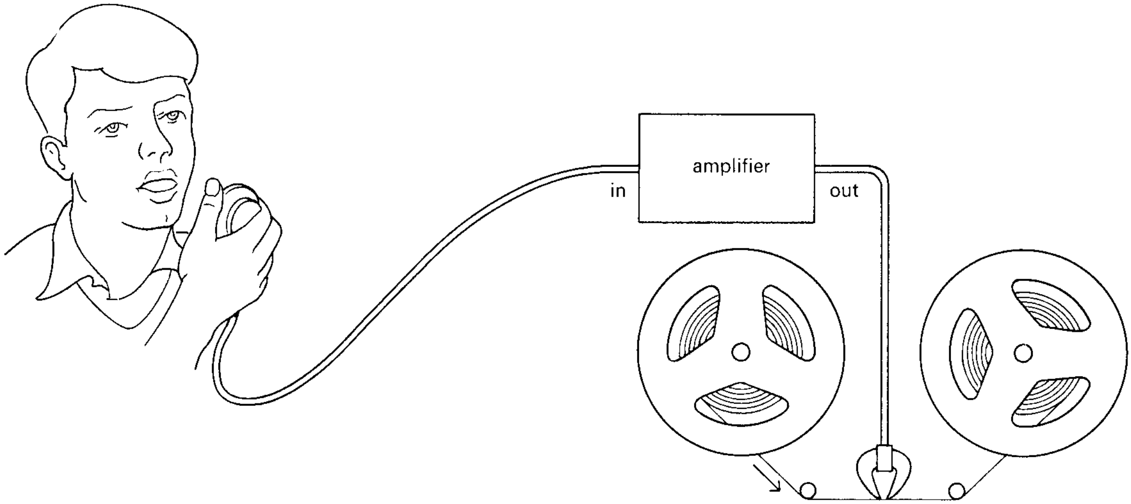
It is possible to 'develop' a tape by the use of a suspension of very fine magnetic powder in a volatile liquid. If this is poured on the tape, the powder will collect on the magnetic poles of the tape, making them 'visible'. This is like sprinkling iron filings near a magnet to study the magnetic field.



This photograph shows such a tape. On the top track the phrase 'shut the door' is seen, while on the lower track is a steady low note of 100 Hz.

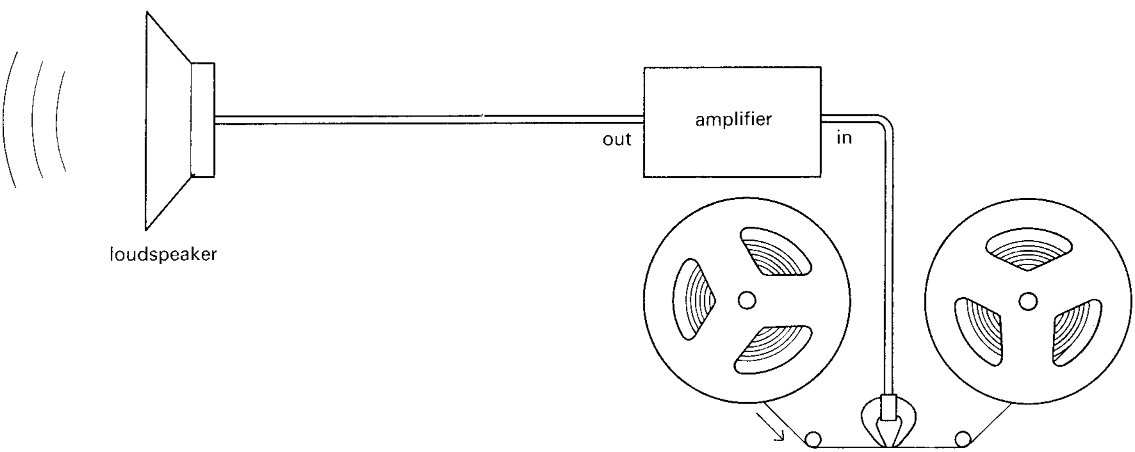
When a recording has been made on the tape, the powder remains magnetised. It can be re-magnetised by passing it again under the head with a current flowing through the coil. But if the tape is pulled under the head when no current is passing through the coil (in the playback position), it is like pulling a row of magnets across the gap. This induces a magnetic field through the iron, which in turn induces a voltage in the coil. The alternations on the tape thus lead to an alternating current.

To make a tape recording, a microphone is connected through an amplifier to the tape recorder head. The ampli-



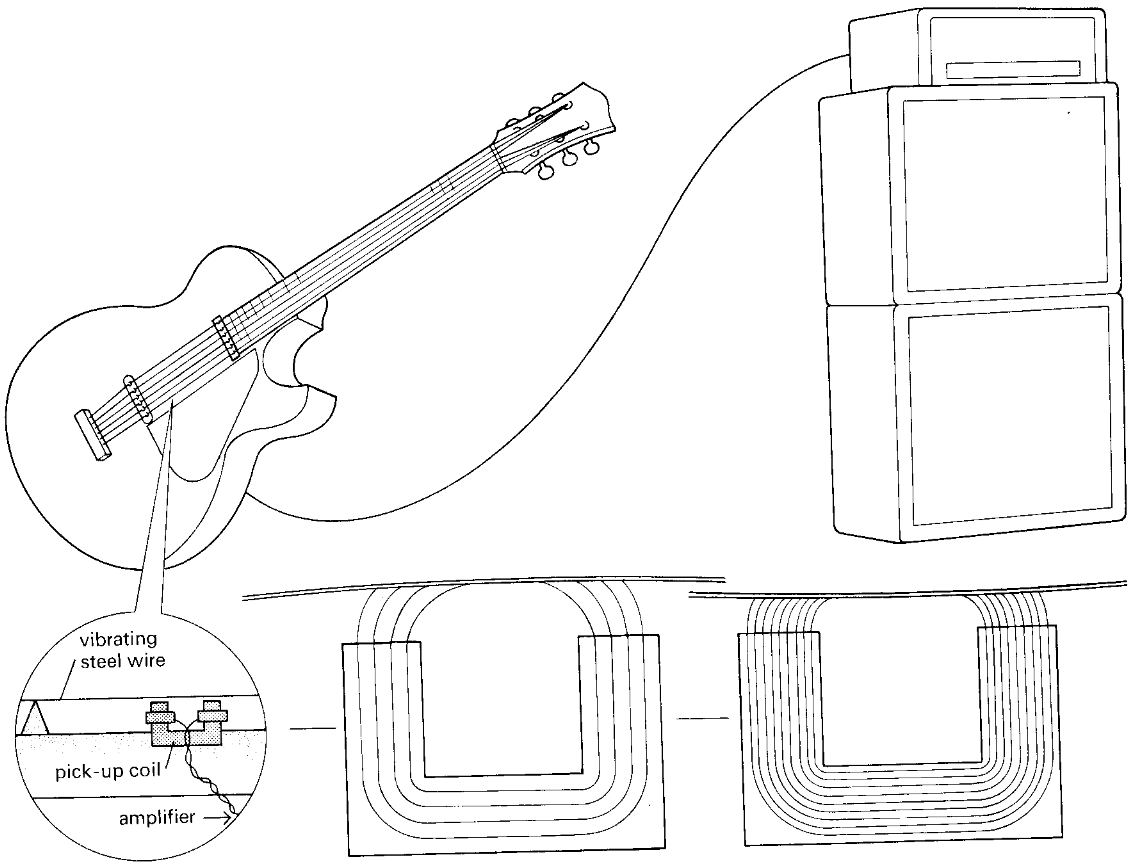
fier is necessary to increase the weak currents from the microphone to large enough currents to imprint a magnetic pattern on the tape as it goes past.

In the play-back position, the head is connected to the input of the amplifier and the outlet to a loudspeaker. The moving tape will induce currents in the head identical to those obtained when recording and the loudspeaker will emit sound waves which are faithful copies of the sound waves which fell originally on the microphone.



THE ELECTRIC GUITAR

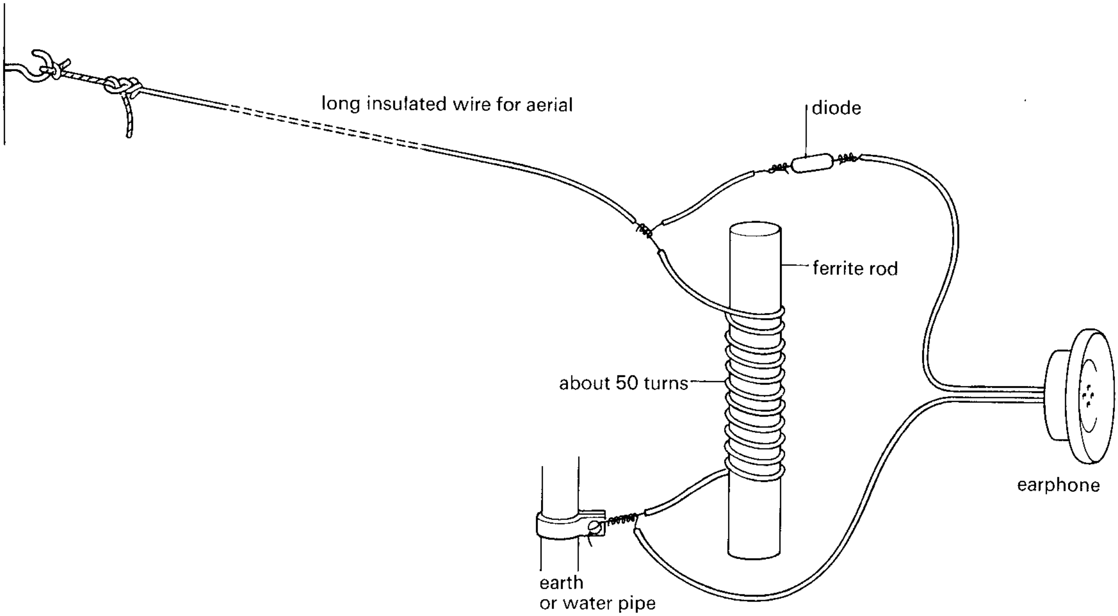
In this musical instrument the sound is produced from a local speaker instead of coming directly from a vibrating string. The strings are of steel wire; under each string is a pick-up coil connected to an amplifier. The pick-up is the same as the earpiece except that the steel wire takes the place of the diaphragm. As it vibrates it changes the magnetic field through the coil in the same way as shown in the diagram on page 45. The resulting voltage appearing across the coil has the same frequency as the vibrating string. This voltage is amplified and used to drive a large moving coil loudspeaker.



Something to do

One use of an earphone you may like to try is to receive a local broadcasting station.

A long high insulated wire, for an aerial, is attached to a tree at the bottom of the garden or a top window of a neighbour's house or perhaps just slung over the roof. The other end is wound about fifty times round a ferrite rod and connected to a convenient pipe: a cold water pipe is usually the best. The ferrite rod can be out of an old scrap transistor radio or can be purchased from a radio component shop. At the same shop you can buy a crystal diode for a shilling or two. If the diode is connected in series with the earphone across the end of the coil, you should be able to hear the local station. Indeed, you may hear several stations at the same time. By adjusting the number of turns or by sliding the ferrite rod in and out of the coil, quite loud signals can be obtained.



THE ELECTRICAL SYSTEM OF THE MOTORCAR

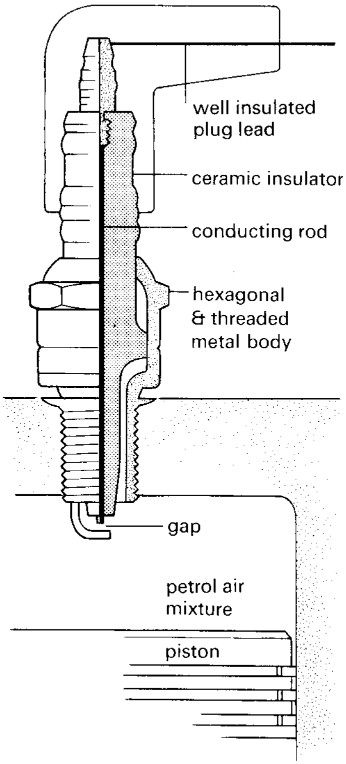
The electrical system of a motorcar is a complete, self-contained system, which will illustrate many of the principles you have already studied in your Physics lessons.

THE IGNITION SYSTEM: THE SPARKING PLUG

The most fundamental is the ignition system, which is essential for every petrol engine. A mixture of petrol and air is compressed inside the cylinder by the piston: it must then be ignited by a spark. The pressure produced by the explosion pushes down the piston, thereby producing the power stroke. The spark must occur just before the piston has reached the top of the stroke which compresses the petrol-air mixture. The ignition system must produce a spark inside the cylinder under pressure, hot enough to ignite the mixture, at exactly the right time.

Into each cylinder is screwed a *sparking plug*. As shown on the left, it consists of a ceramic material, which is a good electrical insulator and can withstand high temperatures and pressures. Through the centre of the insulator runs a conducting rod, connected to the plug lead at one end and protruding into the cylinder at the other, forming one side of the spark gap. The ceramic insulator is held in position inside a metal case which is threaded to screw into the cylinder. A metal projection from this metal case forms the other side of the spark gap.

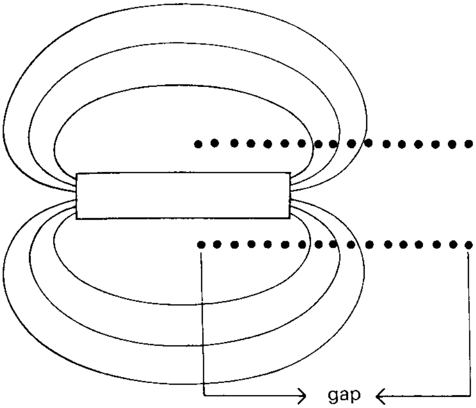
When a very high voltage is applied between the central conductor and the metal frame of the engine, an electrical spark occurs causing ignition of the mixture.

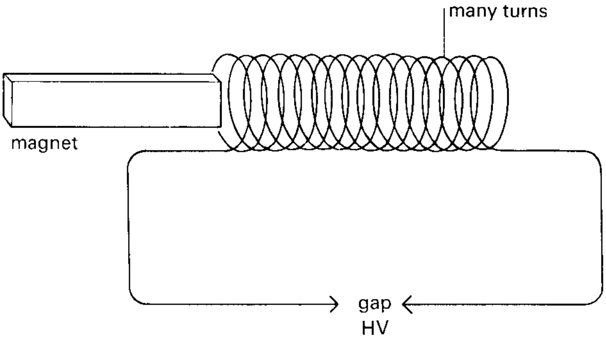


THE IGNITION SYSTEM: THE COIL

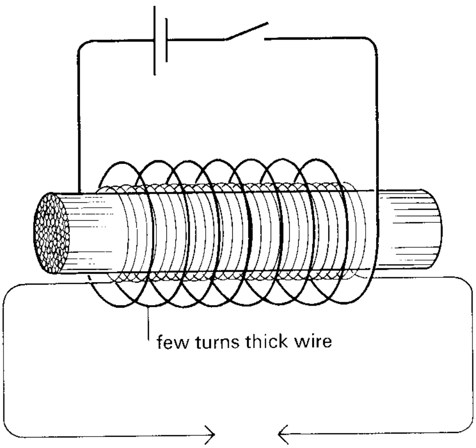
The very high voltage necessary to produce the spark, is produced by electromagnetic induction in an induction coil, or, as it is more usually called, *the coil*.

If a magnet is pulled from within a coil, a voltage will appear across the ends of the coil. If the magnet is removed very, very quickly and if the coil has many turns,





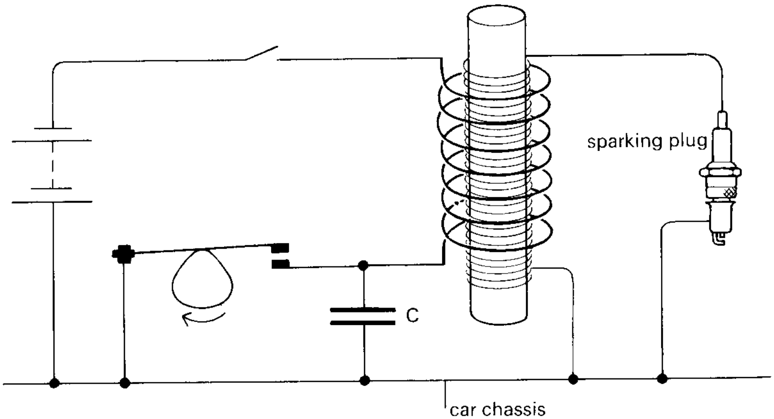
the voltage might be high enough to make a spark jump a gap of a millimetre or so. In practice, it is easier to obtain the effect of removing the magnet quickly by electrical means.



In the figure above, a bundle of soft iron wire has been substituted for the magnet. This core, as it is called, can be magnetised from outside by switching on a current in an outer coil. If the switch is opened, this magnetism disappears suddenly: the effect is the same as withdrawing the magnet very quickly. In practice, it is easier to produce this sudden change by switching off the current than by switching it on. (The current always takes a little time to build up to its full value. The effect is that of putting the magnet in slowly.)

Motorcar ignition coil

The complete unit consists of the soft iron wire core, the primary coil of few turns and the secondary coil of many turns of fine wire, all contained in a metal can as illustrated. The whole unit is usually called *the coil.*



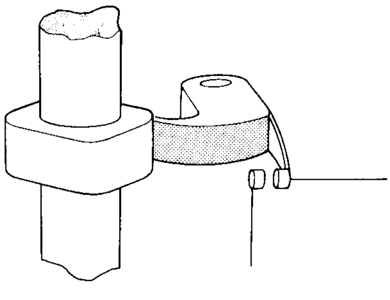
THE ELECTRICAL SYSTEM OF THE MOTORCAR

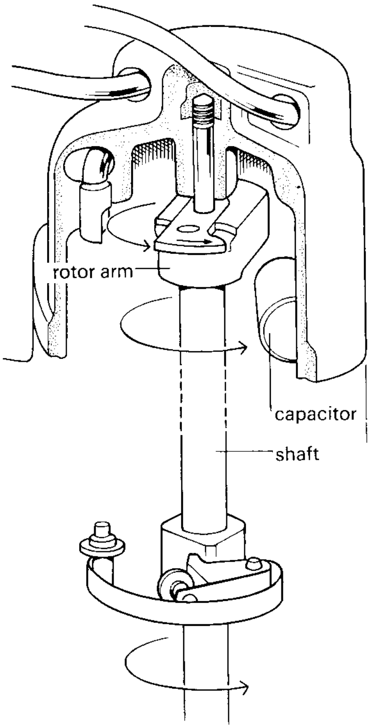
The electrical circuit is shown below, opposite. The battery is connected through the ignition switch to the primary coil, the other end of which is returned through the contact breaker and the frame of the motor car to the other end of the battery. The secondary coil has one end connected to the chassis and the other end to the centre lead of the sparking plug. Thus we see that there are two separate circuits involved, both of which use the metal body of the car for what is often called an *earth return circuit.*

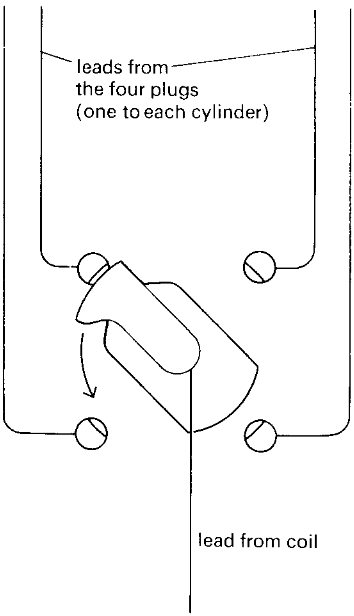
In the circuit shown, two parallel lines are marked C. The lines are a symbol for a capacitor, which you will not yet have met in your school work, but which is very important both in electronics and also here where it helps to make the spark big enough to do its job.

When the contact breaker opens in order to interrupt the current in the primary circuit, there might be sparking across the contact breaker; in other words the current is not stopped as quickly as we should like. The effect of the capacitor is to absorb the energy which might otherwise cause sparking at the contact breaker. With the capacitor connected, the current in the primary coil drops much more suddenly when the contact breaker opens than it would do without it. (Incidentally, by reducing the sparking at the contact breaker, the life of the contact is prolonged.)

The contact breaker shown in the circuit diagram is a switch driven by an (eccentric) cam from the engine. The lift of the cam which opens the contacts is arranged to coincide with the moment at which the spark is needed. The drawing below shows a cam and contact breaker for a 4-cylinder engine: there will be four sparks for one turn of the cam.







THE IGNITION SYSTEM – THE DISTRIBUTOR

With more than one cylinder, a *distributor* is needed which directs the high voltage lead from the coil to the sparking plugs in each of the four cylinders in the correct firing order.

On the same shaft as the cam is a *rotor arm*, a little, well-insulated arm on top of which is a small metal plate. Over the rotor arm is clipped the *distributor cap.* The lead from the coil enters the centre of the cap and connects to the rotor arm via a small carbon brush. From the cap go four leads, one to each sparking plug. Each lead is connected in the cap to a small metal terminal so arranged that the outer end of the rotor arm passes close to it as the spark occurs. In fact we have two sparks, one little spark jumping from the rotor arm to the appropriate lead to the plug and the main spark in the gap of the sparking plug.

INSULATION

As the voltage produced by a coil can be very high – 10 000 – 20 000 volts being typical – you can get an unpleasant shock if you touch the plug connection while the engine is running. It is even possible to feel a shock sometimes when holding the insulation of the plug lead. The shock, as you will understand, lasts a very short time and so usually has no serious consequences. However, this very high voltage calls for special treatment if the engine is to be reliable and very special care must be taken to insulate all the high tension components.

The secondary coil is separated from the primary coil and from the outer case so that the spark does not jump inside. The secondary coil is usually wound in sections for the same reason, each section being well insulated from the next. The high tension lead comes out of a very well insulated terminal at the end of the coil. Some sports cars and racing cars use an oil filling to the coil to improve insulation. The lead from the coil to the distributor cap is covered with very thick insulation and the same type of high tension cable is used for the four plug leads. The distributor cap is also made of a high quality insulating material, as is the rotor arm.

Failure of the insulation anywhere can lead to engine trouble. If there is a weak point such as a crack in the rubber covering of the wire where it runs near some metal part of the engine, a spark will jump there. Once this happens, the rubber is heated so that it is locally decomposed leaving a carbon deposit. This conducts away the current from the sparking plug. Another cause of trouble is condensation on the ceramic plug insulation, again leaking away the high tension current to the chassis directly, instead of across the spark gap. This situation is particularly likely to occur if the car has been left out during a cold spell and a warm, damp day follows.

THE BATTERY

The battery consists of a number of secondary cells, that is cells which can be recharged when they run down. Undoubtedly, the most important function it has to play is that of starting the engine: it has to provide a very large current to the starter motor, although this current is normally required only for a very short time in a properly maintained car.

A current of 50 to 100 amperes may flow through the battery and the starter when the starter button is pushed. This requires very heavy wiring and furthermore these wires have to be kept as short as possible to keep their resistance to a minimum. One main wire goes straight from the battery to the motor through a switch, the other lead goes from the battery to the frame of the car. The chassis or frame completes the circuit between the starter motor and the battery.

Since the wiring must be short, the switch which controls the starter motor is mounted on the motor itself and is controlled by a relay operated from the dashboard, as discussed on page 16.

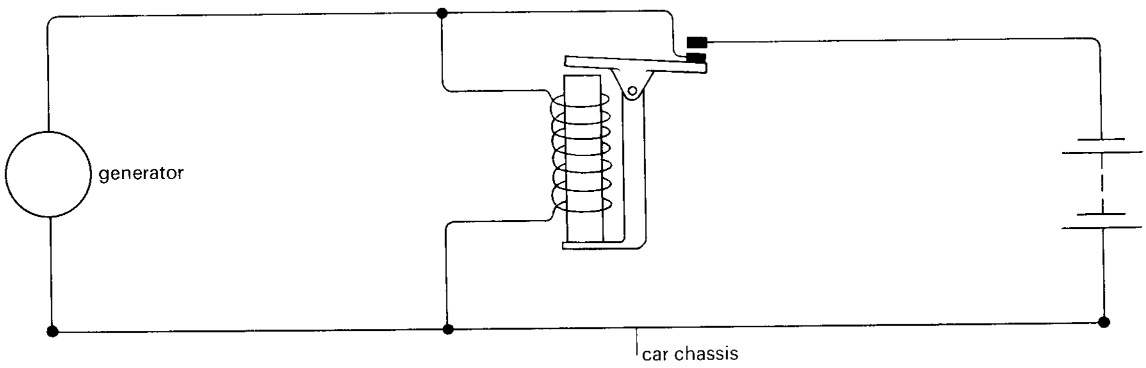
THE GENERATOR

Once the engine is started, it turns the generator (the dynamo) which provides all the current needed when the car is running and it also recharges the battery.

Between the generator and the battery is a control box containing the *cut-out*. The cut-out disconnects the generator from the battery when the engine is running slowly or is stopped. Otherwise the battery would drive the current back through the generator causing it to 'motor', trying to turn the engine. Only when the generator is producing an output voltage equal to or higher than the battery voltage should it be connected to the battery and so charge it.

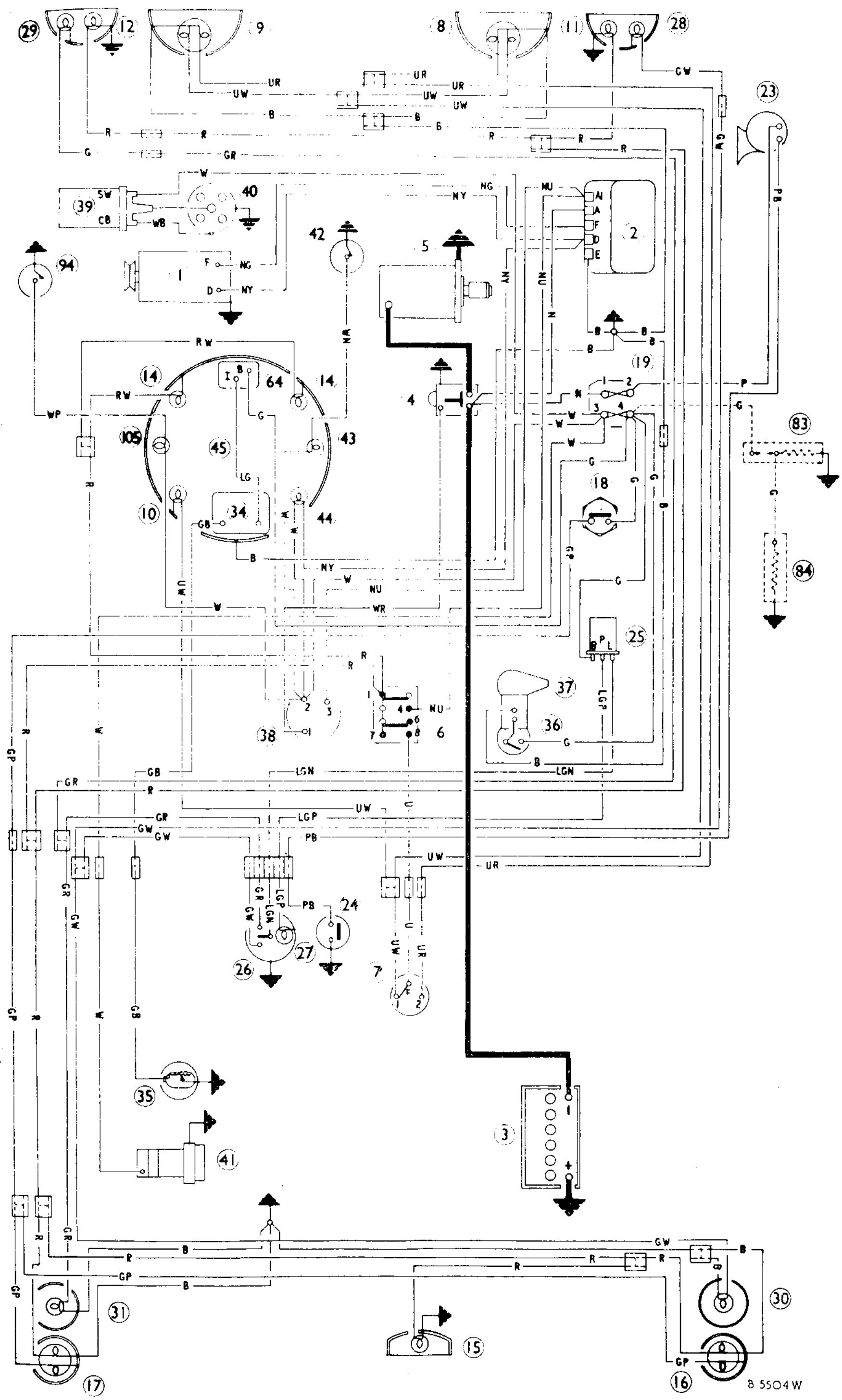
The cut-out is a simple magnetically-operated switch. As the generator output increases with the engine speed, more and more current passes through the solenoid. When it reaches sufficient value, the moving iron armature is attracted to the end of the electromagnet and in doing so closes the switch. By adjusting the gap between the contacts, the cut-out can be made to close at the right voltage.

In practice this device is more complex, and is associated with a voltage regulator. This alters the charging rate according to the state of the battery.



OTHER ELECTRICAL FEATURES

There are many electrical features in a motorcar, some essential, some luxury items and some just gadgets. The wiring, although extensive, is very simple, just like the



Wiring Diagram of B.M.C. Mini Moke

KEY TO WIRING DIAGRAM

No. Description

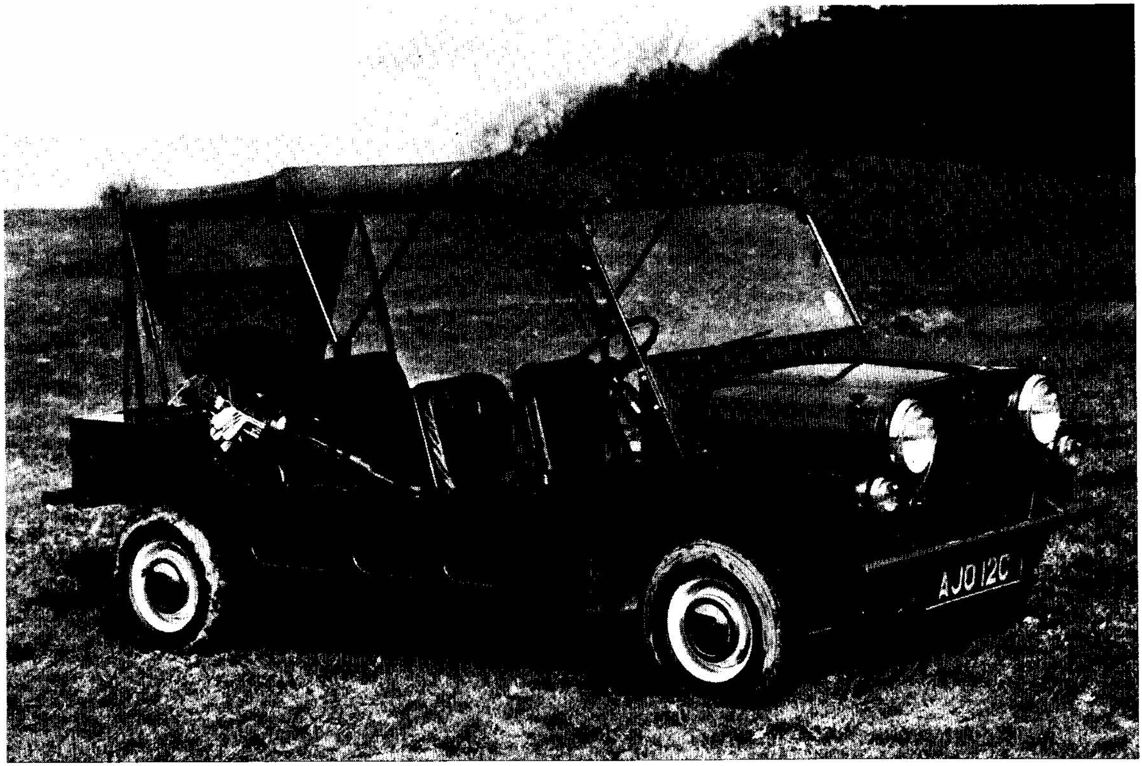
1. Dynamo
2. Control box.
3. 12-volt battery.
4. Starter solenoid.
5. Starter motor.
6. Lighting switch.
7. Headlamp dip switch.
8. R.H. headlamp.
9. L.H. headlamp.
10. Main-beam warning lamp.
11. R.H. sidelamp.
12. L.H. sidelamp.
14. Panel lamps.
15. Number-plate illumination lamp.
16. R.H. stop and tail lamp.
17. L.H. stop and tail lamp.
18. Stop lamp switch.
19. Two-way fuse unit: 1–2, 35 amp.; 3–4, 35 amp.
23. Horn.
24. Horn-push.
25. Flasher unit.
26. Direction indicator switch.
27. Direction indicator warning lamp.
28. R.H. front flasher lamp.
29. L.H. front flasher lamp.
30. R.H. rear flasher lamp.
31. L.H. rear flasher lamp.
34. Fuel gauge.
35. Fuel gauge tank unit.
36. Windscreen wiper switch.
37. Windscreen wiper motor.
38. Ignition starter switch.
39. Ignition coil.
40. Distributor.
41. Fuel pump.
42. Oil pressure switch.
43. Oil pressure warning lamp.
44. Ignition warning lamp.
45. Speedometer.
64. Bi-metal instrument voltage stabilizer.
83. Induction heater and thermostat.
84. Suction chamber heater.
94. Oil filter switch.
105. Oil filter warning lamp.

CABLE COLOR CODE

B. Black U. Blue
G. Green P. Purple
N. Brown R. Red
W. White Y. Yellow
L.G. Light Green

THE ELECTRICAL SYSTEM OF THE MOTORCAR

wiring in an ordinary house. A basic circuit is shown on the previous page. It must provide for the side lights, the tail lights, the head lights, the indicators, the motor for the windscreen wiper, the heater, the fuel gauge and the fuel pump, the ignition light and various safety indicators but it would be inappropriate here to enlarge on all these. Find out for yourself which of these use electromagnetism and how they work.



B.M.C. Mini Moke