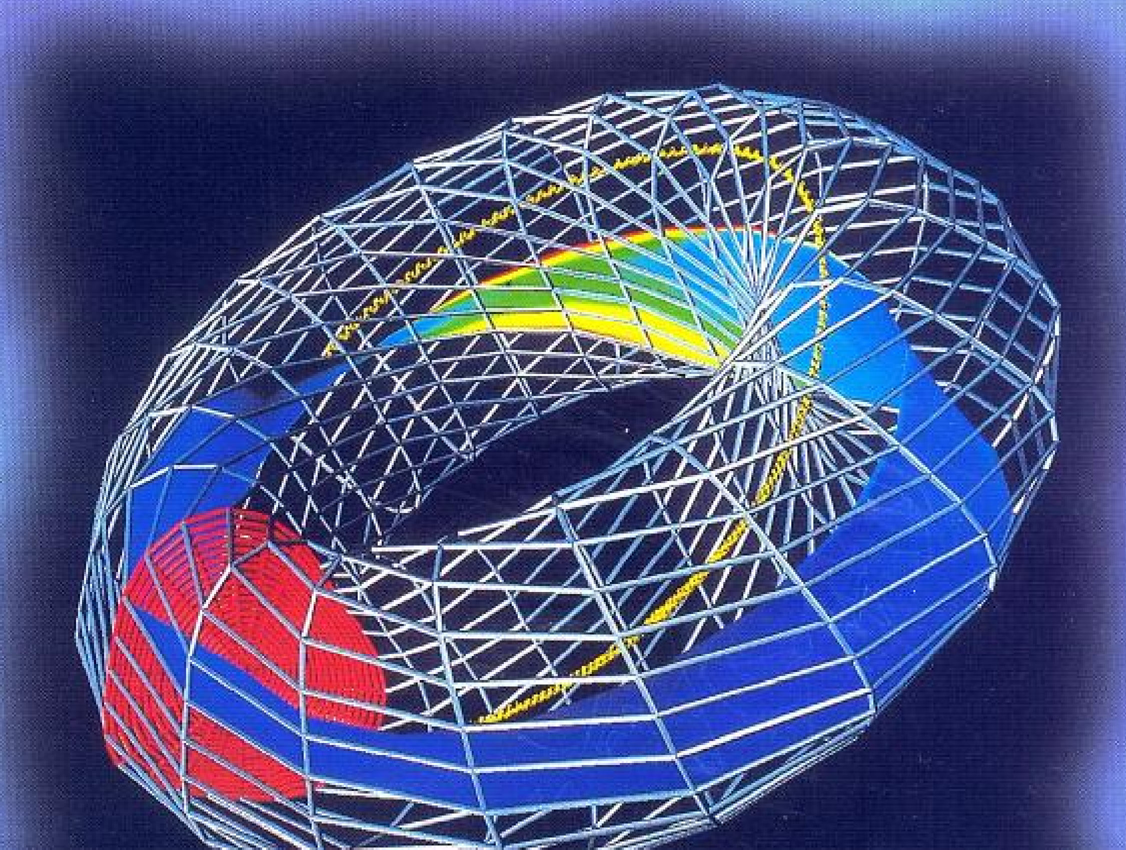
9

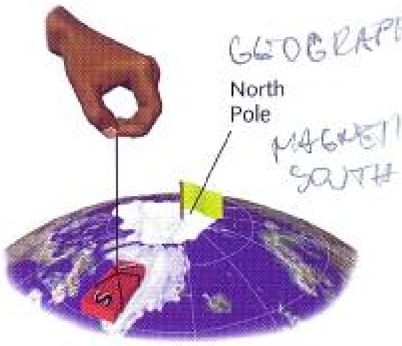
Magnets and Currents

- MAGNETS
- MAGNETIC FIELDS
- MAGNETIC EFFECT OF A CURRENT
- ELECTROMAGNETS
- MAGNETIC FORCE ON A CURRENT
- ELECTRIC MOTORS
- ELECTROMAGNETIC INDUCTION
- GENERATORS
- TRANSFORMERS
- POWER TRANSMISSION AND DISTRIBUTION



Computer model of the magnetic field inside the doughnut-shaped chamber of a nuclear fusion reactor. Like the Sun, fusion reactors release energy by smashing hydrogen atoms together to form helium. One day, they may provide the energy to run power stations on Earth. In the reactor, the magnetic field is used to trap charged particles from hydrogen at a temperature of over 100 million °C.

9.01 Magnets



Magnetic poles

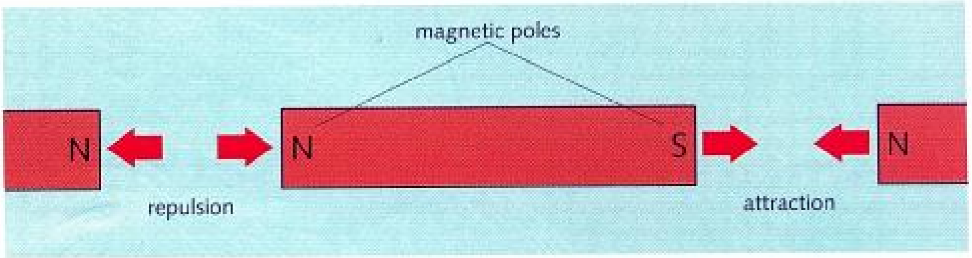
If a small bar magnet is dipped into iron filings, the filings are attracted to its ends, as shown in the photograph on the opposite page. The magnetic force seems to come from two points, called the **poles** of the magnet.

The Earth exerts forces on the poles of a magnet. If a bar magnet is suspended as on the left, it swings round until it lies roughly north–south. This effect is used to name the two poles of a magnet. These are called:

- the **north-seeking pole** (or **N pole** for short)
- the **south-seeking pole** (or **S pole** for short).

If you bring the ends of two similar bar magnets together, there is a force between the poles as shown below:

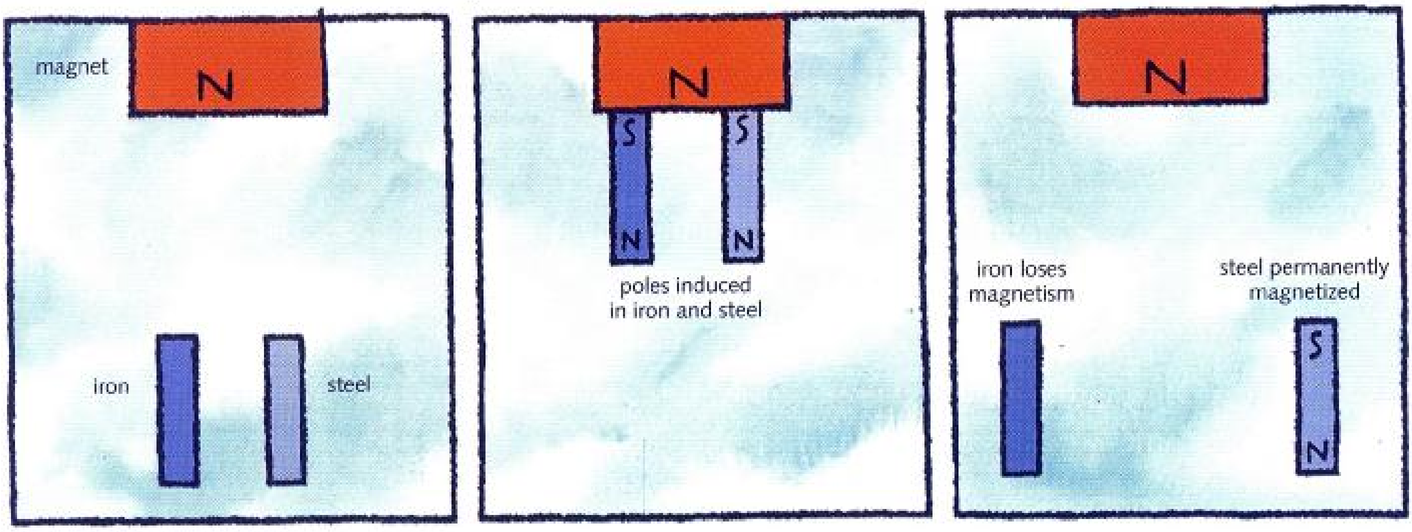
Like poles repel; unlike poles attract.
The closer the poles, the greater the force between them.



Induced magnetism

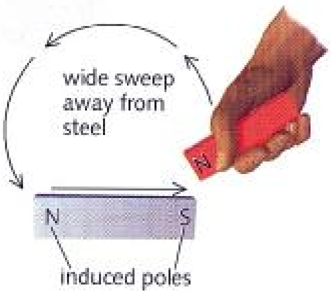
Materials such as iron and steel are attracted to magnets because they themselves become magnetized when there is a magnet nearby. The magnet **induces** magnetism in them, as shown below. In each case, the induced pole nearest the magnet is the *opposite* of the pole at the end of the magnet. The attraction between unlike poles holds each piece of metal to the magnet.

The steel and the iron behave differently when pulled right away from the magnet. The steel keeps some of its induced magnetism and becomes a **permanent magnet**. However, the iron loses virtually all of its induced magnetism. It was only a **temporary magnet**.



Making a magnet

A piece of steel becomes permanently magnetized when placed near a magnet, but its magnetism is usually weak. It can be magnetized more strongly by stroking it with one end of a magnet, as on the right. However, the most effective method of magnetizing it is to place it in a long coil of wire and pass a large, direct (one-way) current through the coil. The current has a magnetic effect which magnetizes the steel.



Magnetizing a piece of steel by stroking it with a magnet.

Magnetic and non-magnetic materials

A **magnetic material** is one which which can be magnetized and is attracted to magnets. All strongly magnetic materials contain iron, nickel, or cobalt. For example, steel is mainly iron. Strongly magnetic metals like this are called **ferromagnetics**. They are described as *hard* or *soft* depending on how well they keep their magnetism when magnetized:

Hard magnetic materials such as steel, and alloys called Alcomax and Magnadur are difficult to magnetize but do not readily lose their magnetism. They are used for permanent magnets.

Soft magnetic materials such as iron and Mumetal are relatively easy to magnetize, but their magnetism is only temporary. They are used in the cores of electromagnets and transformers because their magnetic effect can be 'switched' on or off or reversed easily.

Non-magnetic materials include metals such as brass, copper, zinc, tin, and aluminium, as well as non-metals.

Where magnetism comes from

In an atom, tiny electrical particles called electrons move around a central nucleus. Each electron has a magnetic effect as it spins and orbits the nucleus. In many types of atom, the magnetic effects of the electrons cancel, but in some they do not, so each atom acts as a tiny magnet. In an unmagnetized material, the atomic magnets point in random directions. But as the material becomes magnetized, more and more of its atomic magnets line up with each other. Together, billions of tiny atomic magnets act as one big magnet.

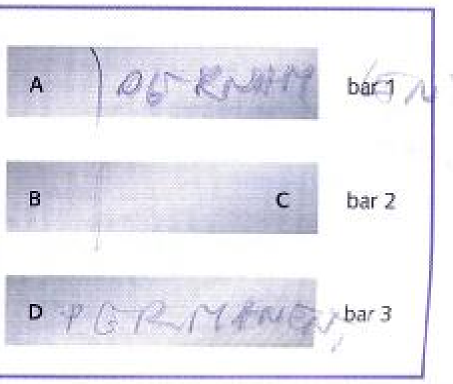
If a magnet is hammered, its atomic magnets are thrown out of line: it becomes **demagnetized**. Heating it to a high temperature has the same effect.

Magnetic materials are attracted to magnets and can be made into magnets.

NORTH -S

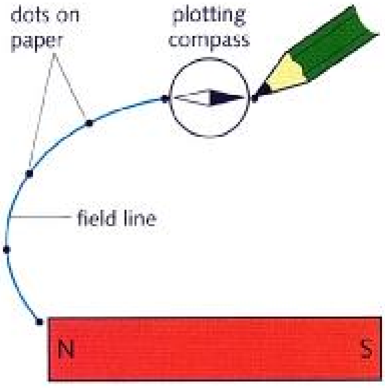
Q

1 What is meant by the *N pole* of a magnet?
2 Magnetic materials are sometimes described as *hard* or *soft*.
  a) What is the difference between the two types?
  b) Give one example of each type.
3 Name *three* ferromagnetic metals.
4 Name *three* non-magnetic metals.
5 The diagram on the right shows three metal bars. When different ends are brought together, it is found that A and B attract, A and C attract, but A and D repel. Decide whether each of the bars is a permanent magnet or not.



9.02 Magnetic fields

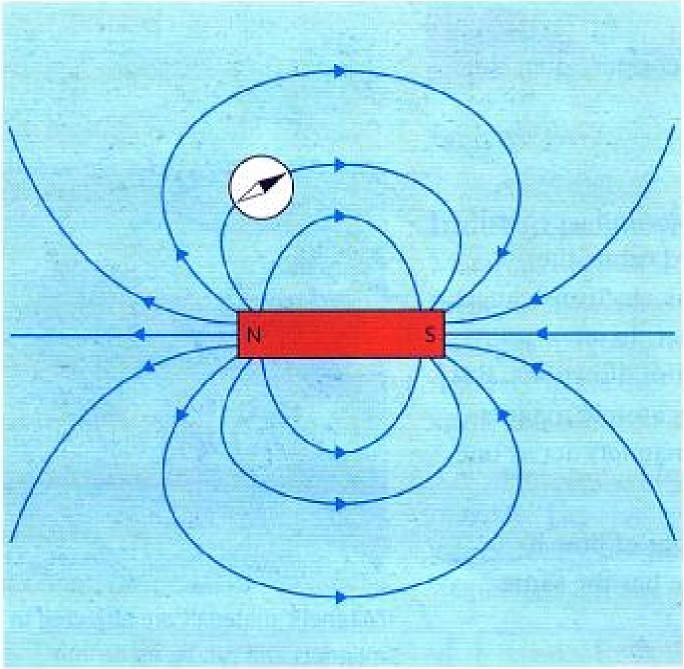
In the photograph below, iron filings have been sprinkled on paper over a bar magnet. The filings have become tiny magnets, pulled into position by forces from the poles of the magnet. Scientifically speaking, there is a **magnetic field** around the magnet, and this exerts forces on magnetic materials in it.

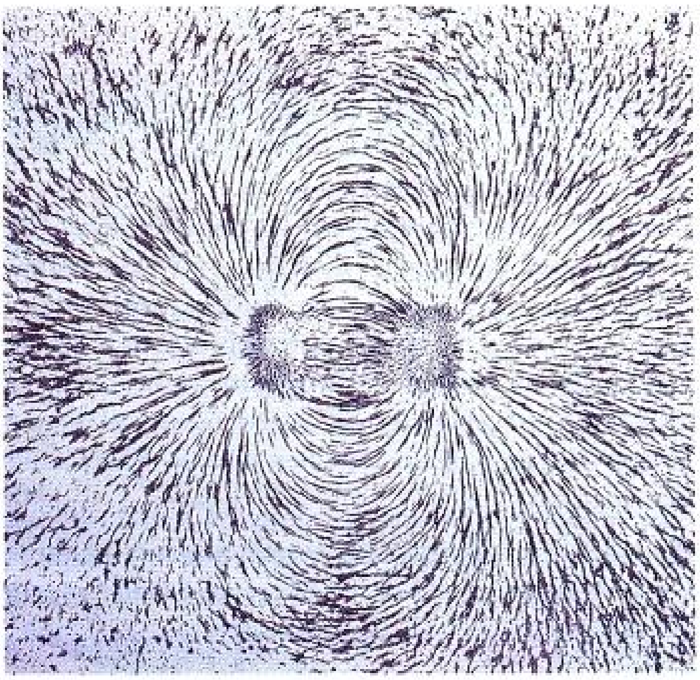


Magnetic field patterns

Magnetic fields can be investigated using a small **compass**. The 'needle' is a tiny magnet which is free to turn on its spindle. When near a magnet, the needle is turned by forces between its poles and the poles of the magnet. The needle comes to rest so that the turning effect is zero.

The diagram on the left shows how a small compass can be used to plot the field around a bar magnet. Starting with the compass near one end of the magnet, the needle position is marked using two dots. Then the compass is moved so that the needle lines up with the previous dot... and so on. When the dots are joined up, the result is a magnetic **field line**. More lines can be drawn by starting with the compass in different positions.





Magnet essentials

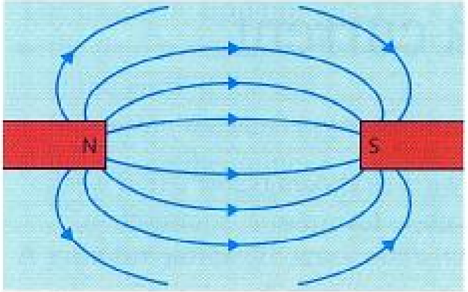
A magnet has a north-seeking (N) pole at one end and a south-seeking (S) pole at the other. When two magnets are brought together:

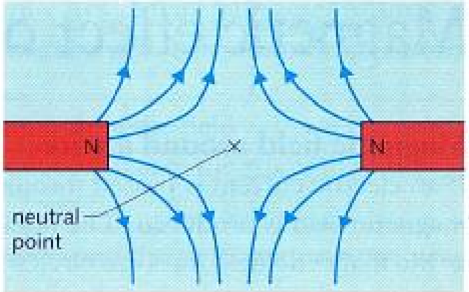
like poles repel, unlike poles attract.

In the diagram above, a selection of field lines has been used to show the magnetic field around a bar magnet:

- The field lines run from the N pole to the S pole of the magnet. The field direction, shown by an arrowhead, is defined as the direction in which the force on a N pole would act. It is the direction in which the N end of a compass needle would point.
- The magnetic field is strongest where the field lines are closest together.

If two magnets are placed near each other, their magnetic fields combine to produce a single field. Two examples are shown at the top of the next page. At the **neutral point**, the field from one magnet exactly cancels the field from the other, so the magnetic force on anything at this point is zero.





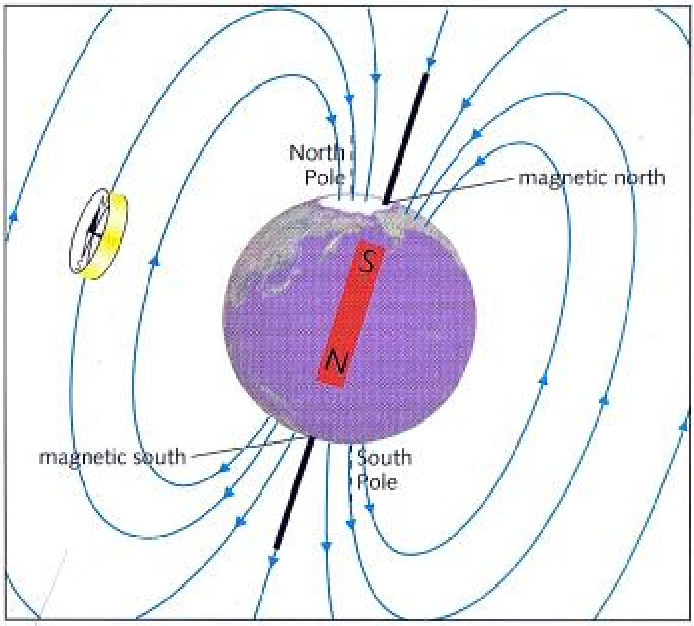
◀ At the neutral point, the fields from the two magnets cancel, so the combined field is of zero strength.

The Earth's magnetic field

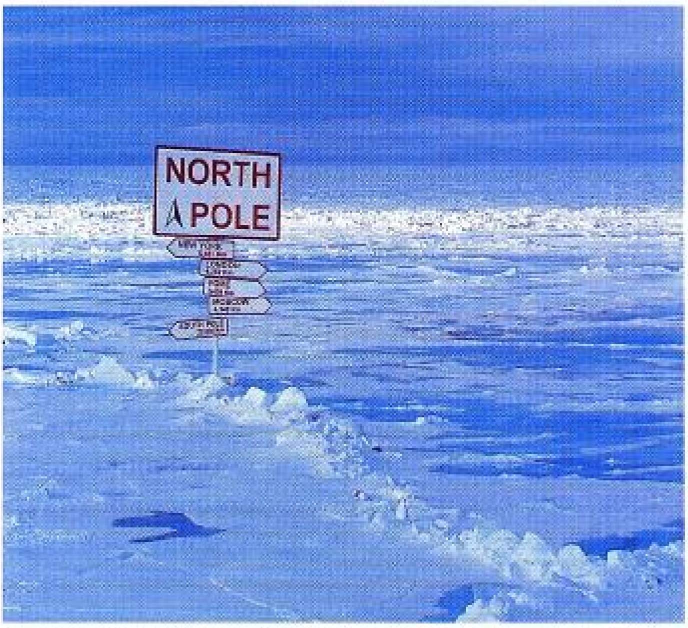
The Earth has a magnetic field. No one is sure of its cause, although it is thought to come from electric currents generated in the Earth's core. The field is rather like that around a large, but very weak bar magnet.

With no other magnets near it, a compass needle lines up with the Earth's magnetic field. The N end of the needle points north. But an N pole is always attracted to an S pole. So it follows that the Earth's magnetic S pole must be in the north! It lies under a point in Canada called **magnetic north**.

Magnetic north is over 1200 km away from the Earth's geographic North Pole. This is because the Earth's magnetic axis is not quite in line with its north-south axis of rotation.



The Earth behaves as if it has a large but very weak bar magnet inside it.



A compass is of no use in polar regions because the Earth's magnetic field lines are vertical.

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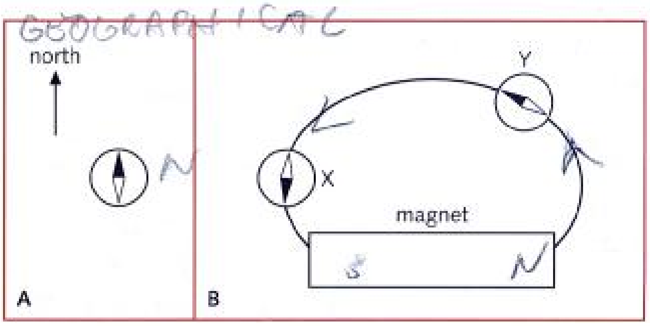
1 In the diagrams on the right, the same compass is being used in both cases.
a) Copy diagram A. Label the N and S ends of the compass needle.
b) Copy diagram B. Mark in the poles of the magnet to show which is N and which is S. Then draw an arrowhead on the field line to show its direction.
c) In diagram B, at which position, X or Y, would you expect the magnetic field to be the stronger?



9.03 Magnetic effect of a current

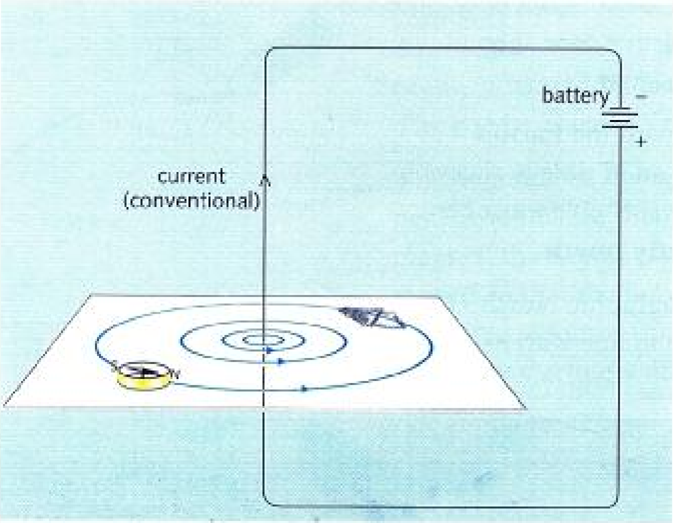
Magnet essentials

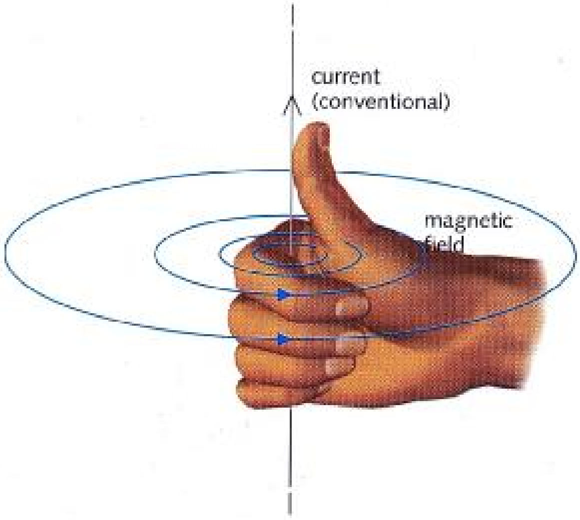
Like poles repel; unlike poles attract. Magnetic field lines show the direction of the force on a N pole.

Magnetic field around a wire

If an electric current is passed through a wire, as shown below left, a weak magnetic field is produced. The field has these features:

- the magnetic field lines are circles
- the field is strongest close to the wire
- increasing the current increases the strength of the field.





Current essentials

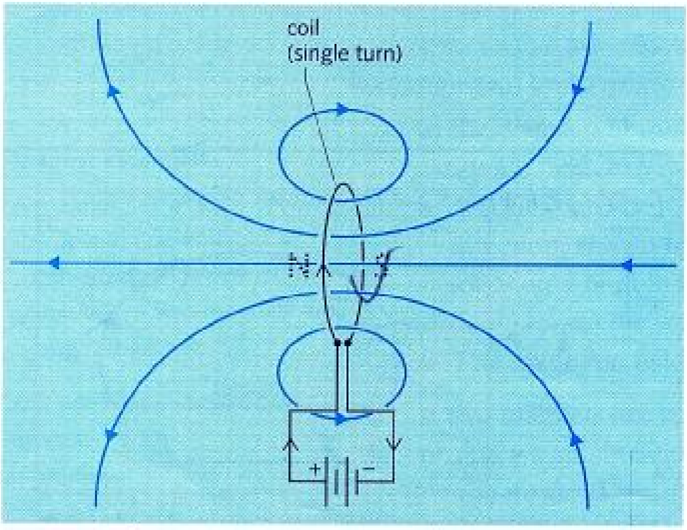
In a circuit the current is a flow of electrons: tiny particles which come from atoms.

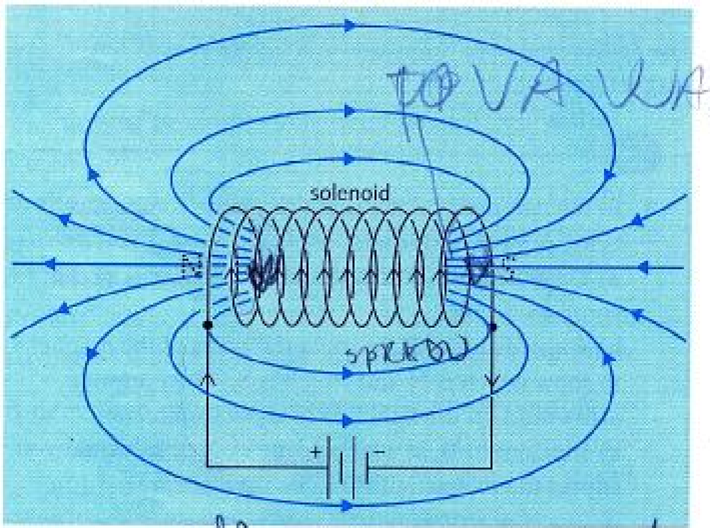
The current arrows shown on circuit diagrams run from + to -. This is the **conventional current direction**. Electrons, being negatively charged, flow the other way.

A rule for field direction The direction of the magnetic field produced by a current is given by the **right-hand grip rule** shown above right. Imagine gripping the wire with your right hand so that your thumb points in the conventional current direction. Your fingers then point in the same direction as the field lines.

Magnetic fields from coils

A current produces a stronger magnetic field if the wire it flows through is wound into a coil. The diagrams below show the magnetic field patterns produced by two current-carrying coils. One is just a single turn of wire. The other is a long coil with many turns. A long coil is called a **solenoid**.



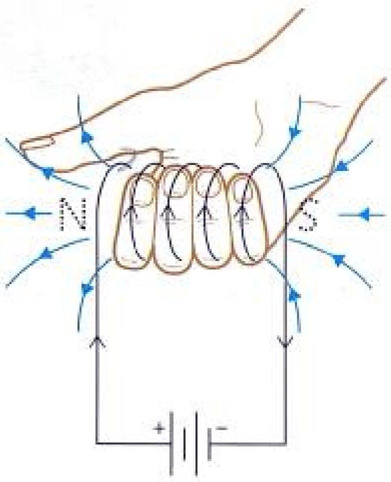


in solenoid N - is towards us if current has anticlockwise

The magnetic field produced by a current-carrying coil has these features:

- the field is similar to that from a bar magnet, and there are magnetic poles at the ends of the coil
- increasing the current increases the strength of the field
- increasing the number of turns on the coil increases the strength of the field.

FINGERS 電 T – B

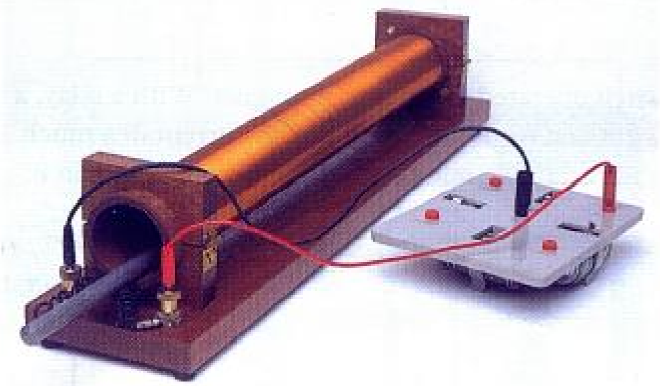


Right-hand grip rule for poles

A rule for poles To work out which way round the poles are, you can use another **right-hand grip rule**, as shown on the right. Imagine gripping the coil with your right hand so that your fingers point in the conventional current direction. Your thumb then points towards the N pole of the coil.

Magnets are made – and demagnetized – using coils, as shown below. In audio and video cassette recorders, tiny coils are used to put magnetic patterns on tape. The patterns store sound and picture information.

Making a magnet



Above, a steel bar has been placed in a solenoid. When a current is passed through the solenoid, the steel becomes magnetized and makes the magnetic field much stronger than before. And when the current is switched off, the steel stays magnetized. Nearly all permanent magnets are made in this way.

Demagnetizing a magnet

Above, a magnet is slowly being pulled out of a solenoid through which an alternating current is passing. Alternating current (AC) flows backwards, forwards, backwards, forwards... and so on. It produces a magnetic field which changes direction very rapidly and throws the atoms in the magnet out of line.

N

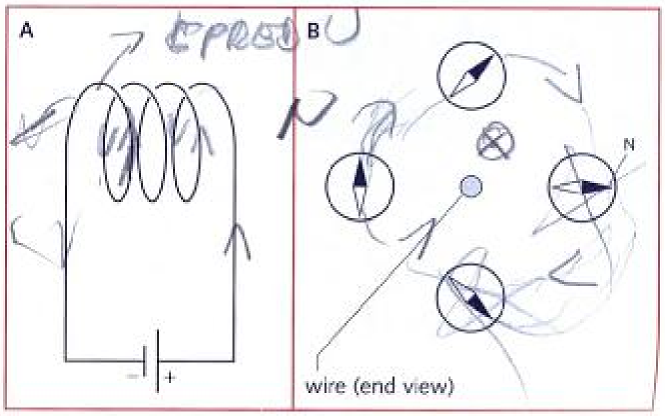
IF WE SEE CURRENT

N

Q

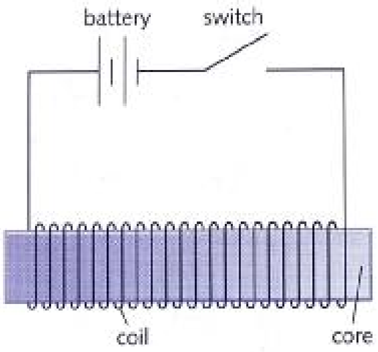
1 The coil in diagram A is producing a magnetic field.
   a) Give *two* ways in which the strength of the field could be increased. I, N
   b) How could the direction of the field be reversed?
   c) Copy the diagram. Show the conventional current direction and the N and S poles of the coil.

2 Redraw diagram B to show which way the compass needles point when a current flows through the wire. (Assume that the black end of each compass needle is a N pole, the conventional current direction is away from you, into the paper, and that the only magnetic field is that due to the current.)



WIRE I B I B = B

9.04 Electromagnets



A simple electromagnet

Unlike an ordinary magnet, an **electromagnet** can be switched on and off. In a simple electromagnet, a **coil**, consisting of several hundred turns of insulated copper wire, is wound round a **core**, usually of iron or Mumetal. When a current flows through the coil, it produces a magnetic field. This magnetizes the core, creating a magnetic field about a thousand times stronger than the coil by itself. With an iron or Mumetal core, the magnetism is only temporary, and is lost as soon as the current through the coil is switched off. Steel would not be suitable as a core because it would become permanently magnetized.

The strength of the magnetic field is increased by:

- increasing the current
- increasing the number of turns in the coil.

Reversing the current reverses the direction of the magnetic field.

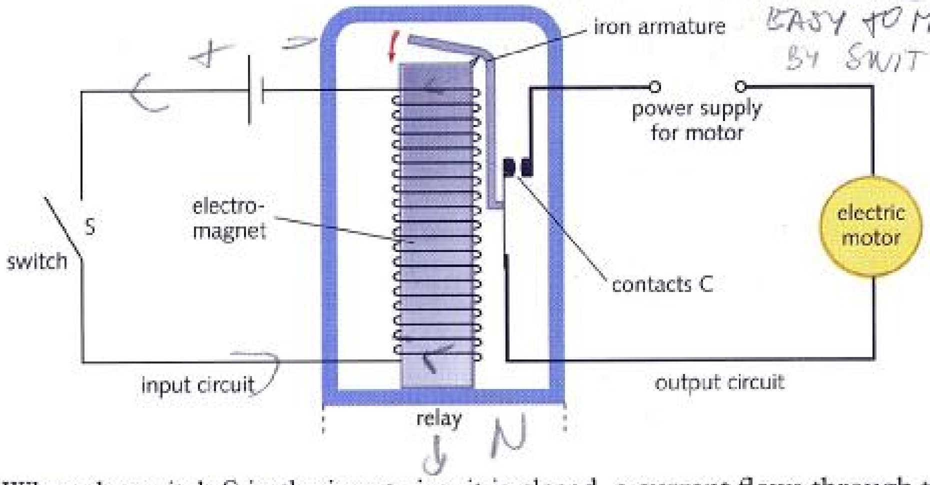
The following devices all contain electromagnets.

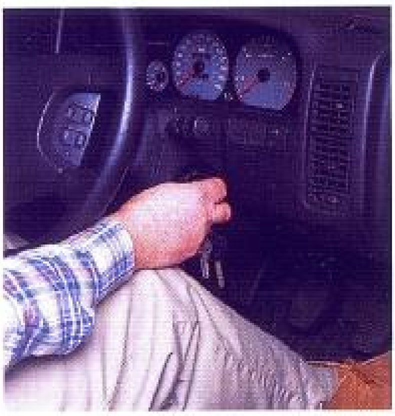
The magnetic relay

relé

A magnetic relay is a switch operated by an electromagnet. With a relay, a small switch with thin wires can be used to turn on the current in a much more powerful circuit – for example, one with a large electric motor in it:

SOFT MAGNETIC
EASY TO MAGNE
BY SWITCH

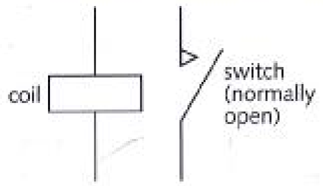




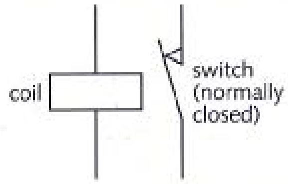
With a relay, a small switch can be used to turn on a powerful starter motor.

When the switch S in the input circuit is closed, a current flows through the electromagnet. This pulls the iron armature towards it, which closes the contacts C. As a result, a current flows through the motor.

The relay above is of the 'normally open' type: when the input switch is OFF, the output circuit is also OFF. A 'normally closed' relay works the opposite way: when the input switch is OFF, the output circuit is ON. In practice, most relays are made so that they can be connected either way.



Normally-open relay (symbol)

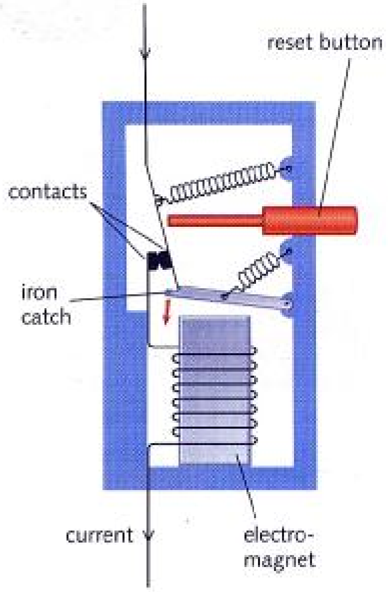


Normally-closed relay (symbol)

The circuit breaker

A circuit breaker is an automatic switch which cuts off the current in a circuit if this rises above a specified value. It has the same effect as a fuse but, unlike a fuse, can be reset (turned ON again) after it has tripped (turned OFF).

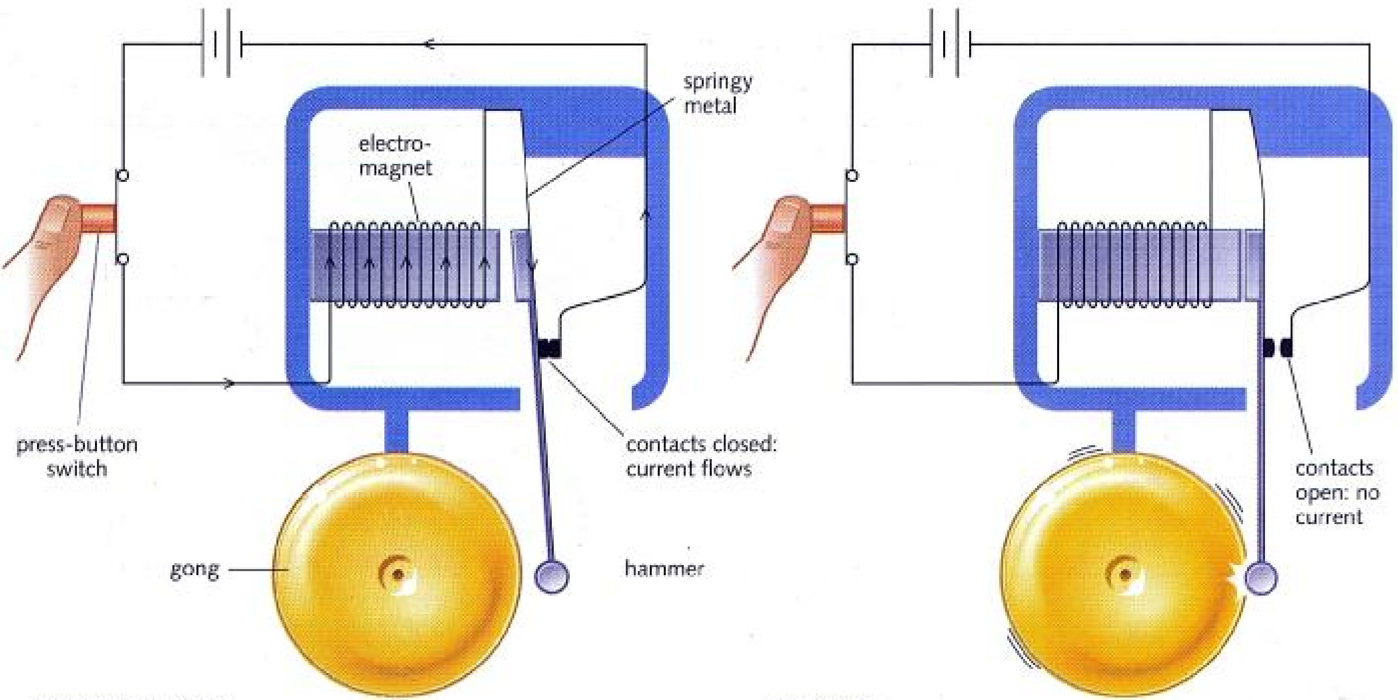
In the type shown on the right, the current flows through two contacts and also through an electromagnet. If the current gets too high, the pull of the electromagnet becomes strong enough to release the iron catch, so the contacts open and stop the current. Pressing the reset button closes the contacts again.



Circuit breaker

The electric bell

An electric bell contains an electromagnet that repeatedly switches itself off and on very rapidly, moving the bell hammer as it does so. The arrangement is called a 'make and break' circuit. It works like this. When you press the switch, current flows through the electromagnet, which pulls the hammer across so that it strikes the gong. The movement separates the contacts and switches off the electromagnet. So the hammer springs back, the contacts close, the electromagnet pulls the hammer across again... and so on.



Electric bell: 'make... ...and break'

Q

1 An electromagnet has a core.
a) What is the purpose of the core?
b) Why is iron a better material for the core than steel?
c) Write down *two* ways of increasing the strength of the magnetic field from an electromagnet.

2 In the diagram on the opposite page, an electric motor is controlled by a switch connected to a relay.
a) What is the advantage of using a relay, rather than a switch in the motor circuit itself?
b) Why does the motor start when switch S is closed?

3 The diagram at the top of the page shows a circuit breaker.
a) What is the purpose of the circuit breaker?
b) How do you think the performance of the circuit breaker would be affected if the coil of the electromagnet had more turns?

4 The diagrams above show an electric bell.
a) What makes the hammer strike the gong?
b) Why does the hammer move back again after the gong has been struck?

Related topics: magnetic materials **9.01**; magnetic fields from coils **9.03**; using circuit breakers **8.11– 8.12**; using relays **10.04**

9.05 Magnetic force on a current

Magnet essentials

The N and S poles of one magnet exert forces on those of another:

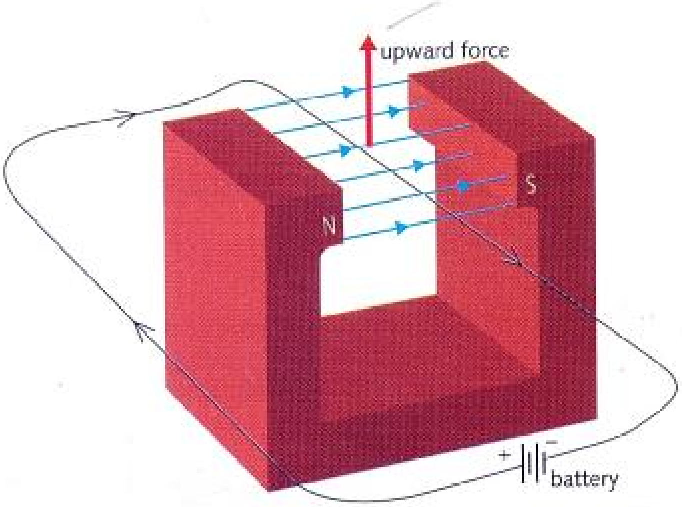
like poles repel, unlike poles attract.

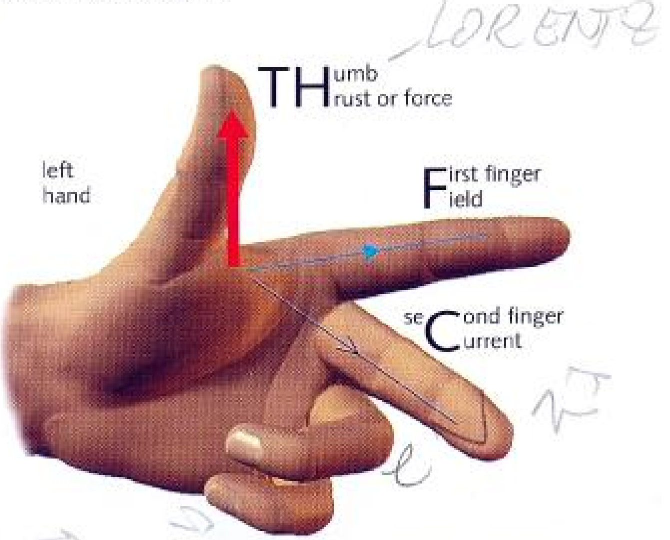
The magnetic field around a magnet can be represented by field lines. These show the direction in which the force on an N pole would act.

In the experiment shown below, a length of copper wire has been placed in a magnetic field. Copper is non-magnetic, so it is feels no force from the magnet. However, with a current passing through it, there is a force on the wire. The force arises because the current produces its own magnetic field which acts on the poles of the magnet. In this case, the force on the wire is upwards (see box below left). It would be downwards if either the magnetic field or the current were reversed. Whichever way the experiment is done, the wire moves *across* the field. It is *not* attracted to either pole.

The force is increased if:

- the current is increased
- a stronger magnet is used
- the length of wire in the field is increased.





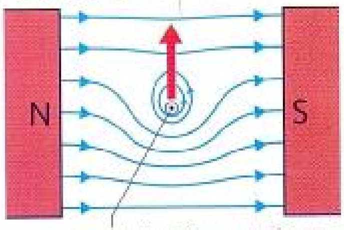
Fleming's left-hand rule

$F = q\vec{v} \times B =$ [illegible] $I(\vec{l} \times B)$

(LORENTZ

F

Field and force



current direction out of paper

By itself, the current in a straight wire produces a circular magnetic field pattern. However, when the wire is between the poles of a magnet, the combined field is as above. In situations like this, the field lines tend to straighten. So, in this case, the wire gets pushed upwards.

Fleming's left-hand rule

In the above experiment, the direction of the force can be predicted using **Fleming's left-hand rule**, as illustrated above right. If the you hold the thumb and first two fingers of your left hand at right angles, and point the fingers as shown, the thumb gives the direction of the force.

In applying the rule, it is important to remember how the field and current directions are defined:

- The field direction is from the N pole of a magnet to the S pole.
- The current direction is from the positive (+) terminal of a battery round to the negative (-). This is called the *conventional* current direction.

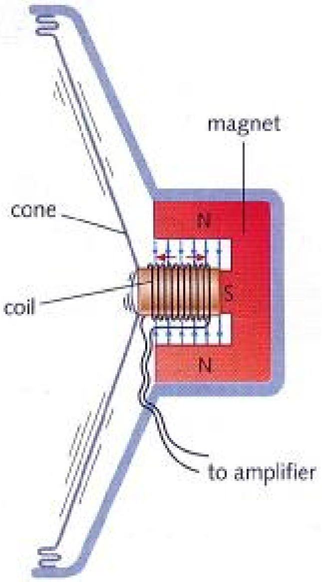
Fleming's left-hand rule only applies if the current and field directions are at right angles. If they are at some other angle, there is still a force, but its direction is more difficult to predict. If the current and field are in the *same* direction, there is *no* force.

Several devices use the fact that there is a force on a current-carrying conductor in a magnetic field. They include the loudspeaker and meter described on the next page and the electric motors on the next spread.

The moving-coil loudspeaker

Most loudspeakers are of the moving-coil type shown on the right. The cylindrical magnet produces a strong radial ('spoke-like') magnetic field at right angles to the wire in the coil. The coil is free to move backwards and forwards and is attached to a stiff paper or plastic cone.

The loudspeaker is connected to an amplifier which gives out alternating current. This flows backwards, forwards, backwards... and so on, causing a force on the coil which is also backwards, forwards, backwards.... As a result, the cone vibrates and gives out sound waves. The sound you hear depends on how the amplifier makes the current alternate.



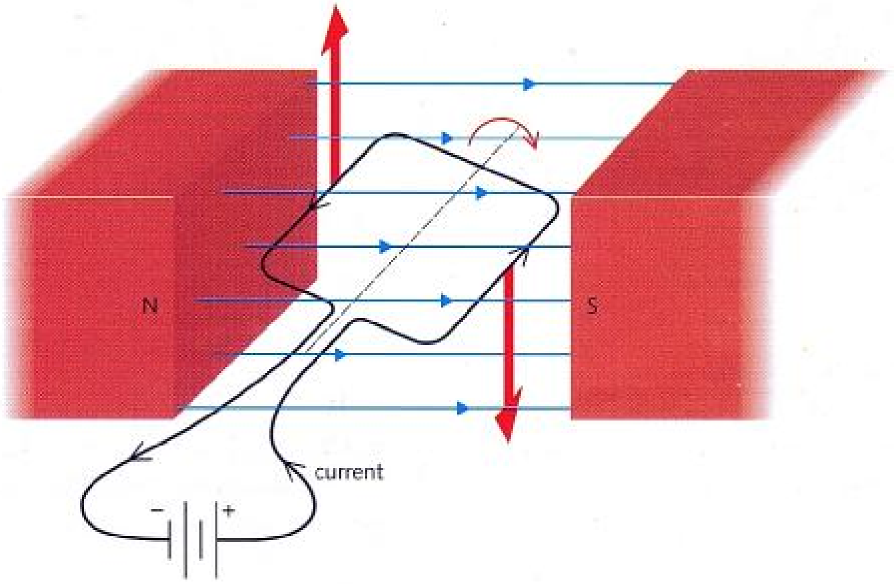
Moving-coil loudspeaker

REPRODUK

Turning effect on a coil

The coil below lies between the poles of a magnet. The current flows in opposite directions along the two sides of the coil. So, according to Fleming's left-hand rule, one side is pushed *up* and the other side is pushed *down*. In other words, there is a turning effect on the coil. With more turns on the coil, the turning effect is increased.

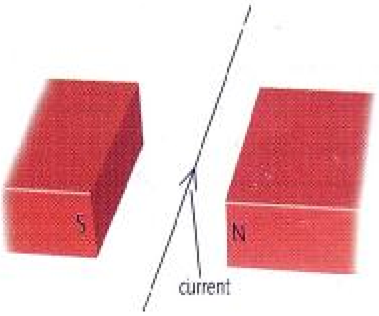
The meter in the photograph uses the above principle. Its pointer is attached to a coil in the field of a magnet. The higher the current through the meter, the further the coil turns against the springs holding it, and the further the pointer moves along the scale.



Moving-coil meter

Q

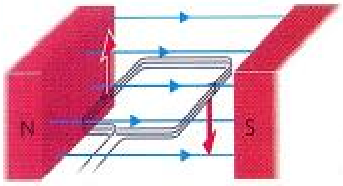
1 There is a force on the wire in the diagram on the right.
   a) Give *two* ways in which the force could be increased.
   b) Use Fleming's left-hand rule to work out the direction of the force.
   c) Give *two* ways in which the direction of the force could be reversed.
2 Explain why the cone of a loudspeaker vibrates when alternating current passes through its coil.
3 The diagram above shows a current-carrying coil in a magnetic field. What difference would it make if
   a) there were more turns of wire in the coil
   b) the direction of the current were reversed?



9.06 Electric motors

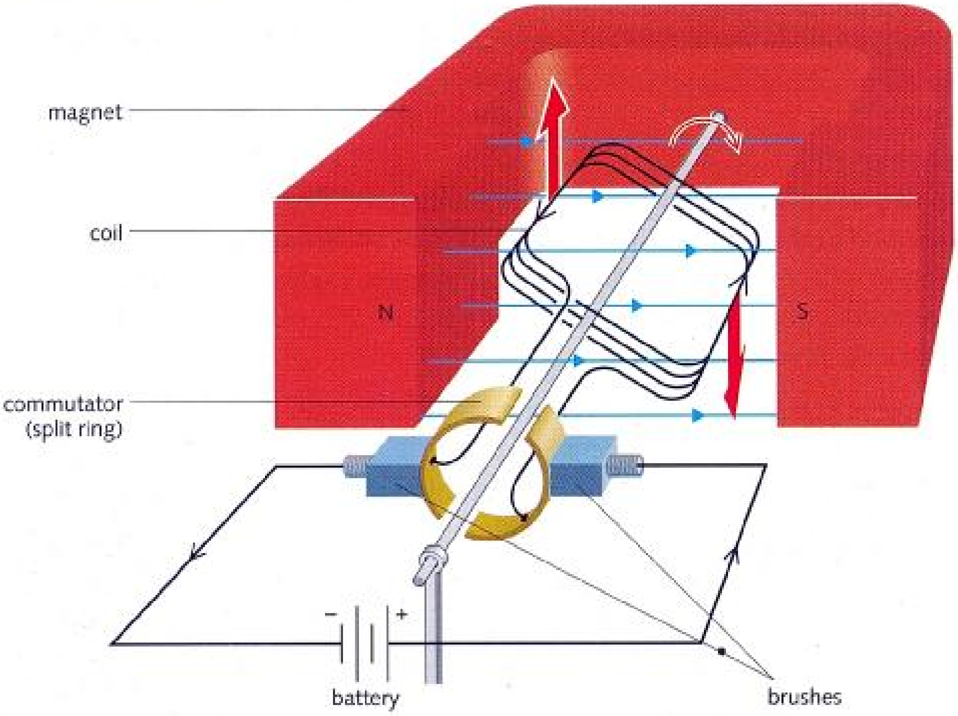
If a coil is carrying a current in a magnetic field, as on the left, the forces on it produce a turning effect. Many electric motors use this principle.

Turning effect on a coil



When a current flows through this coil, there is an upward force on one side and a downward force on the other. The direction of each force is given by Fleming's left-hand rule, explained on the previous spread.

A simple DC motor



The diagram above shows a simple electric motor. It runs on direct current (DC), the 'one-way' current that flows from a battery.

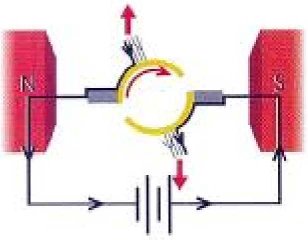
The coil is made of insulated copper wire. It is free to rotate between the poles of the magnet. The **commutator**, or split-ring, is fixed to the coil and rotates with it. Its action is explained below and in the diagrams on the left. The **brushes** are two contacts which rub against the commutator and keep the coil connected to the battery. They are usually made of carbon.

When the coil is horizontal, the forces are furthest apart and have their maximum turning effect (leverage) on the coil. With no change to the forces, the coil would eventually come to rest in the vertical position. However, as the coil overshoots the vertical, the commutator changes the direction of the current through it. So the forces change direction and push the coil further round until it is again vertical... and so on. In this way, the coil keeps rotating clockwise, half a turn at a time. If either the battery or the poles of the magnet were the other way round, the coil would rotate anticlockwise.

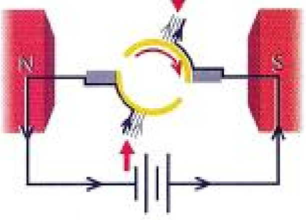
The turning effect on the coil can be increased by:

- increasing the current
- using a stronger magnet
- increasing the number of turns on the coil
- increasing the area of the coil. (A longer coil means higher forces because there is a greater length of wire in the magnetic field; a wider coil gives the forces more leverage.)

The action of the commutator



When the coil is nearly vertical, the forces cannot turn it much further...

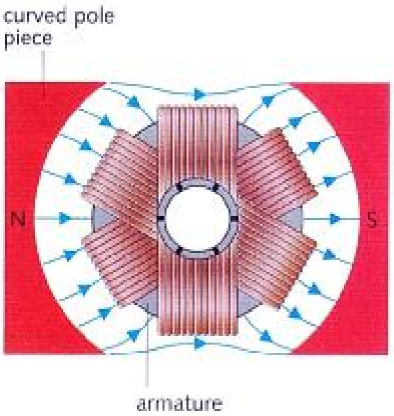


...but when the coil overshoots the vertical, the commutator changes the direction of the current through it, so the forces change direction and keep the coil turning.

Practical motors

The simple motor on the opposite page produces a low turning effect and is jerky in action, especially at low speeds. Practical motors give a much better performance for these reasons:

- Several coils are used, each set at a different angle and each with its own pair of commutator segments (pieces), as shown on the right. The result is a greater turning effect and smoother running.
- The coils contain hundreds of turns of wire and are wound on a core called an **armature**, which contains iron. The armature becomes magnetized and increases the strength of the magnetic field.
- The pole pieces are curved to create a radial ('spoke-like') magnetic field. This keeps the turning effect at a maximum for most of the coil's rotation.



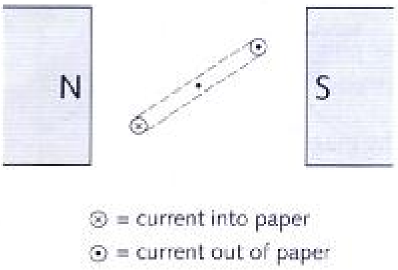
Practical motors have curved pole pieces, and several coils wound on an iron armature.

In some motors, the field is provided by an electromagnet rather than a permanent magnet. One advantage is that the motor can be run from an alternating current (AC) supply. As the current flows backwards and forwards in the coil, the field from the electromagnet changes direction to match it, so the turning effect is always the same way and the motor rotates normally. The mains motors in drills and food mixers work like this.

◀ In this electric drill, the motor is is in the centre. Note the commutator segments at the right hand end, and the electromagnet.

Q

1 Which part(s) of an electric motor
  a) connect the power supply to the split-ring and coil
  b) changes the current direction every half-turn?
2 On the right, there is an end view of the coil in a simple electric motor.
  a) Redraw the diagram to show the position of the coil when the turning effect on it is i) maximum ii) zero.
  b) Give *three* ways in which the maximum turning effect on the coil could be increased.
  c) Use Fleming's left-hand rule to work out which way the coil will turn.
3 What is the advantage of using an electromagnet in an electric motor, rather than a permanent magnet?

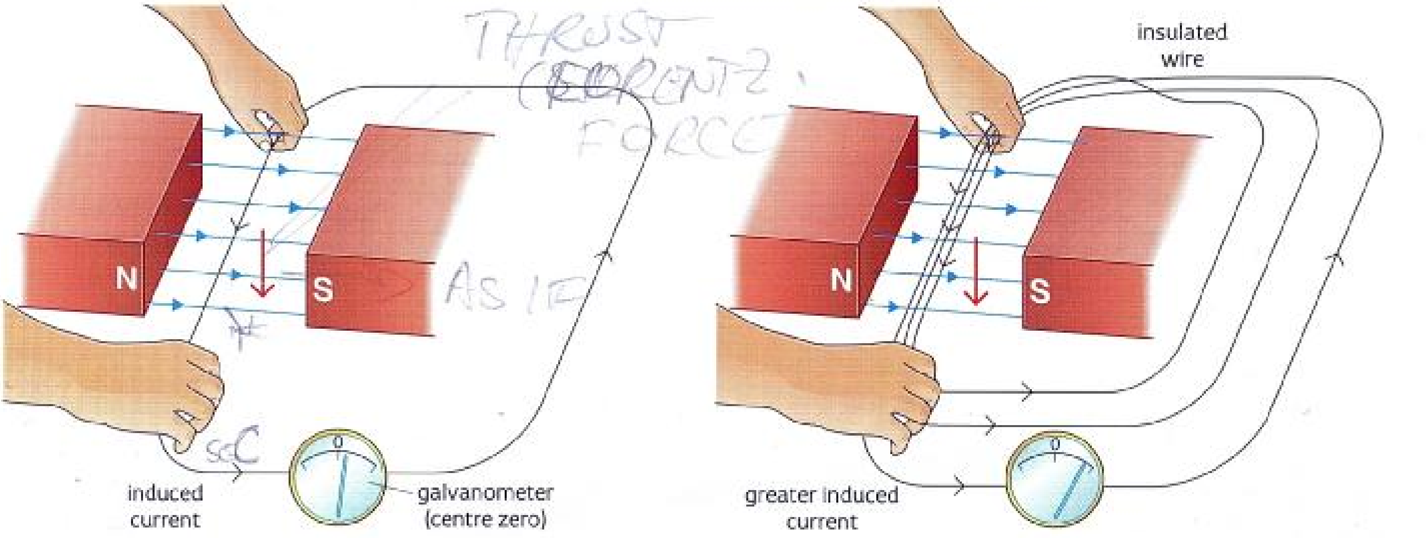


Related topics: current **8.03**; AC and DC **8.11**; magnetic fields **9.02**; electromagnets **9.04**; Fleming's left-hand rule and turning effect **9.05**

9.07 Electromagnetic induction

A current produces a magnetic field. However, the reverse is also possible: a magnetic field can be used to produce a current.

Induced EMF and current in a moving wire



When a wire is moved across a magnetic field, as shown above left, a small EMF (voltage) is generated in the wire. The effect is called **electromagnetic induction**. Scientifically speaking, an EMF is **induced** in the wire. If the wire forms part of a complete circuit, the EMF makes a current flow. This can be detected by a meter called a **galvanometer**, which is sensitive to very small currents. The one shown in the diagram is a centre-zero type. Its pointer moves to the left or right of the zero, depending on the current direction.

The induced EMF (and current) can be increased by:

- moving the wire faster
- using a stronger magnet
- increasing the length of wire in the magnetic field – for example, by looping the wire through the field several times, as shown above right.

The above results are summed up by **Faraday's law of electromagnetic induction**. In simplified form, this can be stated as follows:

> The EMF induced in a conductor is proportional to the rate at which magnetic field lines are cut by the conductor.

In applying this law, remember that field lines are used to represent the strength of a magnetic field as well as its direction. The closer together the lines, the stronger the field.

Either of the following will reverse the direction of the induced EMF and current:

- moving the wire in the opposite direction
- turning the magnet round so that the field direction is reversed.

If the wire is not moving, or is moving parallel to the field lines, there is no induced EMF or current.

Circuit essentials

For a current to flow in a circuit, the circuit must be complete, with no breaks in it. Also, there must a source of EMF (voltage) to provide the energy. A battery is one such source. Others include a wire moving through a magnetic field, as explained on the right.

EMF stands for electromotive force. It is measured in volts.

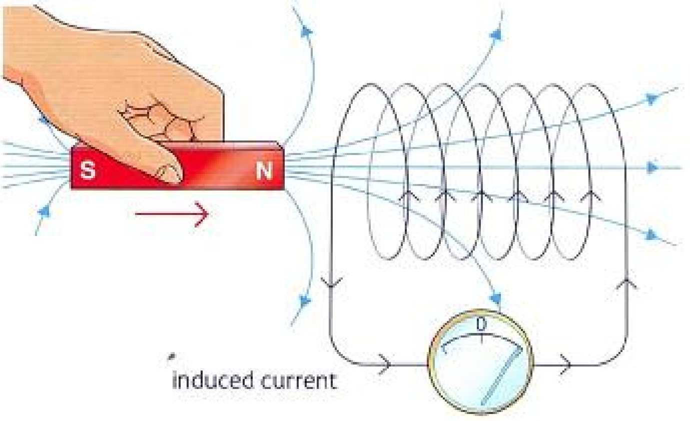
Magnet essentials

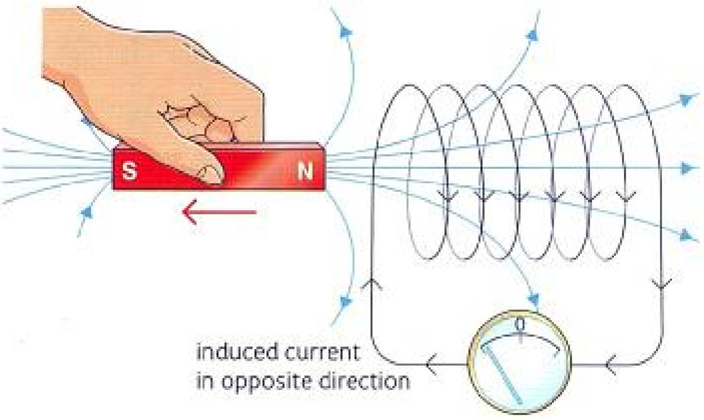
The N and S poles of one magnet exert forces on those of another:

like poles repel, unlike poles attract.

The magnetic field around a magnet can be represented by field lines. These show the direction in which the force on an N pole would act.

Induced EMF and current in a coil





If a bar magnet is pushed into a coil, as shown above left, an EMF is induced in the coil. In this case, it is the magnetic field that is moving rather than the wire, but the result is the same: field lines are being cut. As the coil is part of a complete circuit, the induced EMF makes a current flow.

The induced EMF (and current) can be increased by:

- moving the magnet faster
- using a stronger magnet
- increasing the number of turns on the coil (as this increases the length of wire cutting through the magnetic field).

Experiments with the magnet and coil also give the following results.

- If the magnet is pulled *out of* the coil, as shown above right, the direction of the induced EMF (and current) is reversed.
- If the S pole of the magnet, rather than the N pole, is pushed into the coil, this also reverses the current direction.
- If the magnet is held still, no field lines are cut, so there is no induced EMF or current.

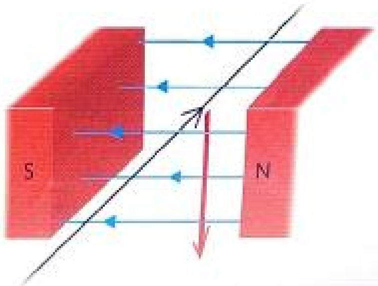
The playback heads in audio and video cassette recorders contain tiny coils. A tiny, varying EMF is induced in the coil as the magnetized tape passes over it and field lines are cut by the coil. In this way, the magnetized patterns on the tape are changed into electrical signals which can be used to recreate the original sound or picture.

The pick-ups under the strings of this guitar are tiny coils with magnets inside them. The steel strings become magnetized. When they vibrate, current is induced in the coils, boosted by an amplifier, and used to produce sound.

Q

1 The wire on the right forms part of a circuit. When the wire is moved downwards, a current is induced in it. What would be the effect of
  a) moving the wire upwards through the magnetic field
  b) holding the wire still in the magnetic field
  c) moving the wire parallel to the magnetic field lines?

2 In the experiment at the top of the page, what would be the effect of
  a) moving the magnet faster
  b) turning the magnet round, so that the S pole is pushed into the coil
  c) having more turns on the coil?



Related topics: current **8.03**; EMF **8.04**; magnetic fields **9.02**; direction of induced current (Lenz's law) **9.12**; recording signals **10.07**

9.08 Generators

Electromagnetic induction

If a conductor is moved through a magnetic field so that it cuts field lines, an EMF (voltage) is induced in it. In a complete circuit, the induced EMF makes a current flow.

AC

Alternating current (AC) flows alternately backwards and forwards. Mains current is AC.

With AC circuits, giving voltage and current values is complicated by the fact that these vary all the time, as the graph on this page shows. To overcome the problem, a type of average called a **root mean square (RMS)** value is used. For example, Europe's mains voltage, 230 V, is an RMS value. It is equivalent to the steady voltage which would deliver energy at the same rate.

Most of our electricity comes from huge **generators** in power stations. There are smaller generators in cars and on some bicycles. These generators, or dynamos, all use electromagnetic induction. When turned, they induce an EMF (voltage) which can make a current flow. Most generators give out alternating current (AC). AC generators are also called **alternators**.

A simple AC generator

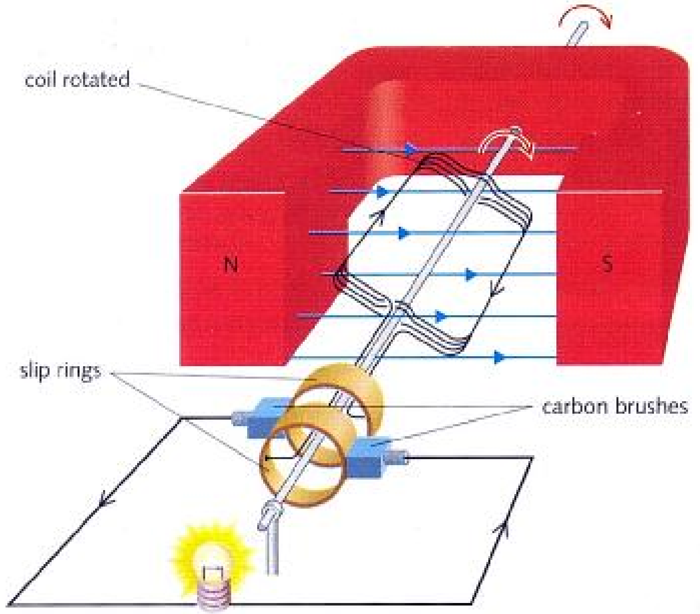
The diagram below shows a simple AC generator. It is providing the current for a small bulb. The coil is made of insulated copper wire and is rotated by turning the shaft. The **slip rings** are fixed to the coil and rotate with it. The **brushes** are two contacts which rub against the slip rings and keep the coil connected to the outside part of the circuit. They are usually made of carbon.

When the coil is rotated, it cuts magnetic field lines, so an EMF is generated. This makes a current flow. As the coil rotates, each side travels upwards, downwards, upwards, downwards... and so on, through the magnetic field. So the current flows backwards, forwards... and so on. In other words, it is AC. The graph shows how the current varies through one cycle (rotation). It is a maximum when the coil is horizontal and cutting field lines at the fastest rate. It is zero when the coil is vertical and cutting no field lines.

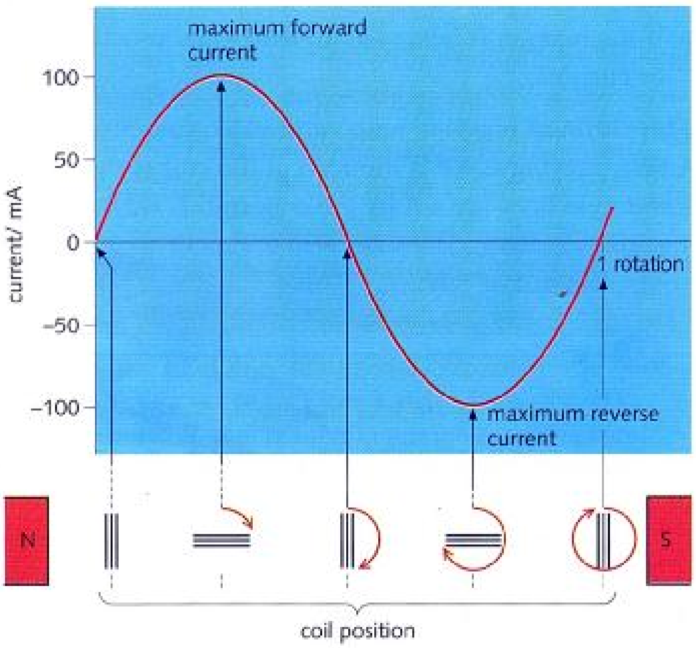
The following all increase the maximum EMF (and the current):

- increasing the number of turns on the coil
- increasing the area of the coil
- using a stronger magnet
- rotating the coil faster.

Faster rotation also increases the frequency of the AC. Mains generators must keep a steady frequency – for example, 50 Hz (cycles per second) in the UK.



Simple AC generator, connected to a bulb



Graph showing the generator's AC output

Practical generators

◀ One of the alternators (AC generators) in a large power station. It is turned by a turbine, blown round by the force of high-pressure steam. It generates an EMF of over 30 000 volts, although consumers get their supply at a much lower voltage than this.

▲ Alternator from a car

Unlike the simple generator on the opposite page, most AC generators have a fixed set of coils arranged around a rotating electromagnet. The various coils are made from many hundreds of turns of wire. To create the strongest possible magnetic field, they are wound on specially-shaped cores containing iron. Slip rings and brushes are still used, but only to carry current to the spinning electromagnet. As the other coils are fixed, the current delivered by the generator does not have to flow through sliding contacts. (Sliding contacts can overheat if the current is very high.)

Direct current (DC) is 'one-way' current like that from a battery. DC generators are similar in construction to DC motors, with a fixed magnet, rotating coil, brushes, and a commutator to reverse the connections to the outside circuit every half-turn. When the coil is rotated, alternating current is generated. However, the action of the commutator means that the current in the outside circuit always flows the same way – in other words, it is DC.

Cars need DC for recharging the battery and running other circuits. To produce current, the engine turns a generator. However, an alternator is used, rather than a DC generator, because it can deliver more current. A device called a **rectifier** changes its AC output to DC.

Moving-coil microphone

Like generators, some microphones use the principle of electromagnetic induction.

In a moving-coil microphone, incoming sound waves strike a thin metal plate called a diaphragm and make it vibrate. The vibrating diaphragm moves a tiny coil backwards and forwards in a magnetic field. As a result, a small alternating current is induced in the coil. When amplified (made larger), the current can be used to drive a loudspeaker.

Q

1 The diagram on the right shows the end view of the coil in a simple generator. The coil is being rotated. It is connected through brushes and slip rings to an outside circuit.

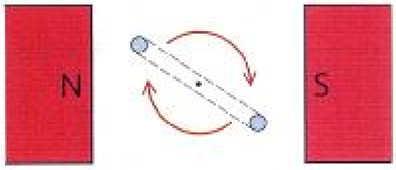
a) What type of current is generated in the coil, AC or DC? Explain why it is this type of current being generated.

b) Give *three* ways in which the current could be increased.

c) The current varies as the coil rotates. What is the position of the coil when the current is a maximum? Why is the current a maximum in this position?

d) What is the position of the coil when the current is zero? Why is the current zero in this position?

2 Give *three* differences between the simple AC generator on the opposite page and most practical AC generators.

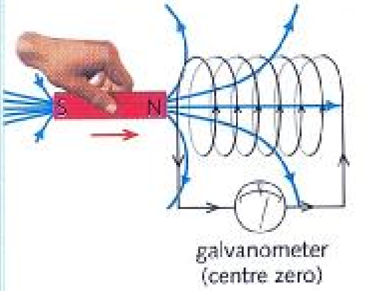


Related topics: EMF **8.04**; mains AC **8.11**; electromagnets **9.04**; DC motors **9.06**; electromagnetic induction **9.07**; rectifiers **10.02**

9.09 Coils and transformers (1)

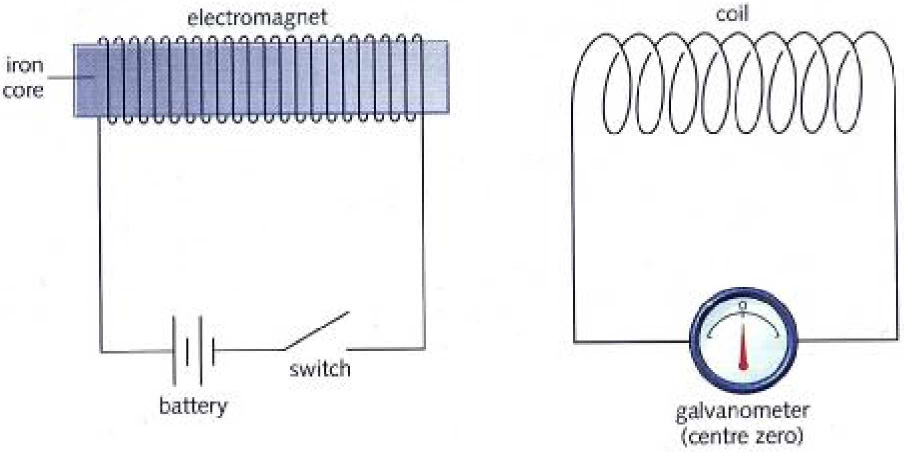
A *moving* magnetic field can induce an EMF (voltage) in a conductor, as on the left. A *changing* magnetic field can have the same effect.

Electromagnetic induction



If a magnet is pushed in or out of a coil, the coil cuts through magnetic field lines, so an EMF (voltage) is induced in it. This is an example of electromagnetic induction. If the coil is in a complete circuit, the induced voltage makes a current flow.

Mutual induction

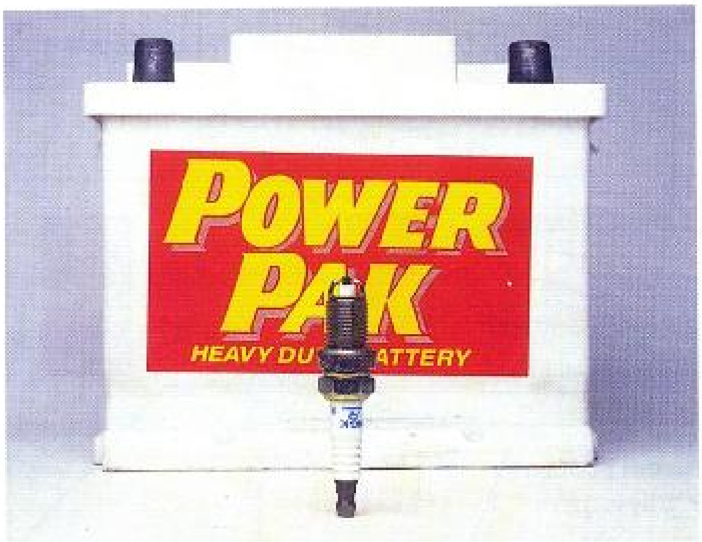


As the electromagnet above is switched on, an EMF is induced in the other coil, but only for a fraction of a second. The effect is equivalent to pushing a magnet towards the coil very fast. With a steady current through the electromagnet, no EMF is induced because the magnetic field is not changing. As the electromagnet is switched off, an EMF is induced in the opposite direction. The effect is equivalent to pulling a magnet away from the coil very fast.

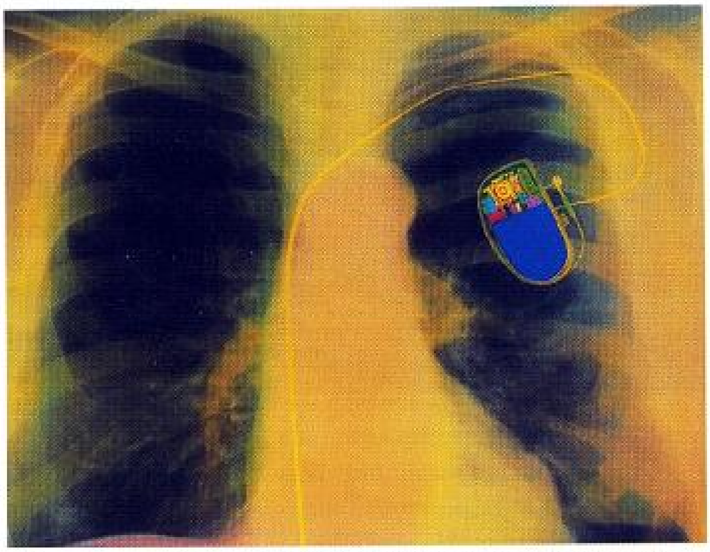
The induced EMF at switch-on or switch-off is increased if:

- the core of the electromagnet goes right through the second coil
- the number of turns on the second coil is increased.

When coils are magnetically linked, as above, so that a changing current in one causes an induced EMF in the other, this is called **mutual induction**.

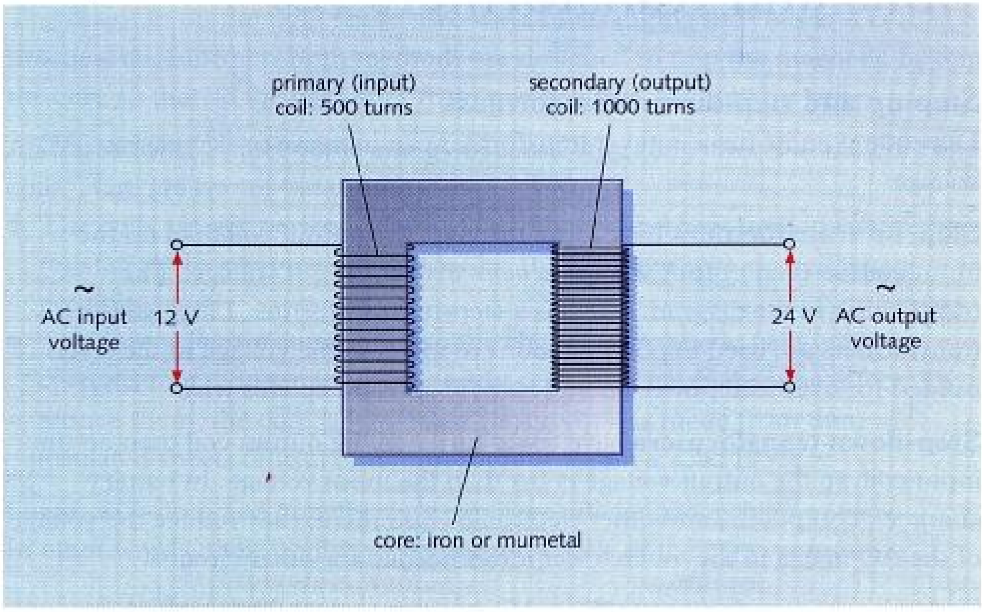


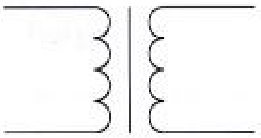
Using mutual induction, 10 000 volts for spark plugs is produced from a 12 volt supply. The high voltage is induced in a coil by switching an electromagnet on and off electronically.



A heart pacemaker uses mutual induction. Pulses of current through a coil in the pacemaker unit induce pulses in a coil fitted in the patient's chest. These trigger heartbeats.

A simple transformer





Symbol for a transformer

AC voltages can be increased or decreased using a **transformer**. A simple transformer is shown in the diagram above. It works by mutual induction.

When alternating current flows through the **primary** (input) coil, it sets up an alternating magnetic field in the core and, therefore, in the **secondary** (output) coil. This changing field induces an alternating voltage in the output coil. Provided all the field lines pass through both coils, and the coils waste no energy because of heating effects, the following equation applies:

$$\frac{\text{output voltage}}{\text{input voltage}} = \frac{\text{turns on output coil}}{\text{turns on input coil}}$$

In symbols: $$\frac{V_2}{V_1} = \frac{n_2}{n_1}$$

For the transformer above, $n_2/n_1 = 1000/500 = 2$. The transformer has a **turns ratio** of 2. The same ratio links the voltages: $V_2/V_1 = 24/12 = 2$. Put in words, the output coil has twice the number of turns of the input coil, so the output voltage is twice the input voltage.

A transformer does not give you something for nothing. If it increases voltage, it reduces current. This is explained in the next spread.

DC and AC

Direct current (DC) flows one way only.

Alternating current (AC) flows alternately backwards and forwards.

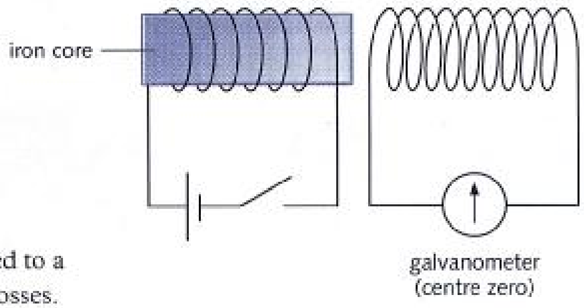
PD, EMF, and voltage

PD (potential difference) is the scientific name for voltage. The PD produced within a battery or other source is called the EMF (electromotive force).

For convenience, engineers often use the word voltage rather than PD or EMF, especially when dealing with AC.

Voltages in AC circuits are commonly called AC voltages, although, strictly speaking, an 'alternating current voltage' doesn't make much sense!

Q



1 In the experiment on the right, what happens when
  a) the switch is closed (turned ON)
  b) the switch is left in the closed (ON) position
  c) the switch is then opened (turned OFF)?
2 In the experiment on the right, what would be the effect of
  a) extending the iron core so that it goes through both coils
  b) replacing the battery and switch by an AC supply?
3 A transformer has a turns ratio of 1/4. Its input coil is connected to a 12 volt AC supply. Assuming there are no energy or field line losses.
  a) What is the output voltage?
  b) What turns ratio would be required for an output voltage of 36 volts?

Related topics: PD and EMF **8.04**; magnetic field lines **9.02**; electromagnets **9.04**; electromagnetic induction **9.07**; DC and AC **9.08**

9.10 Coils and transformers (2)

A small transformer with other components from inside a TV

Power essentials

Energy is measured in joules (J).

Power is measured in watts (W).

An appliance with a power output of 1000 W delivers energy at the rate of 1000 joules per second.

In circuits, power can be calculated using this equation:

power = voltage × current
(watts) (volts) (amperes)
(W) (V) (A)

Step-up and step-down transformers

Depending on its turns ratio, a transformer can increase or decrease an AC voltage.

Step-up transformers have more turns on the output coil than on the input coil, so their output voltage is *more* than the input voltage. The transformer in the diagram below is a step-up transformer. Large step-up transformers are used in power stations to increase the voltage to the levels needed for overhead power lines. The next spread explains why.

Step-down transformers have fewer turns on the output coil than on the input coil, so the output voltage is *less* than the input voltage. In battery chargers, computers, and other electronic equipment, they reduce the voltage of the AC mains to the much lower levels needed for other circuits.

Both types of transformer work on AC, but not on DC. Unless there is a *changing* current in the input coil, no voltage is induced in the output coil. Connecting a transformer to a DC supply can damage it. A high current flows through the input coil which can make it overheat.

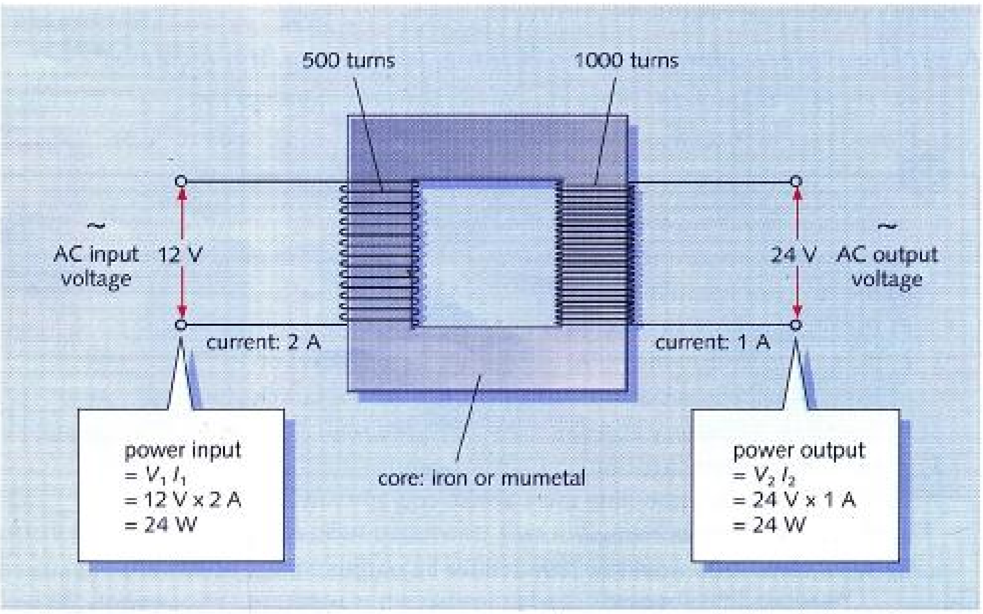
Power through a transformer

If no energy is wasted in a transformer, the power (energy per second) delivered by the output coil will be the same as the power supplied to the input coil. So:

input voltage × input current = output voltage × output current

In symbols: $V_1 I_1 = V_2 I_2$

As voltage × current is the same on both sides of a transformer, it follows that a transformer which *increases* the voltage will *reduce* the current in the same proportion, and vice versa. The figures in the diagram below illustrate this.



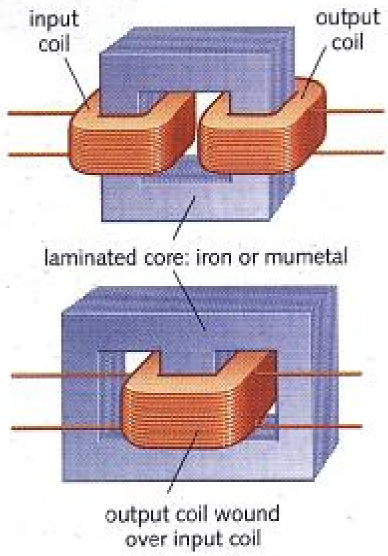
Practical transformers

The diagram on the right shows two ways of arranging the coils and core in a practical transformer. Both methods are designed to trap the magnetic field in the core so that all the field lines from one coil pass through the other.

All transformers waste some energy because of heating effects in the core and coils. Here are two of the causes:

- The coils are not perfect electrical conductors and heat up because of their resistance. To keep the resistance low, thick copper wire is used where possible.
- The core is itself a conductor, so the changing magnetic field induces currents in it. These circulating **eddy currents** have a heating effect. To reduce them, the core is laminated (layered): it is made from thin, insulated sheets of iron or Mumetal, rather than a solid block.

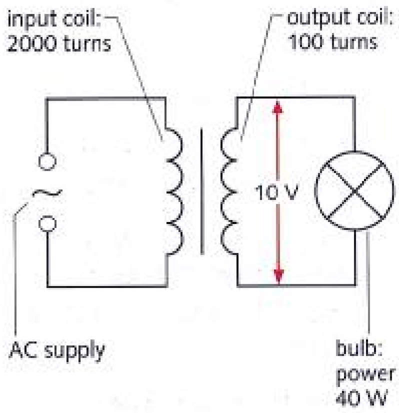
Large, well-designed transformers can have efficiencies as high as 99%. In other words, their useful power output is 99% of their power input.



Practical transformers

Solving problems

Example Assuming that the transformer on the right has an efficiency of 100%, calculate **a)** the supply voltage **b)** the current through the input coil.



a) This is solved using the transformer equation: $\dfrac{V_2}{V_1} = \dfrac{n_2}{n_1}$

where V_1 is the supply voltage to be calculated.

Substituting values: $\dfrac{10\text{ V}}{\text{supply voltage}} = \dfrac{100}{2000}$

Rearranged, this gives: supply voltage $= 200\text{ V}$

b) This is solved using the power equation: $V_1 I_1 = V_2 I_2$

where $V_2 I_2$ is already known to be 40 W.

Substituting values: $200\text{ V} \times \text{input current} = 40\text{ W}$

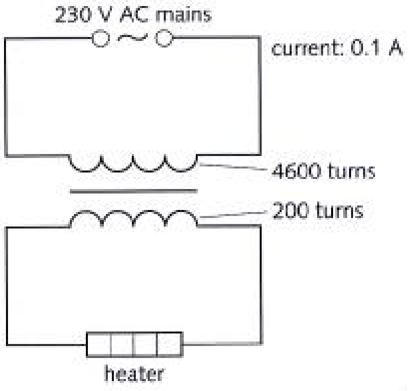
Rearranged, this gives: input current $= 0.2\text{ A}$

Q

1 How does a step-up transformer differ from a step-down transformer?

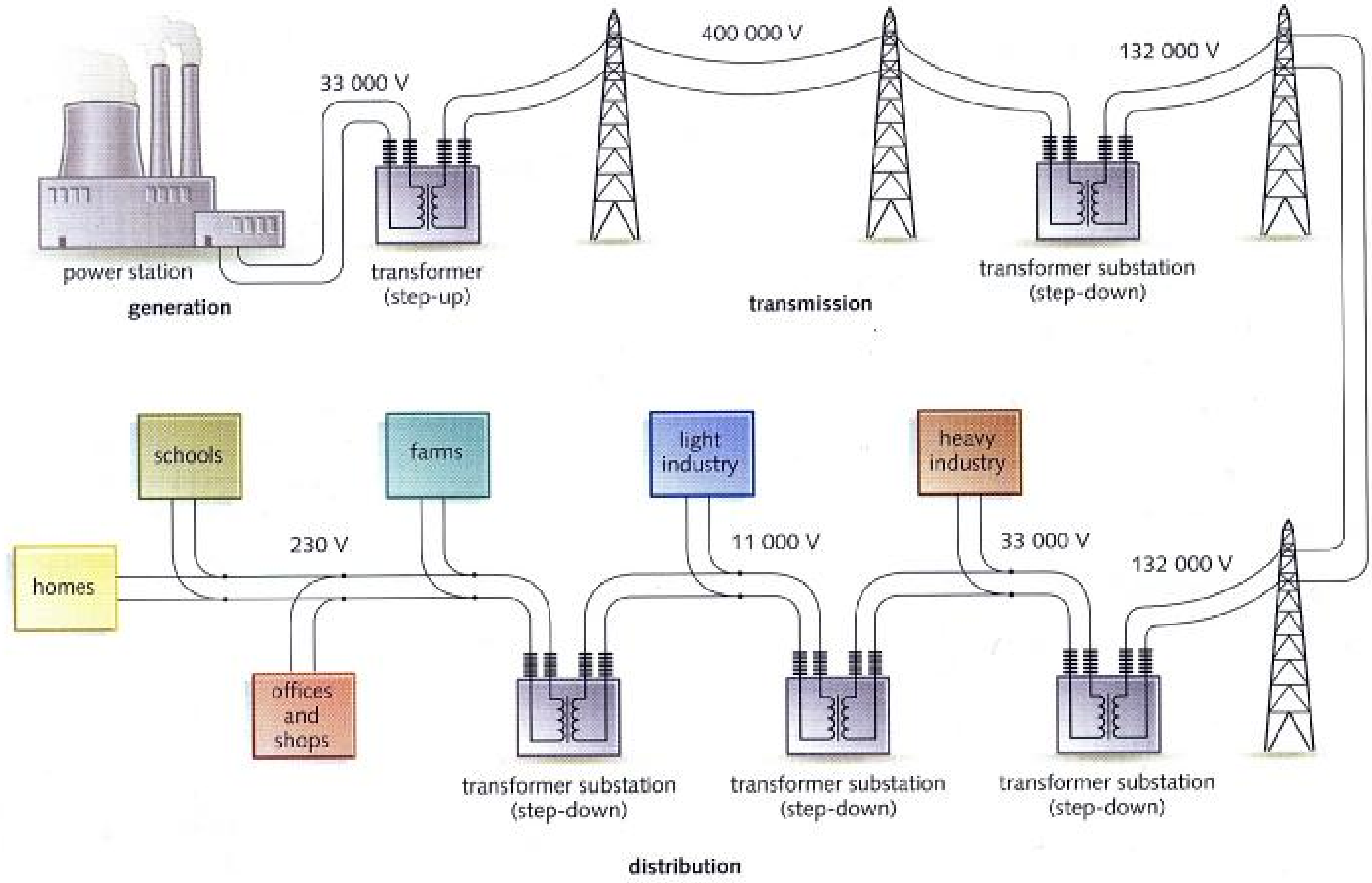
2 Explain each of the following:
  a) a transformer will not work on DC
  b) the core of a transformer needs to be laminated
  c) if a transformer increases voltage, it reduces current.

3 In the circuit on the right, a transformer connected to the 230 V AC mains is providing power for a low-voltage heater. Using the information in the diagram, and assuming that the efficiency is 100%, calculate
  a) the voltage across the heater
  b) the power supplied by the mains
  c) the power delivered to the heater
  d) the current through the heater.



Related topics: resistance **8.05**; power calculations **8.10**; DC and AC **9.08**; power transmission **9.11**; eddy currents **9.12**

9.11 Power across the country



Power essentials

An appliance with a power output of 1000 watts (W) delivers energy at the rate of 1000 joules per second.

In circuits

power	=	voltage	×	current
(watts)		(volts)		(amperes)
(W)		(V)		(A)

Transformer essentials

Transformers are used to increase or decrease AC voltages. If a transformer is 100% efficient, its power output and input are equal. So if it *increases* voltage, it *reduces* current in the same proportion so that 'voltage × current' stays the same.

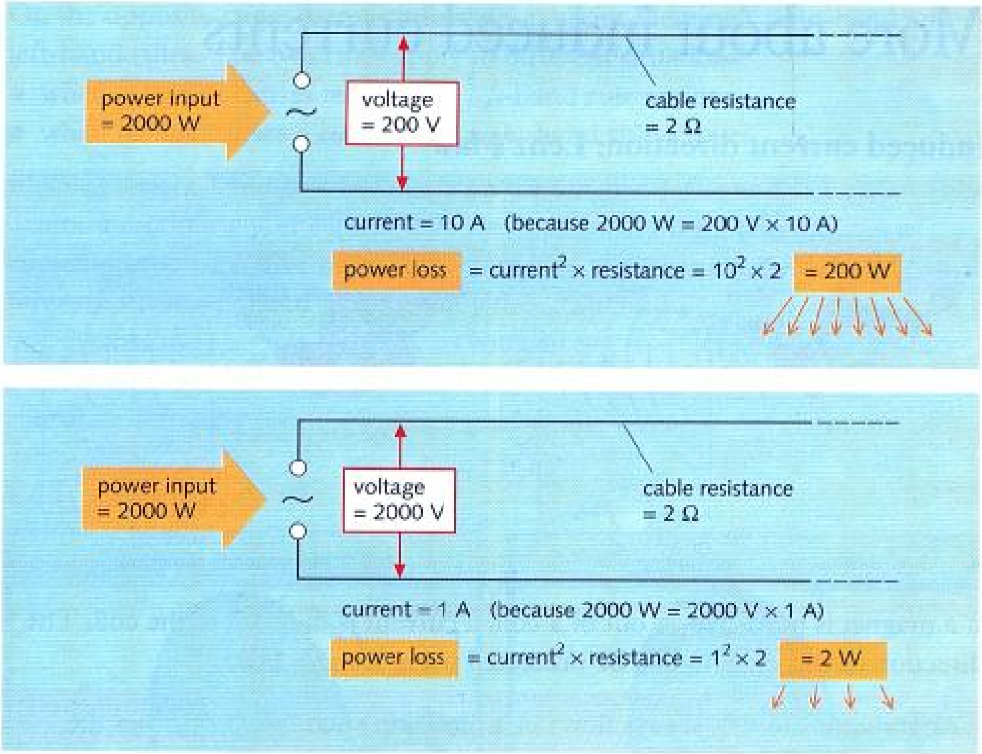
Power for the AC mains is *generated* in power stations, *transmitted* (sent) through long-distance cables, and then *distributed* to consumers.

Typically, a large power station might contain four generators, each producing a current of 20 000 amperes at a voltage of 33 000 volts. The current from each generator is fed to a huge step-up transformer which transfers power to overhead cables at a greatly increased voltage (275 000 V or 400 000 V in the UK). The reason for doing this is explained on the next page. The cables feed power to a nationwide supply network called the **Grid**. Using the Grid, power stations in areas where the demand is low can be used to supply areas where the demand is high. Also power stations can be sited away from heavily populated areas.

Power from the Grid is distributed by a series of **substations**. These contain step-down transformers which reduce the voltage in stages to the level needed by consumers. In Europe, for example, this is 230 V for home consumers, although industry usually takes its power at a higher voltage.

Transmission issues

AC or DC? Alternating current (AC) is used for the mains. On a large scale, it can be generated more efficiently than 'one-way' direct current (DC). However, the main advantage of AC is that voltages can be stepped up or down using transformers. Transformers will not work with DC.



◀ These calculations show the power losses in a cable when the same amount of power is sent at two different voltages (for simplicity, some units have been omitted).

Resistance and power loss

The resistance of a conductor is measured in ohms (Ω).

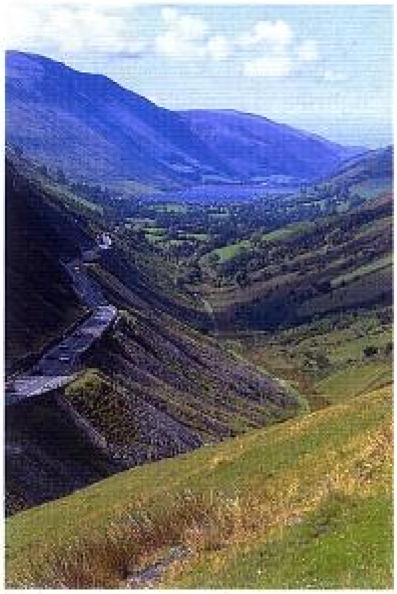
When a current flows through a resistance, it has a heating effect, so power is wasted. The power loss can be calculated like this:

$$\text{power loss} = \text{current}^2 \times \text{resistance}$$

High or low voltage? Transmission cables are good conductors, but they still have significant resistance – especially when they are hundreds of kilometres long. This means that energy is wasted because of the heating effect of the current. The calculations above demonstrate why less power is lost from a cable if power is transmitted through it at high voltage. By using a transformer to increase the voltage, the current is reduced, so thinner, lighter, and cheaper cables can be used.

Overhead or underground? High-voltage cables are the cheapest way of sending power over long distances. However, to prevent sparking, the only effective way of insulating the cables is to keep huge air spaces around them. That is why they have to be suspended from pylons.

Underground cables are more difficult to insulate and must therefore be used at lower voltages. To transmit the same power, they have to carry a higher current. This means that they must be thicker. They are also more expensive to lay. Despite their extra cost, underground cables are used in areas of outstanding natural beauty, where pylons would damage the environment by spoiling the landscape.



Pylons and overhead cables are not usually permitted in areas like this.

Q

1 What is the main advantage of the Grid network?

2 What are substations for?

3 Explain each of the following.
  a) AC rather than DC is used for transmitting mains power.
  b) The voltage is stepped up before power from a generator is fed to overhead transmission cables.

4 Give an example of where underground transmission cables might be used instead of overhead ones, despite the extra cost.

5 The second paragraph on the opposite page describes the output of the four generators in a typical, large power station. Calculate the power station's total power output in MW. (1 MW = 1 000 000 W)

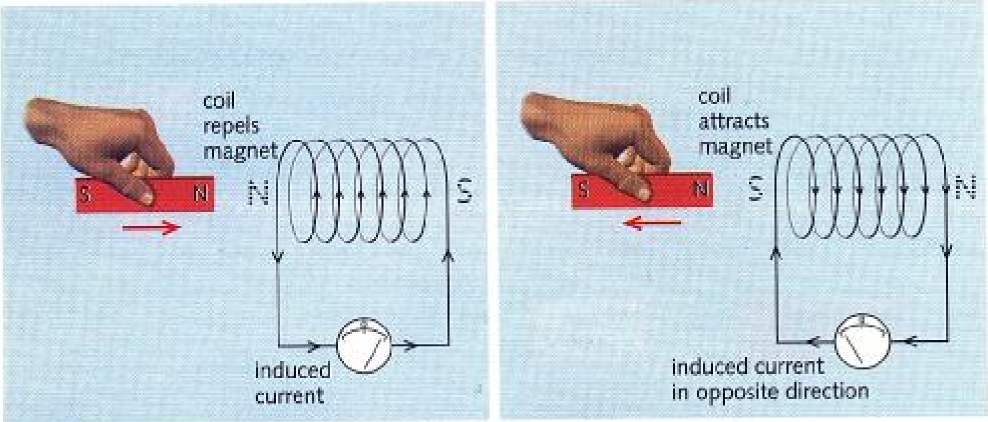
6 The diagram at the top of this page compares power losses from a cable at two different voltages. Calculate the power loss if the same power is sent at 20 000 V.

7 4 kW of power is fed to a transmission cable of resistance 5 Ω. Calculate the power loss in the cable if the power is transmitted at **a)** 200 V **b)** 200 000 V.

Related topics: power stations **4.06–4.07**; power dissipation **8.10**; mains electricity **8.11–8.12**; generators **9.08**; transformers **9.09–9.10**

9.12 More about induced currents

Induced current direction: Lenz's law



If a magnet is moved in or out of a coil, a current is induced in the coil. The direction of this current can be predicted using **Lenz's law**:

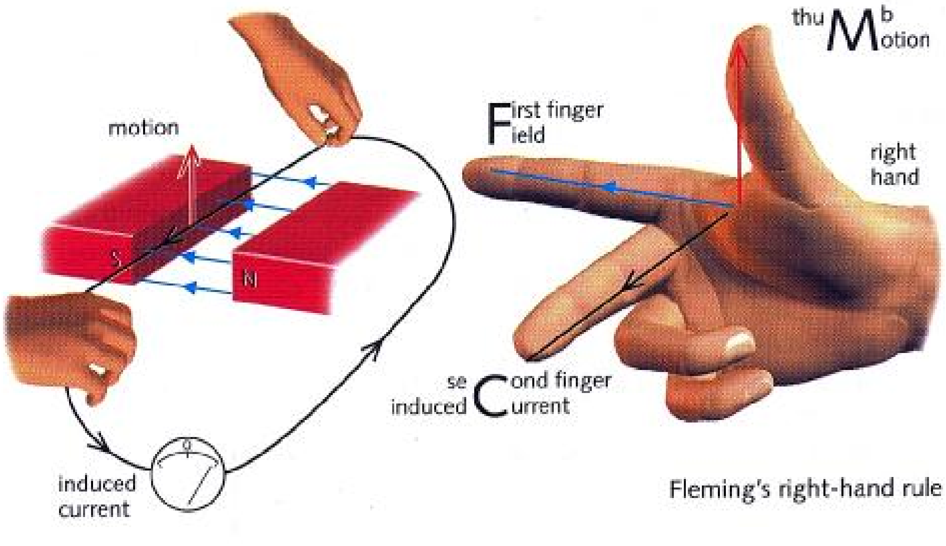
> An induced current always flows in a direction such that it opposes the change which produced it.

Above, for example, the induced current turns the coil into a weak electromagnet whose N pole *opposes* the approaching N pole of the magnet. When the magnet is pulled *out of* the coil, the induced current alters direction and the poles of the coil are reversed. This time, the coil attracts the magnet as it is pulled away. So, once again, the change is opposed.

Lenz's law is an example of the law of conservation of energy. Energy is spent when a current flows round a circuit, so energy must be spent to induce the current in the first place. In the example above, you have to spend energy to move the magnet against the opposing force.

Induced current direction: Fleming's right-hand rule

If a straight wire (in a complete circuit) is moving at right angles to a magnetic field, the direction of the induced current can be found using **Fleming's right-hand rule**, as shown below:

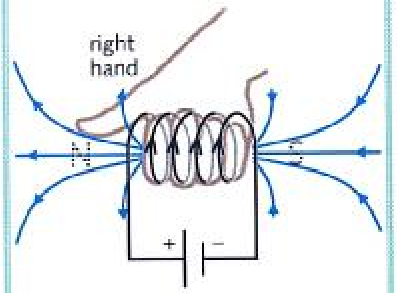


Fleming's right-hand rule

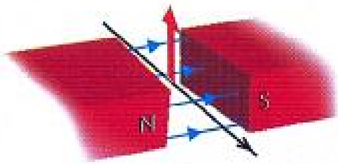
Magnetic essentials

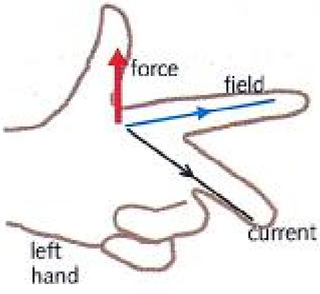
Like magnetic poles repel; unlike ones attract. Magnetic field lines run from the N pole of a magnet to the S pole.

In diagrams, the *conventional* current direction is used. This runs from the + of the supply to the -.



A current-carrying coil produces a magnetic field. The **right-hand grip rule** above tells you which end is the N pole. It is the end your thumb points at when your fingers point the same way as the current.





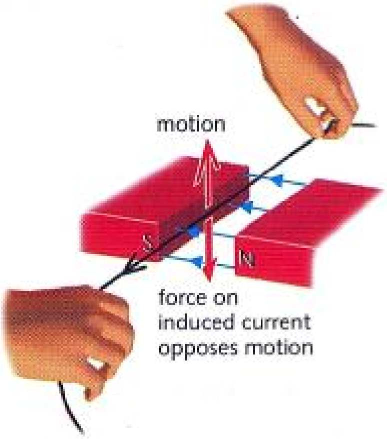
If a current-carrying wire is in a magnetic field as above, the direction of the force is given by **Fleming's left-hand rule**.

If a conductor is moving through a magnetic field, or in a changing field, an EMF (voltage) is induced in it.

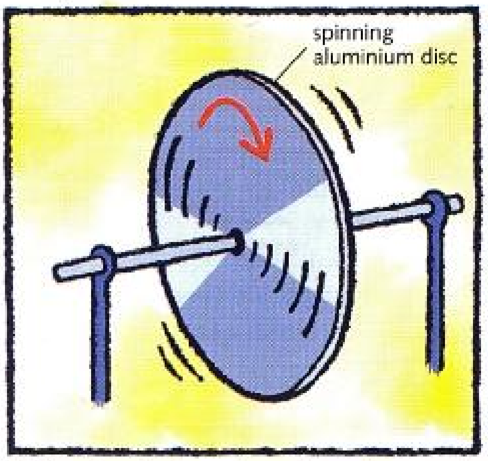
On the opposite page, there is information about Fleming's right-hand and left-hand rules. The two rules apply to different situations:

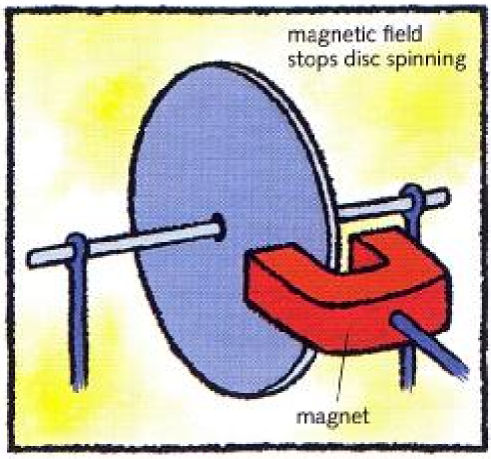
- when a *current* causes *motion*, the *left*-hand rule applies
- when *motion* causes a *current*, the *right*-hand rule applies.

Fleming's right-hand rule follows from the left-hand rule and Lenz's law. The diagram on the right illustrates this. Here, the upward motion induces a current in the wire. The induced current is in the magnetic field, so there is a force on it whose direction is given by the *left*-hand rule. The force must be downwards to *oppose* the motion, so you can use this fact and the left-hand rule to work out which way the current must flow. However, the *right*-hand rule gives the same result – without you having to reason out all the steps!



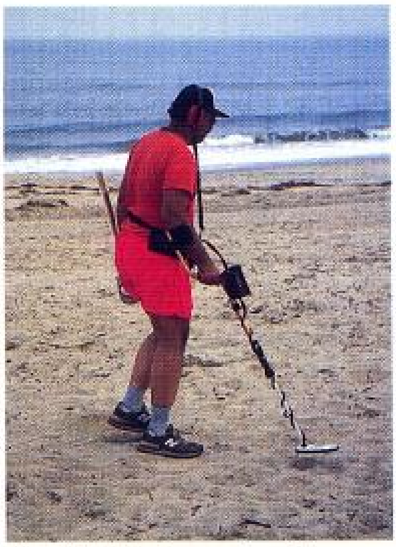
Eddy currents





If the aluminium disc above is set spinning, it may be many seconds before frictional force finally brings it to rest. However, if it spinning between the poles of a magnet, it stops almost immediately. This is because the disc is a good conductor and currents are induced in it as it moves through the magnetic field. These are called **eddy currents**. They produce a magnetic field which, by Lenz's law, opposes the motion of the disc. Eddy currents occur wherever pieces of metal are in a changing magnetic field – for example, in the core of a transformer.

Metal detectors rely on eddy currents. Typically, a pulse of current through a flat coil produces a changing magnetic field. This induces eddy currents in any metal object underneath. The eddy currents give off their own changing field which induces a second pulse in the coil. This is detected electronically.



A metal detector creates eddy currents in metal objects and then detects the magnetic fields produced.

Q

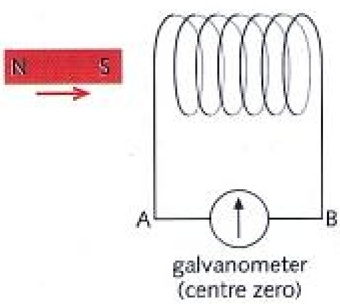
1 Look at the diagrams on the opposite page, illustrating Fleming's right-hand rule. If the directions of the magnetic field and the motion were both reversed, how would this affect the direction of the induced current?

2 On the right, a magnet is being moved towards a coil.

a) As current is induced in the coil, what type of pole is formed at the left end of the coil? Give a reason for your answer.

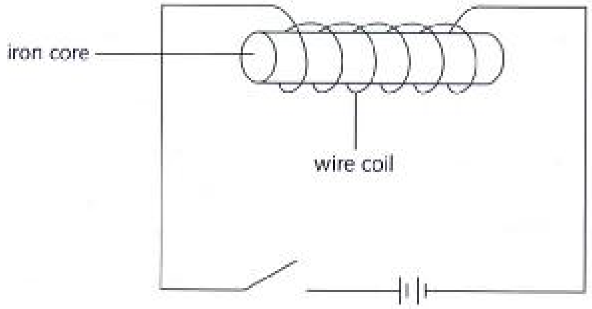
b) In which direction does the (conventional) current flow through the meter, AB or BA?

3 Aluminium is non-magnetic. Yet a freely-spinning aluminium disc quickly stops moving if a magnet is brought close to it. Explain why.



Related topics: law of conservation of energy **4.02**; right-hand grip rule **9.03**; Fleming's left-hand rule **9.05**; induced current **9.07**

1 An electromagnet is made by winding wire around an iron core.



The diagram shows an electromagnet connected to a circuit.

a) State **two** ways of making the strength of the electromagnet weaker. [2]

b) Explain why the core is made of iron instead of steel. [1]

WJEC

2 **A**, **B**, **C** and **D** are small blocks of different materials. The table below shows what happens when two of the blocks are placed near one another.

Arrangement of blocks		*Effect*
A	B	attraction
B	C	attraction
A	C	no effect
B	D	no effect

a magnet	*a magnetic material*	*a non-magnetic material*

Use one of the phrases in the above boxes to describe the magnetic property of each block. Each phrase may be used once, more than once or not at all.

a) Block **A** is ____________

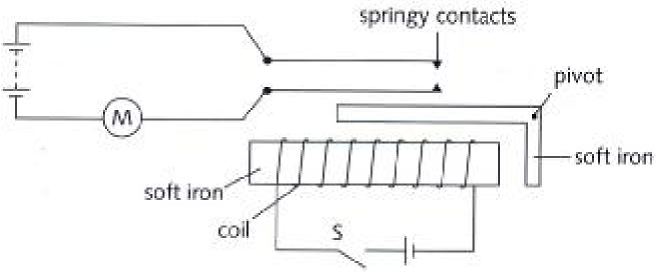
b) Block **B** is ____________

c) Block **C** is ____________

d) Block **D** is ____________ [4]

WJEC

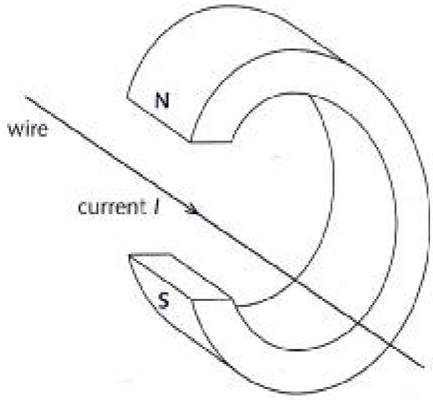
3 The figure below shows a circuit, that includes an electrical relay, used to switch on a motor M.



Explain in detail, how closing switch S causes the motor M to start. [4]

UCLES (O)

4 The diagram shows a long wire placed between the poles of a magnet. When current ***I*** flows through the wire, a force acts on the wire causing it to move.



a) Use Fleming's left hand rule to find the direction of the force on the wire. Copy the diagram and show the direction of the force on your copy with an arrow labelled ***F***. [1]

b) State what happens to the force on the wire when

(i) the size of the current through the wire is increased, [1]

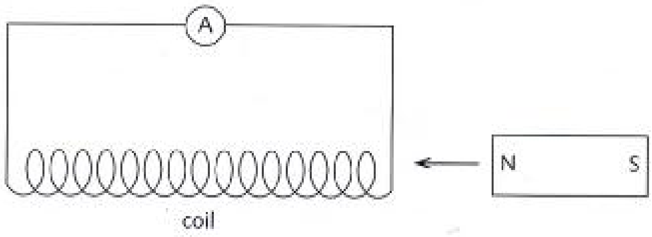
(ii) a weaker magnet is used, [1]

(iii) the direction of the current is reversed. [1]

c) Name **one** practical device which uses this effect. [1]

WJEC

5 The diagram below shows a permanent magnet being moved towards a coil whose ends are connected to a sensitive ammeter. As the magnet approaches, the ammeter needle gives a **small** deflection to the **left**.



a) State what you would expect the ammeter to show if, in turn,

(i) the magnet was pulled away from the coil

(ii) the magnet was reversed so that the S pole was moved towards the coil

(iii) the magnet was now pulled away from the coil, at a much higher speed. [4]

b) Give the name of the process which is illustrated by these experiments. [1]

UCLES (O)

6 **a)** The chemical energy stored in a fossil fuel produces heat energy when the fuel is burned. Describe how this heat energy is then used to produce electrical energy at a power station. [2]

b) Power stations use transformers to increase the voltage to very high values before transmitting it to all parts of the country. Explain why electricity is transmitted at very high voltages. [1]

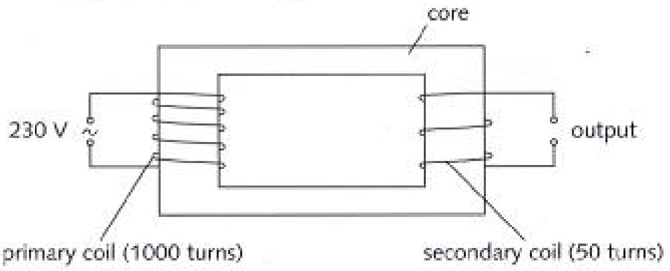
c) A power station produces electricity at 25 000 V which is increased by a transformer to 400 000 V. The transformer has 2000 turns on its primary coil. Use the formula

$$\frac{\text{voltage across primary coil}}{\text{voltage across secondary coil}} = \frac{\text{number of turns on primary coil}}{\text{number of turns on secondary coil}}$$

to calculate the number of turns on its secondary coil. [2]

WJEC

7 The diagram shows a simple transformer.



The transformer is a **step-down** transformer.

a) What is a **step-down** transformer? [1]

b) How can you tell from the diagram that this is a **step-down** transformer? [1]

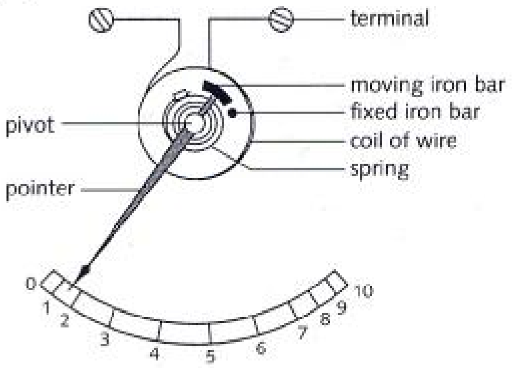
c) Calculate the output voltage of this transformer. [3]

d) Explain why transformers are used in the National Grid. [3]

e) What is the core of a transformer usually made of? [2]

MEG

8 The diagram shows the main parts of one type of ammeter. There are two short iron bars inside a coil of insulated wire. One bar is fixed and cannot move and the other is on the end of a pivoted pointer. The diagram shows the ammeter in use and measuring a current of 1.5 amperes (A).



a) How much electrical charge will pass through this ammeter in one minute? Include in your answer the equation you are going to use. Show clearly how you get to your final answer and give the unit. [3]

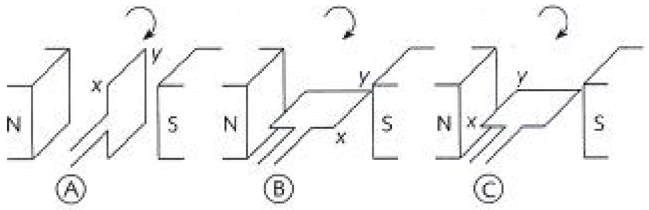
b) (i) Apart from heat, what will be produced by the coil of wire when the electricity passes through it? [1]

(ii) What effect will this have on the two iron bars? What causes the effect? Draw one or more diagrams if this will help you to explain. [4]

To answer part a), you will need information from Section 8

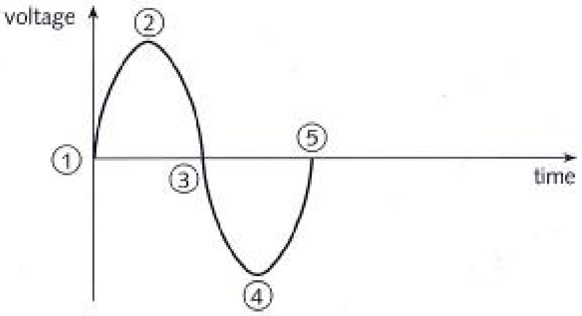
SEG

9 **a)** When a coil rotates in a magnetic field, an alternating voltage is produced. Explain how the voltage is produced [2]



b) The diagrams A B and C show three positions of a coil as it rotates clockwise in a magnetic field produced by two poles.

The graph below shows how the voltage produced changes as the coil rotates.



When the coil is in the position shown by diagram A, the output voltage is zero and is marked as 1 on the voltage-time graph. State which point on the voltage-time graph corresponds to the coil position shown by

(i) diagram B, [1]

(ii) diagram C. [1]

c) State **one** way of increasing the size of the voltage produced by **this** coil rotating in a magnetic field. [1]

WJEC

REVISION CHECKLIST

Photocopy the list of topics below and tick the boxes of the ones that are included in your examination syllabus. (Your teacher should be able to tell you which they are.) Use your list when you revise. The spread number in brackets tells you where to find more information.

☐ **1** The two types of magnetic pole. (9.01)

☐ **2** The direction of the force between magnetic poles. (9.01)

☐ **3** Induced magnetism: permanent and temporary magnets. (9.01)

☐ **4** Methods of making a magnet. (9.01 and 9.03)

☐ **5** Magnetic and non-magnetic materials. (9.01)

☐ **6** Hard and soft magnetic materials. (9.01)

☐ **7** Demagnetizing a magnet. (9.01 and 9.03)

☐ **8** The magnetic field around a magnet. (9.02)

☐ **9** Finding field patterns with a plotting compass. (9.02)

☐ **10** The Earth's magnetic field. (9.02)

☐ **11** The magnetic field around a current-carrying wire. (9.03)

☐ **12** The magnetic field around a current-carrying coil. (9.03)

☐ **13** Factors affecting the magnetic field from a coil. (9.03)

☐ **14** The right-hand grip rule for poles. (9.03)

☐ **15** The electromagnet. (9.04)

☐ **16** Factors affecting an electromagnet's field strength. (9.04)

☐ **17** How a magnetic relay works. (9.04)

☐ **18** How a circuit breaker works. (9.04)

☐ **19** How an electric bell works. (9.04)

☐ **20** The force on a current in a magnetic field, and the factors affecting it. (9.05)

☐ **21** Fleming's left-hand rule. (9.05)

☐ **22** How a moving-coil loudspeaker works. (9.05)

☐ **23** The turning effect on a current-carrying coil in a magnetic field. (9.05)

☐ **24** How a simple DC motor works. (9.06)

☐ **25** Features of practical electric motors. (9.06)

☐ **26** Electromagnetic induction and the factors affecting it. (9.07)

☐ **27** Demonstrating an induced EMF (voltage) in a coil. (9.07)

☐ **28** Faraday's law of electromagnetic induction. (9.07)

☐ **29** How a simple AC generator works. (9.08)

☐ **30** Features of practical generators. (9.08)

☐ **31** AC voltage and current values. (9.08)

☐ **32** Demonstrating mutual induction. (9.09)

☐ **33** The action of a transformer. (9.09)

☐ **34** The equation linking a transformer's input and output voltages. (9.09)

☐ **35** The difference between a step-up and step-down transformer. (9.10)

☐ **36** The equation linking a transformer's input and output powers. (9.10)

☐ **37** Practical transformer design. (9.10)

☐ **38** The transmission and distribution of mains power across country. (9.11)

☐ **39** Why AC is used for power transmission. (9.11)

☐ **40** Why power is transmitted at high voltage. (9.11)

☐ **41** Lenz's law. (9.12)

☐ **42** Fleming's right-hand rule. (9.12)

☐ **43** Eddy currents and their effects. (9.12)