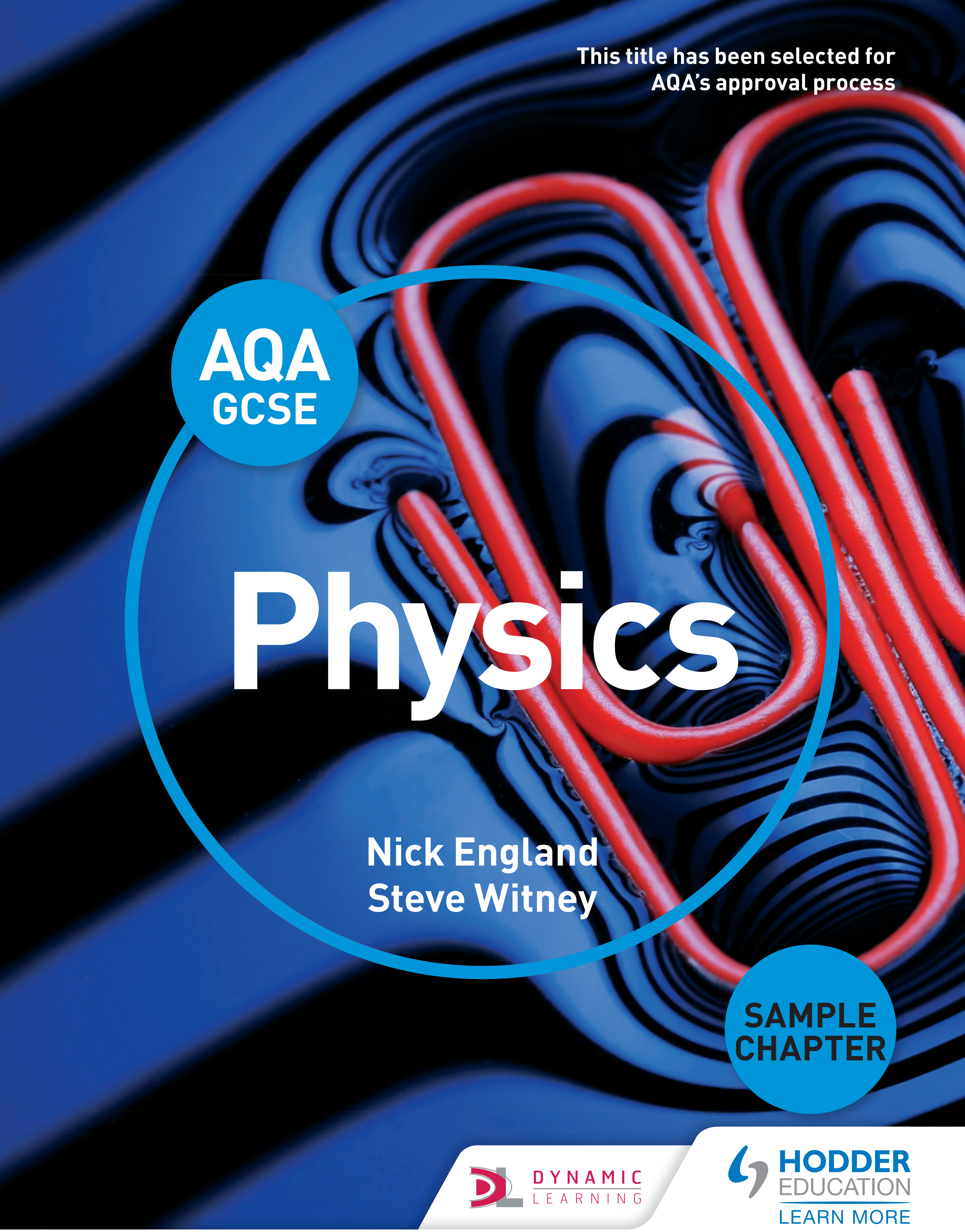

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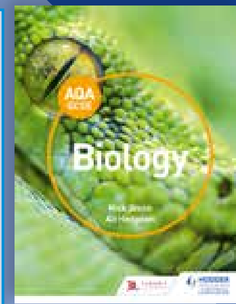

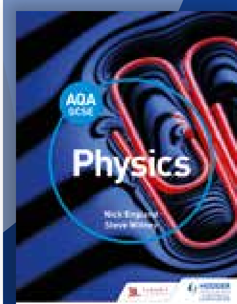

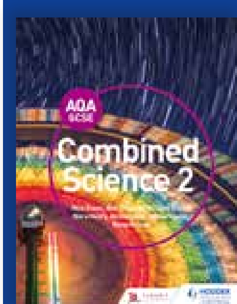

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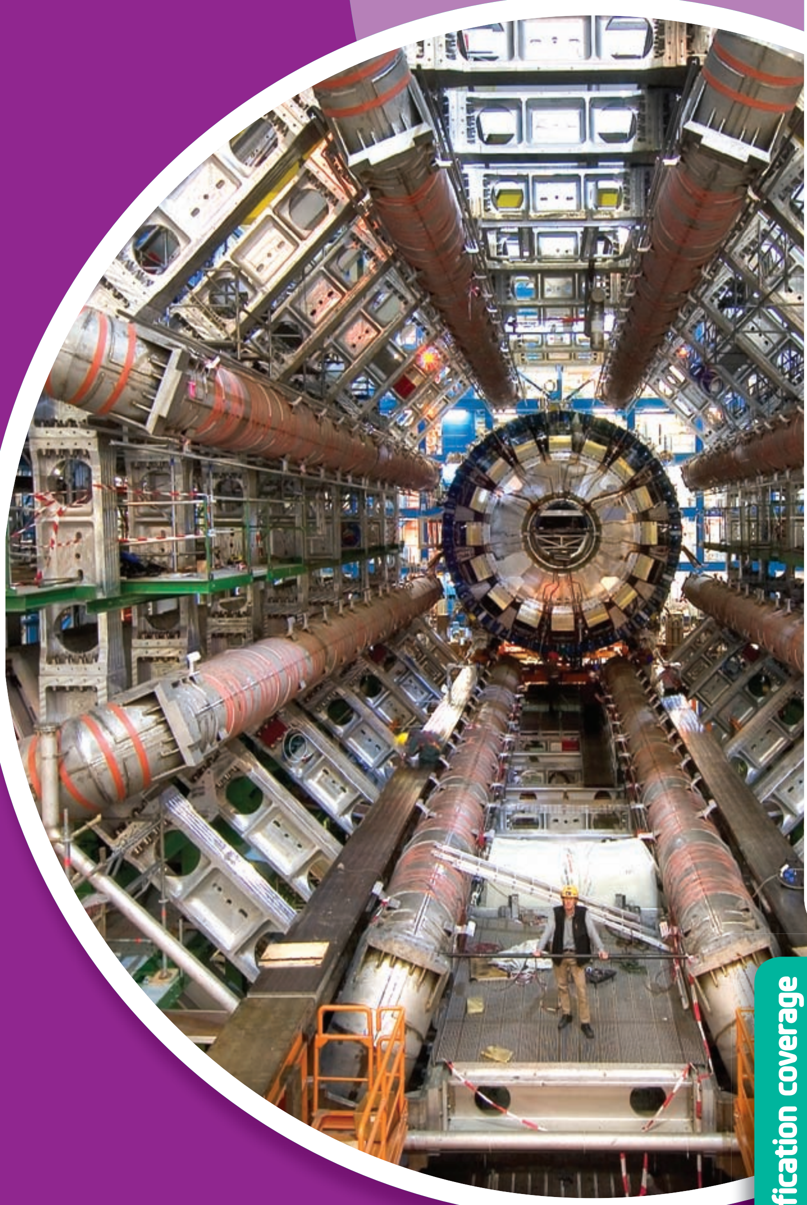
5 Magnetism and electromagnetism

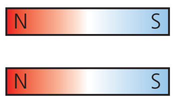


At home you might use a magnet for a purpose as simple as attaching your shopping list to the fridge door. The photograph opposite shows a completely different application of magnetism. Here you can see central view of a particle detector at the Large Hadron Collider in the European Centre for Nuclear Research (CERN). The particle detector is an arrangement of eight magnetic coils (each weighing 100 tonnes), which are used to deflect high-energy particles into the central detector. The coils are cooled to a temperature of −269 °C at which temperature the coils are superconducting – this means that the coils have no electrical resistance. A current of about 21 000 A is used to produce very strong magnetic fields.

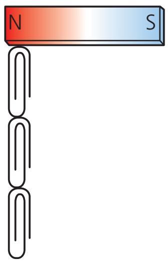
Specification coverage

This chapter covers specification points 4.5.1, Permanent and induced magnetism, magnetic forces and fields, 4.5.2, The motor effect and 4.5.3, Induced potential, transformers and the national grid.

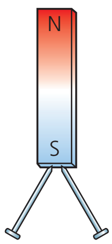
Prior knowledge



▲ Figure 5.1



▲ Figure 5.2



▲ Figure 5.3

Previously you could have learned:

- **Some materials are magnetic. The most common magnetic materials are iron and steel.**
- **Magnets have two poles, north and south.**
- **Magnets attract magnetic materials at a distance. Magnetism is a non-contact force.**
- **Two like poles repel each other: a north pole repels a north pole; a south pole repels a south pole.**
- **Two unlike poles attract: a north pole attracts a south pole.**

Test yourself on prior knowledge

1. Copy Figure 5.1 and add arrows to show the direction of the magnetic forces acting on each magnet.
2. In Figure 5.2, three steel paper clips are attracted to a magnet. Copy the sentences below and fill in the gaps to explain why this happens.
   - The magnetic field of the magnet . . . . the paper clips.
   - The top of each clip becomes a . . . . magnetic pole and the bottom of each paper clip becomes a . . . . magnetic pole. Each clip attracts the one below. The size of the magnetic attraction is greater than the . . . . of each clip.
3. Explain why the steel pins repel each other in Figure 5.3.

Permanent and induced magnetism, magnetic forces and fields

Poles

Some metals, for example iron, steel, cobalt and nickel, are **magnetic**. A magnet will attract them. If you drop some steel pins on the floor you can pick them up using a magnet. A magnetic force is an example of a non-contact force, which acts over a distance.

In Figure 5.4, you can see a bar magnet which is hanging from a fine thread. When it is left for a while, one end always points north. This end of the magnet is called the **north-seeking pole**. The other end of the magnet is the **south-seeking pole**. We usually refer to these poles as the north and south poles of the magnet.

The magnetic forces on steel pins, iron filings and other magnetic objects are always greatest when they are near the poles of a magnet. Every magnet has two poles which are equally strong.

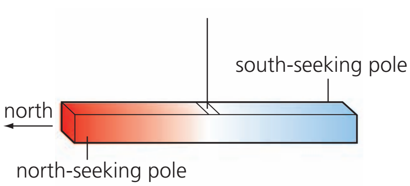
When you hold two magnets close together you find that two north poles (or two south poles) repel each other, but a south pole attracts a north pole (Figure 5.5).

KEY TERMS

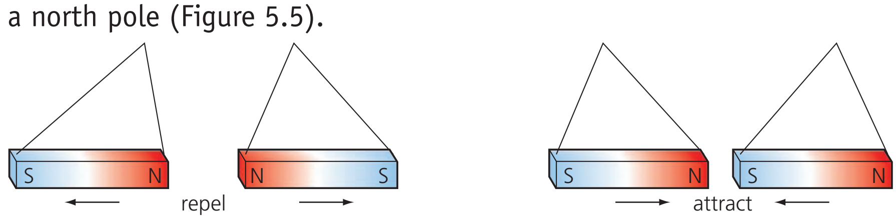
Magnetic Materials that will be attracted by a magnet.

North-seeking pole End of the magnet that points north.

South-seeking pole End of the magnet that points south.



▲ Figure 5.4 A bar magnet which is hanging from a fine thread



(a) like poles repel

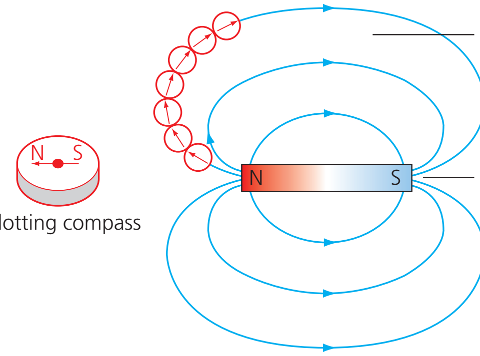
(b) unlike poles attract

▲ Figure 5.5 Hold two magnets close together

Magnetic fields

There is a magnetic field in the area around a magnet. In this area, a force will act on a magnetic object or another magnet. If the field is strong the force is big. If the field is weak the force is small.

The direction of a magnetic field can be found by using a small plotting compass. The compass needle always points along the direction of the field. Figure 5.6 shows how you can investigate the magnetic field near to a bar magnet using a compass.



▲ **Figure 5.6** Investigating the magnetic field near to a bar magnet, using a compass

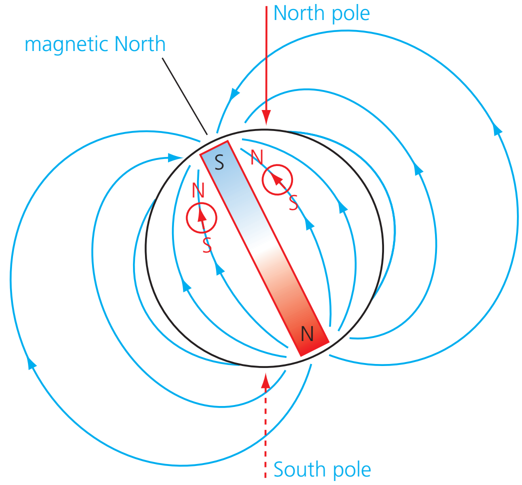
▲ **Figure 5.7** A compass, which you can use to find north when you are walking

We use magnetic field lines to represent a magnetic field. Magnetic field lines always start at a north pole and finish on a south pole. When the field lines are close together, the field is strong. The further apart the lines are, the weaker the field is. A magnetic field is strongest at the poles of a magnet and gets weaker as the distance from the magnet increases.

Magnetic field lines are not real, but are a useful model to help us to understand magnetic fields.

Compass

Figure 5.7 shows a compass that you can use to find north when you are walking. A compass contains a small bar magnet that can rotate. When a compass is held at rest in your hand, the needle always settles along a north south direction. This behaviour provides evidence that the Earth has a magnetic field. The pole that points towards north is called a north-seeking pole. Since unlike poles attract, this tells us that at the magnetic north pole, there is a south-seeking pole. Figure 5.8 shows the shape of the Earth's magnetic field.

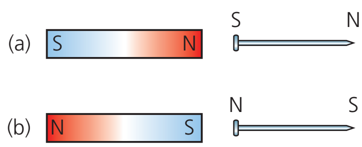


◀ **Figure 5.8** The shape of the Earth's magnetic field

KEY WORDS

Permanent magnet A permanent magnet produces its own magnetic field. It always has a north pole and a south pole.

Induced magnet An induced magnet becomes magnetic when it is placed in a magnetic field.



▲ **Figure 5.9** The nail becomes magnetised by the magnet's field. The nail is always attracted to the magnet.

Permanent and induced magnets

Some magnets are **permanent magnets**. Permanent magnets produce their own magnetic field. They always have a north and south pole. You can check to see if a magnet is a permanent magnet by placing it near to another magnet that you know is permanent. If both magnets are permanent, then you will be able to see that they can repel each other, as well as attract.

An **induced magnet** is a material that becomes magnetic when it is placed in a magnetic field. Induced magnets are temporary magnets. An induced magnet is always attracted towards a permanent magnet. This is because the induced magnet is magnetised in the direction of the permanent magnet's field. When the induced magnet is taken away from the permanent magnetic field it will lose all (or most) of its magnetism quickly.

Practical

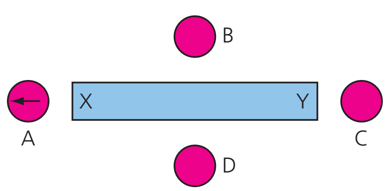
Plotting fields

Method

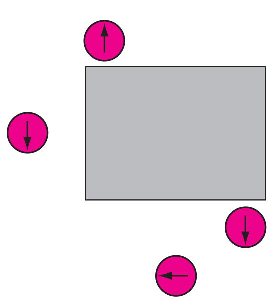
Use a bar magnet and a small plotting compass as shown in Figure 5.6.

Place the compass close to the north pole. Put a small mark at the end of the compass to show the direction of the field. Move the compass to see how the field changes direction.

Make a sketch of the shape of the magnetic field. Note that when you make a sketch, your field lines should not cross because the field can only point in one direction.



▲ **Figure 5.10** Bar magnet surrounded by four plotting compasses



▲ **Figure 5.11** Magnets in box

Test yourself

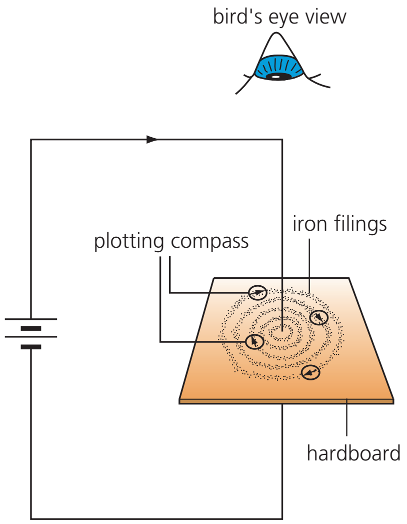
1. Which of the following items will a bar magnet pick up?
   Brass screw   Steel pin   Iron nail   Aluminium can
2. a) Figure 5.10 shows a bar magnet surrounded by four plotting compasses. Copy the diagram. Mark in the direction of the compass needle for the positions B, C and D.
   b) Which is the north pole of the magnet, X or Y? Give the reason for your answer.
3. Two bar magnets have been hidden in a box. Use the information in Figure 5.11 to suggest how they are arranged inside the box.
4. a) Explain what is meant by a permanent magnet.
   b) Explain what is meant by an induced magnet.

Show you can...

Complete this task to show you understand the nature of magnets.

Plan an experiment to show the difference between permanent and induced magnets.

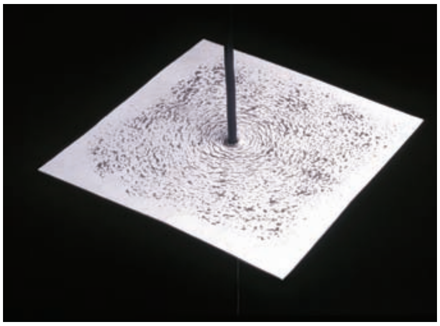
The motor effect



▲ **Figure 5.12** This experiment shows there is a magnetic field around a current-carrying wire

KEY WORD

Right-hand grip rule A way to work out the direction of the magnetic field if you know the direction of the current.



▲ **Figure 5.13** The circular shape of the magnetic field is shown by the pattern of ironfi lings

The magnetic field near a straight wire

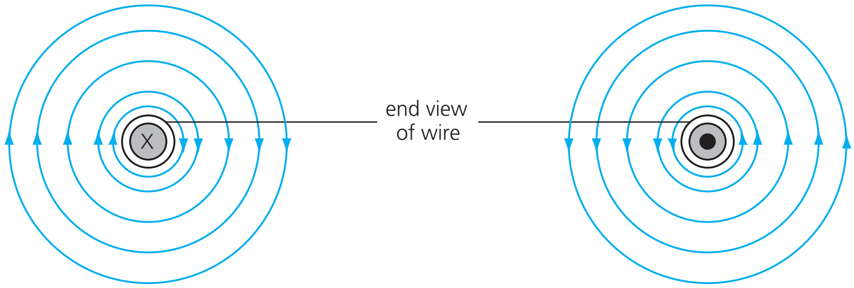
An electric current in a conducting wire produces a magnetic field around the wire.

In Figure 5.12, a long straight wire carrying an electric current is placed vertically so that it passes through a horizontal piece of hardboard. Iron filings have been sprinkled onto the board to show the shape of the field. Here is a summary of the important points of the experiment.

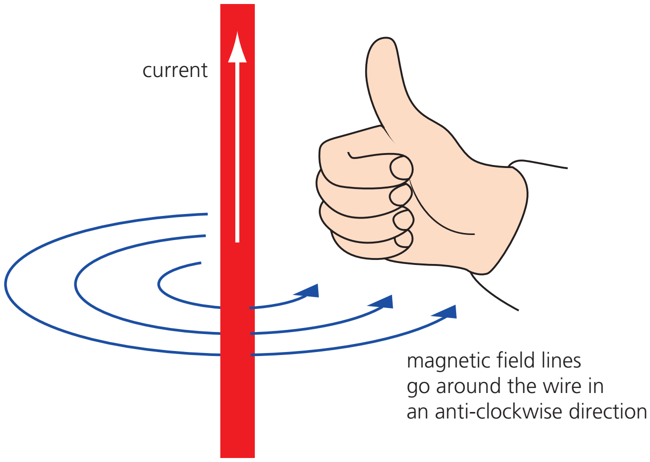
- When the current is small, the magnetic field is too weak to notice. However, when a large current is used, the iron filings show a circular magnetic field pattern (see Figure 5.13).
- The magnetic field gets weaker further away from the wire.
- The direction of the magnetic field can be found using a compass. If the current direction is reversed, the direction of the magnetic field is reversed.

Figure 5.14 shows the pattern of magnetic field lines surrounding a wire. When the current flows into the paper (shown ⊗) the field lines point in a clockwise direction around the wire. When the current flows out of the paper (shown ⊙) the field lines point anti-clockwise.

The right-hand grip rule will help you to remember this (Figure 5.15). Put the thumb of your right hand along a wire in the direction of the current. Now your fingers point in the direction of the magnetic field.



▲ **Figure 5.14** The direction of the magnetic field depends on the direction of the current



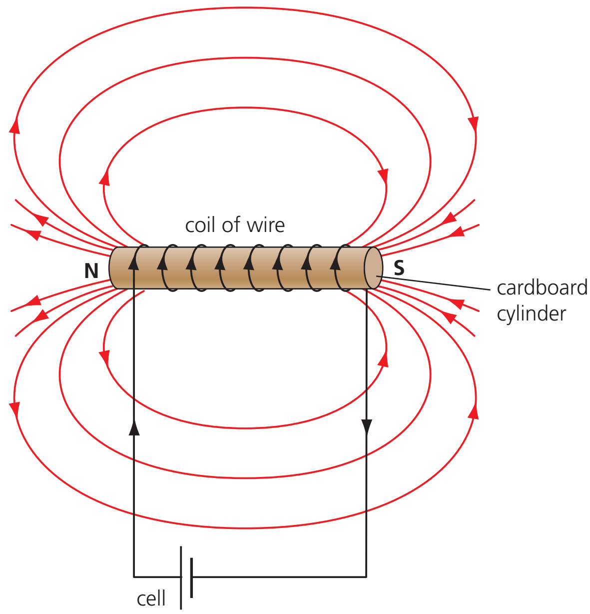
▲ **Figure 5.15** The right-hand grip rule

KEY WORD

Solenoid A solenoid is a long coil of wire, as shown in Figure 5.16.

The magnetic field of a solenoid

Figure 5.16 shows the magnetic field that is produced by a current flowing through a long coil of wire or **solenoid**. The magnetic field from each loop of wire adds on to the next. The result is a magnetic field that is like a long bar magnet's field.



▲ **Figure 5.16** The magnetic field around a solenoid is similar in shape to that of a bar magnet

The strength of the magnetic field produced by a solenoid can be increased by:

- using a larger current
- using more turns of wire
- putting the turns closer together
- putting an iron core into the middle of the solenoid.

▲ **Figure 5.17** An electromagnet in action

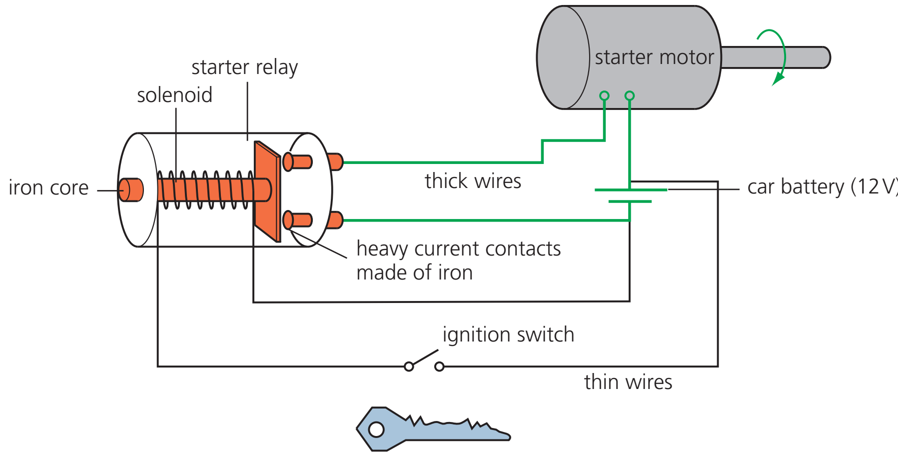
Electromagnets

The photograph (Figure 5.17) shows a practical laboratory electromagnet. It is made into a strong magnet by two coils with many turns of wire to increase the magnetising effect of the current. When the current is switched off, the magnet loses its magnetism and so the iron filings fall off.

A car starter motor needs a very large current of about 100 A to make it turn. Switching large currents on and off needs a special heavy-duty switch. If you have such a large switch inside the car it would be a nuisance since it would take up a lot space. The switch would spark and it would be unpleasant and dangerous. A way round this problem is to use a relay.

TIP

Electromagnets are made with a soft iron core. Here soft is used to mean that the iron is a temporary magnet that is easily magnetised. Soft iron loses its magnetism quickly when the magnetising field is removed.



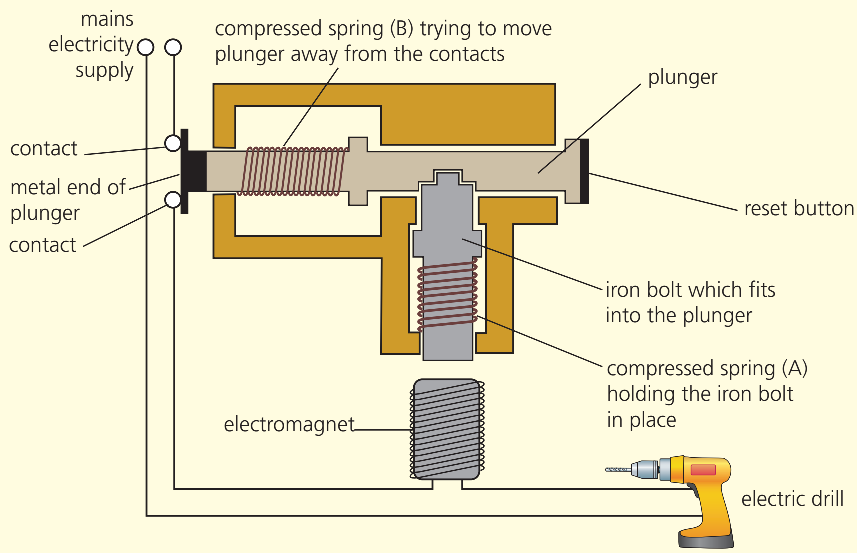
▲ **Figure 5.18** How a car starter relay works

Inside the relay a solenoid is wound round an iron core. When the car ignition is turned, a small current magnetises the solenoid and its iron core. The solenoid is attracted towards the heavy-duty electrical contacts, which are also made of iron. Now current can flow from the battery to the starter motor. This system allows the car engine to be started by turning a key at a safe distance.

Practical

Circuit breakers

Circuit breakers prevent wires and cables from overheating and causing fires when faults occur in the electricity supply. They also prevent painful electric shocks and possible death to people using electric appliances in which a fault occurs. Small electromagnets are used in circuit breakers like the one shown in Figure 5.19.



▲ **Figure 5.19** Circuit breaker

Method

When the current through the circuit is less than 15 amps, the force of attraction from the electromagnet is not sufficient to attract the iron bolt and compress spring A further. However, if a fault occurs in the rest of the circuit, a current greater than 15 amps flows and this is sufficient for the circuit breaker to operate.

Questions

1 Look carefully through the jumbled sentences below. Copy them out in the correct order to explain how the circuit breaker works. Start with the first statement in the list and finish with the last statement in the list.

- A fault occurs in the electric drill.
- The iron bolt moves towards the electromagnet out of its slot in the plunger.
- The force of the electromagnet attracts the iron bolt.

- A current greater than 15 amps flows through the electromagnet.
- Spring B can now move the plunger away from the contacts.
- The metal ends of the plunger move away from the contacts.
- The circuit is broken and the current ceases to flow.

2 Suppose you wanted to make the circuit breaker operate at a lower current, for example when the current was only 5 amps. Suggest two modifications that would allow the circuit breaker to switch off circuits carrying 5 amps.

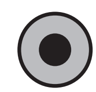
Test yourself

5 List four ways to increase the strength of an electromagnet.

6 Why must you use insulated wire to make an electromagnet?

7 Sort these sentences out into the correct order to explain how the relay operates to connect the car starter motor to the battery in Figure 5.19.

A The ignition switch is turned.
B The motor is connected to the battery.
C The iron core becomes magnetised.
D A current flows through the solenoid.
E The solenoid moves to connect to the contacts.

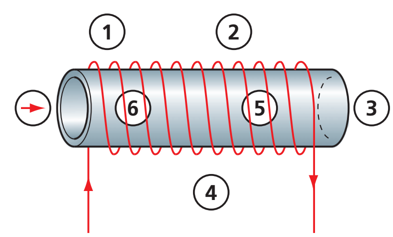


▲ **Figure 5.20** A wire placed vertically with the current flowing out of the paper

8 Figure 5.20 represents a wire placed vertically, with the current flowing out of the paper towards you. Copy the diagram and draw the magnetic field lines round the wire, showing how the field decreases with distance away from the wire.

9 Figure 5.21 shows a long Perspex tube with wire wrapped round it to make a solenoid.

a) Copy the diagram and mark in the direction of the compass needles 1-6, when the current flows through the wire.
b) Which end of the solenoid acts as the south pole?
c) What happens when the current is reversed?
d) Copy the diagram again, leaving out the compasses. Sketch the shape of the magnetic field.

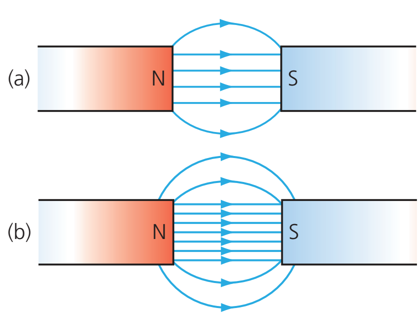


▲ **Figure 5.21** A solenoid made from a long Perspex tube with wire wrapped around it

Show you can...

Complete this task to show you understand about electromagnets.

Explain how you would use an iron nail, insulated wire and a cell to make an electromagnet that can be used to pick up some steel paper clips.



▲ **Figure 5.22** Lines of magnietic flux between two pairs of magnets. The flux density is greater in (b) than in (a)

Magnetic flux density

We represent magnetic fields by drawing lines that show the direction of a force on a north pole. These lines are also known as lines of magnetic flux.

Figure 5.22 shows the lines of magnetic flux between two pairs of magnets. The magnets in Figure 5.22 (b) are stronger than the magnets in Figure 5.22 (a). This means that they will exert a stronger attractive force on a magnetic material such as an iron nail. We show that the magnets are stronger by drawing more lines of magnetic flux for the area of the magnets.

KEY WORD

Flux density The number of lines of magnetic flux in a given area.

The strength of the magnetic force is determined by the **flux density**, *B*.

The flux density is measured in tesla, T. A laboratory bar magnet produces a flux density of about 0.1 T near to its poles.

Calculating the force on a wire

The force on a wire of length *L* at right angles to a magnetic field and carrying a current, *I*, is given by the equation $F = BIL$:

F	=	B		I		L
force	=	magnetic flux density	x	current	x	length
(newtons, N)		(tesla, T)		(amperes, A)		(metres, m)

Example

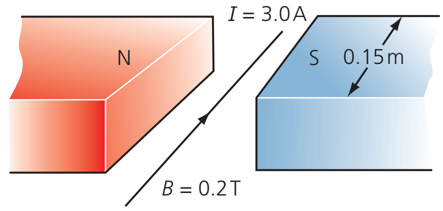
In Figure 5.23 the wire carries a current of 3.0A. Calculate the force acting on the wire.

Answer

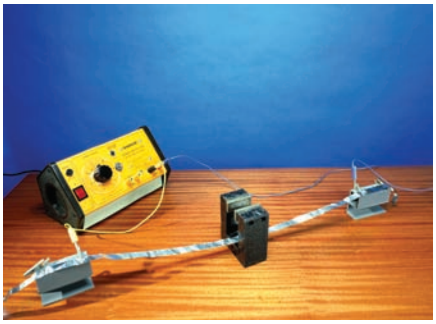
$F = B\,I\,L$

$= 0.2 \times 3.0 \times 0.15$

$= 0.09$ N



▲ **Figure 5.23** A wire carrying a current of 3.0 A



▲ **Figure 5.24** The aluminium foil carrying a current is pushed out of the magnetic field.

The motor effect

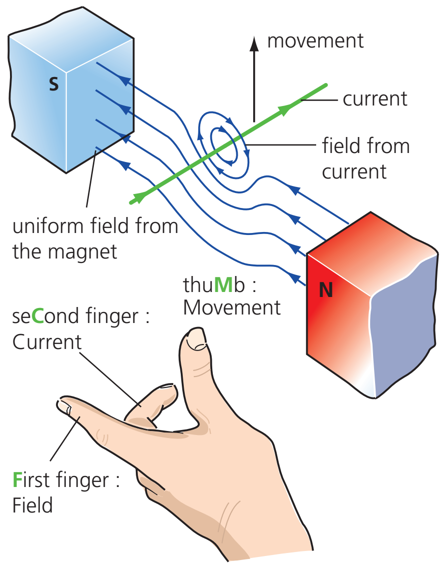
In Figure 5.24 you can see a piece of aluminium foil that was between the poles of a strong magnet. A current through the foil has caused it to be pushed down, away from the poles of the magnet. Reversing the current would make the foil move upwards, again away from the poles of the magnet. This is called the **motor effect**. It happens because of an interaction between the two magnetic fields, one from the permanent magnet and one produced by the current in the foil.

Combining two magnetic fields

In Figure 5.25 you can see the way in which the two fields combine. By itself the field between the poles of the magnet would be of constant strength and direction. The current around the foil produces a circular magnetic field. In one direction the magnetic field from the current squashes the field between the poles of the magnet. It is the squashing of the field that produces a force on the foil, upwards in this case.

The size of the force acting on the foil depends on:

- the magnetic flux density between the poles
- the current
- the length of the foil between the poles.



▲ **Figure 5.25** You can use the left-hand rule to predict the direction of movement of the wire.

The left-hand rule

To predict the direction in which a straight conductor moves in a magnetic field you can use **Fleming's left-hand rule** (Figure 5.25). Spread out the first two fingers and the thumb of your left hand so that they are at right angles so each other. Let your first finger point along the direction of the magnet's field (north to south), and your second finger point in the direction of the current (positive to negative). Your thumb then points in the direction in which the wire moves.

This rule works when the field and the current are at right angles to each other. When the field and the current are parallel to each other, there is no force on the wire and it stays where it is.

Try using the left-hand rule to show that the direction of the force on the conductor will reverse if:

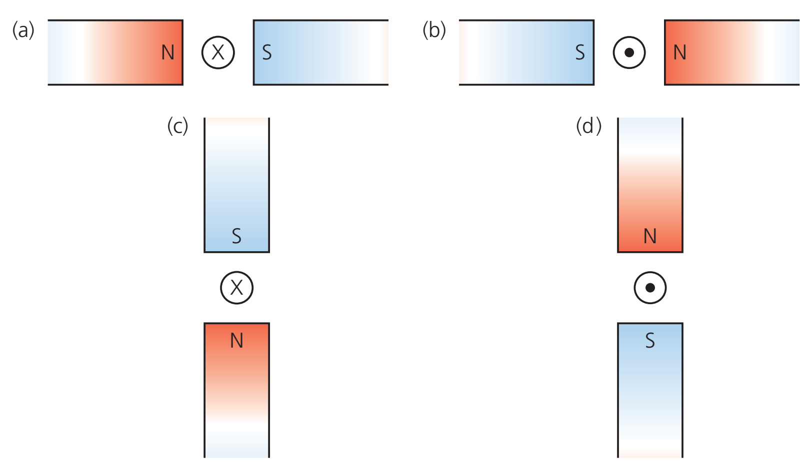
- the direction of the magnetic field is reversed
- the direction of the current is reversed.

Test yourself

10 State two ways of increasing the force on a conductor carrying a current in a magnetic field.

11 How is it possible to position a wire carrying a current in a magnetic field, so that there is no force acting on the wire?

12 Use the left-hand rule to predict the direction of the force on the wire in each of the following cases.



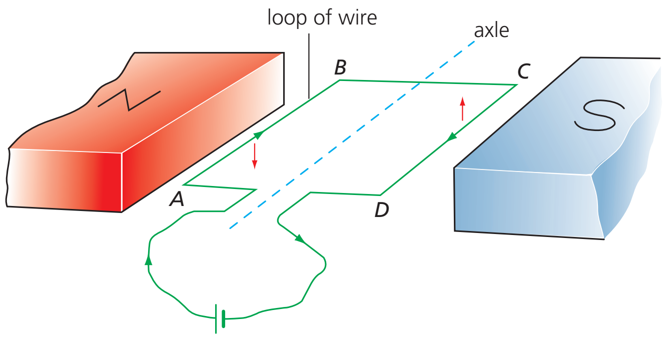
▲ **Figure 5.26**

13 A wire of length 0.2 m is placed at right angles to a region with a magnetic flux density 2.0 T. A current of 4.5 A is passed through the wire. Calculate the force acting on the wire.

Electric motor

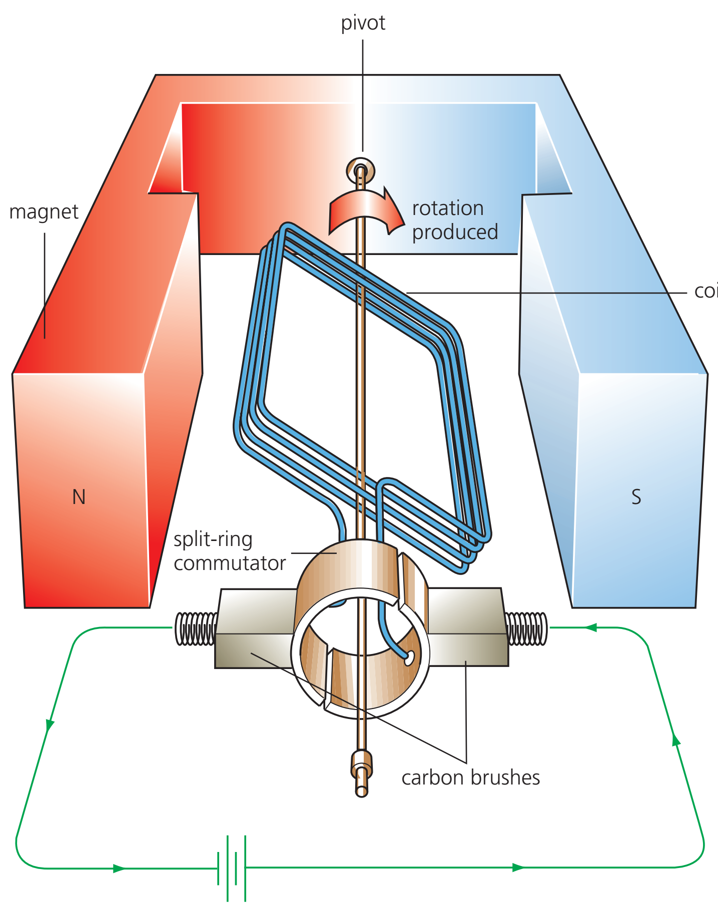
Figure 5.27 shows a coil of wire that is able to rotate about an axle. When a current flows, as shown in the diagram, there is an upward force on the side CD and a downwards force on the side AB. So the coil begins to rotate anti-clockwise, but the coil will rotate no further than a vertical position.

H



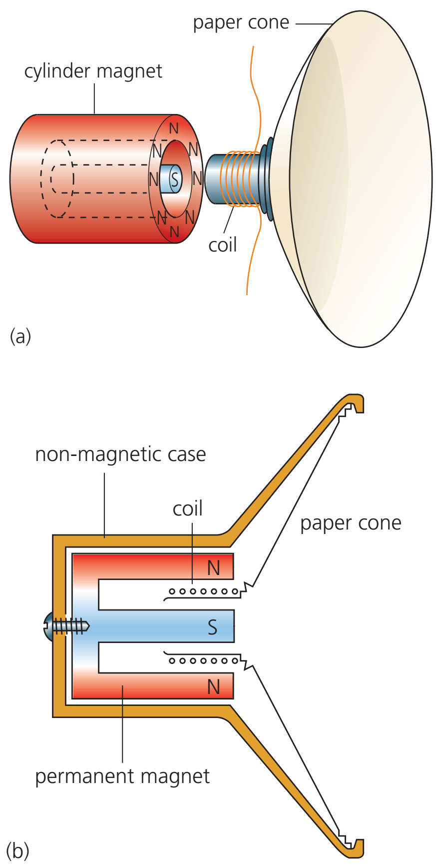
▲ **Figure 5.27** A coil of wire which is able to rotate about an axle

Figure 5.28 shows how we can design a motor so that direct current can keep a coil rotating all the time.

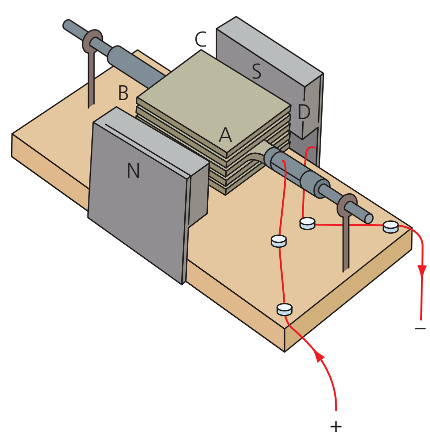


▲ **Figure 5.28** How we can design a motor so that direct current can keep a coil rotating all the time

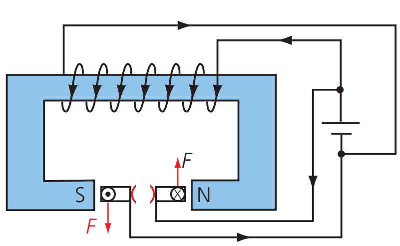
The coil is kept rotating by using a **split-ring commutator**, which rotates with the coil between the carbon brush contacts. As the coil passes the vertical position, the two halves of the commutator change contact from one carbon brush to the other. This causes the direction of the current in the coil to reverse, so that the forces continue to act on the coil in the same direction. The coil will continue to rotate clockwise as long as there is a current.



▲ **Figure 5.29** A loudspeaker in your radio and television



▲ **Figure 5.30** A model electric motor



▲ **Figure 5.31** An electric motor that is made using an electromagnet

The moving-coil loudspeaker

The loudspeaker in your radio and television is probably made like the one shown in Figure 5.29. Your headphones and earphones work in the same way, but with smaller and less powerful speakers.

Electrical signals from the receiver cause the current flowing in the coil to change. A change in the current causes the force acting on the coil to change in size and direction. In this way the paper cone is made to move in and out. The vibrations of the cone produce sound waves.

You can check the forces on the loudspeaker coil by looking at Figure 5.29(b). When the current in the upper side of the coil is flowing into the paper, the current in the lower side of the coil flows out of the paper. If you now apply the left hand rule to both sides of the coil, you will find that both sides experience a force to the left. When the current is reversed, the coil experiences a force to the right.

Test yourself

14 Look at Figure 5.27. Explain why there is no force acting on the side BC.

15 Give three ways in which you can increase the speed of rotation of the coil of an electric motor.

16 The question refers to the loudspeaker in Figure 5.29. In Figure (b) the current flows into the page as we look at the top of the coil, and out of the page at the bottom.

- **a)** Use the left-hand rule to predict the direction of the force on the coil.
- **b)** What happens to the coil when the direction of the current is reversed?
- **c)** Explain what happens to the coil when an ac current is supplied to it.
- **d)** What happens to the sound produced by the loudspeaker when these changes are made to an ac supply to the coil:
  - **i)** the frequency is increased
  - **ii)** the size of the current is increased.

17 Figure 5.30 shows a model electric motor. In the diagram the current flows round the coil in the direction A to B to C to D.

- **a)** What is the direction of the force on
  - **(i)** side AB
  - **(i)** side CD?
- **b)** In which direction will the coil rotate?
- **c)** In which position is the coil most likely to stop?

18 Figure 5.31 shows an electric motor that is made using an electromagnet. The arrows show the direction of the forces on the coil.

- **a)** The battery is now reversed. What effect does this have on:
  - **i)** the polarity of the magnet?
  - **ii)** the direction of the current in the coil?
  - **iii)** the forces acting on the coil?
- **b)** Explain why this motor works using an a.c. supply as well as a d.c. supply.
- **c)** Why are the electromagnet and coil run in parallel from the supply, not in series?

Show you can...

Show you understand the purpose of the split-ring commutator in a motor, by explaining how the split ring commutator keeps an electric motor spinning in the same direction all the time.

Induced potential, transformers and the national grid

Induced potential

When a conducting wire moves through a magnetic field a potential difference is produced across the ends of the wire. A potential difference (p.d.) produced in this way is described as an induced potential difference. A potential difference will also be induced if there is a change in the magnetic field around a stationary conducting wire.

If the wire is part of a complete circuit the potential difference will cause a current in the circuit. This is an induced current.

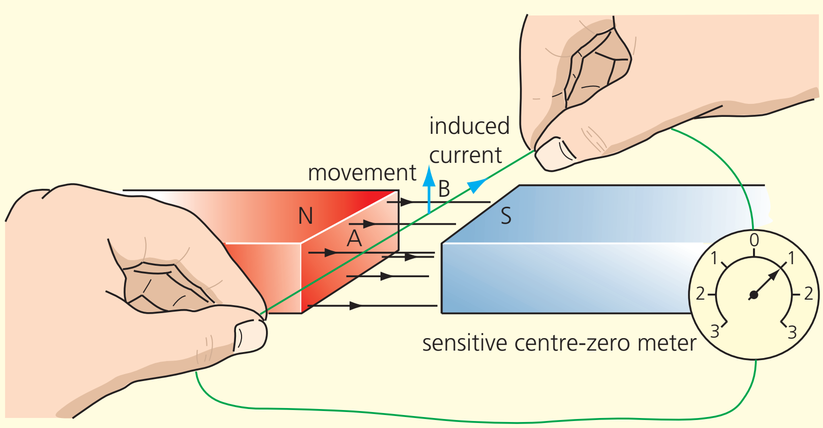
Changing the direction of motion of the conducting wire or changing the polarity of the magnetic field will change the direction of the induced p.d. and reverse the direction of the induced current.

Inducing a p.d. or a current in this way is called the generator effect, because this is how we generate electricity.

Practical

Investigating induced potential differences

Figure 5.32 shows how you can investigate the induced potential difference.

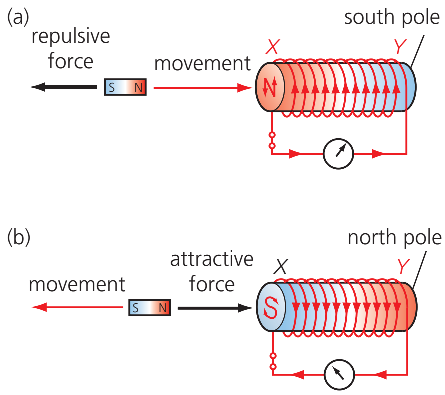


▲ **Figure 5.32** Investigating the induced potential difference

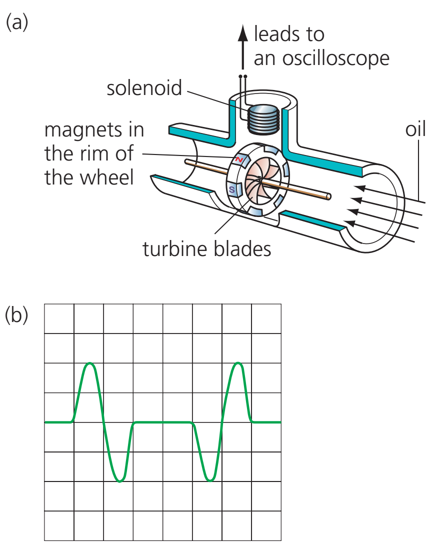
To induce a p.d. across the ends of the wire the wire must be moved up and down between the poles of the magnets. This is often described as the wire 'cutting' the magnetic field lines.

Method
Use the apparatus to show that the induced p.d. increases if:
- the wire is moved faster.
- stronger magnets are used.

Use the apparatus to check that when the the direction of the wire movement changes, from up to down, the direction of the induced p.d. changes.



▲ **Figure 5.33** (a) A north pole of a magnet is pushed into a solenoid (b) The magnet is pulled out of the solenoid



▲ **Figure 5.34** (a) An electromagnetic flowmeter. (b) The induced p.d. changes as the magnets rotate.

Coils and magnets

We can also induce a p.d. in a coil of wire by changing the magnetic field near it. In Figure 5.33(a) a north pole of a magnet is pushed into a solenoid. Note that the induced current flows in a direction that makes the end of the solenoid (X), next to the magnet, also behave like a north pole.

When the magnet is pulled out of the solenoid, the direction of the induced current is reversed. Now the end X behaves like a south pole.

When a current is induced in a conducting wire, the induced current itself generates a magnetic field. This magnetic field opposes whatever the original change was that caused it. This may be the movement of the conducting wire or the change in the magnetic field.

Consider Figures 5.33(a) and (b), in each case as the magnet is moved and a current induced, there is a force which opposes the movement of the magnet. So when you move a magnet to induce a current you do work. So you really cannot get something for nothing.

Figure 5.34 shows a way to measure the rate of flow of oil through an oil pipeline. A small turbine is placed in the pipe, so that the oil flow turns the blades round. Some magnets have been placed in the rim of the turbine, so that they move past a solenoid. These moving magnets induce a p.d. in the solenoid. The p.d. can be measured on an oscilloscope (Figure 5.34(b)). The faster the turbine rotates, the larger the p.d. induced in the solenoid. By measuring this p.d. an engineer can tell at what rate the oil is flowing.

Test yourself

19 A wire is made to move through a magnetic field so that a potential difference is induced across its ends. State two ways in which the size of the induced potential difference can be increased.

20 This question refers to the magnet and solenoid shown in Figure 5.33.
- **a)** The magnet is stationary inside the solenoid. State the size of the induced potential difference.
- **b)** The magnet is now moved towards the solenoid as follows. In each case state the direction of the deflection on the meter.
  - **i)** A south pole is moved towards X.
  - **ii)** A south pole is moved away from X.
  - **iii)** A north pole is moved towards Y.

21 This question refers to the flow meter shown in Figure 5.34.
- **a)** The poles of the magnets on the wheel are arranged alternatively with a north pole, then south pole facing outwards. Use this fact to explain the shape of the trace on the oscilloscope.
- **b)** Sketch the trace on the oscilloscope for these two separate changes:
  - **i)** the number of turns in the solenoid is doubled
  - **ii)** the oil flow rate slows down, so the turbine rotates at half the speed.

Uses of the generator effect

H

Figure 5.35(a) shows the design of a simple electricity generator. This one generates alternating current, so it is called an alternator.

By turning the axle you can make a coil rotate in a magnetic field. This causes a p.d. to be induced between the ends of the coil.

The slip-rings provide a continuous contact between the rotating sides of the coil and the connections to the oscilloscope, marked ① and ② in Figure 5.35.

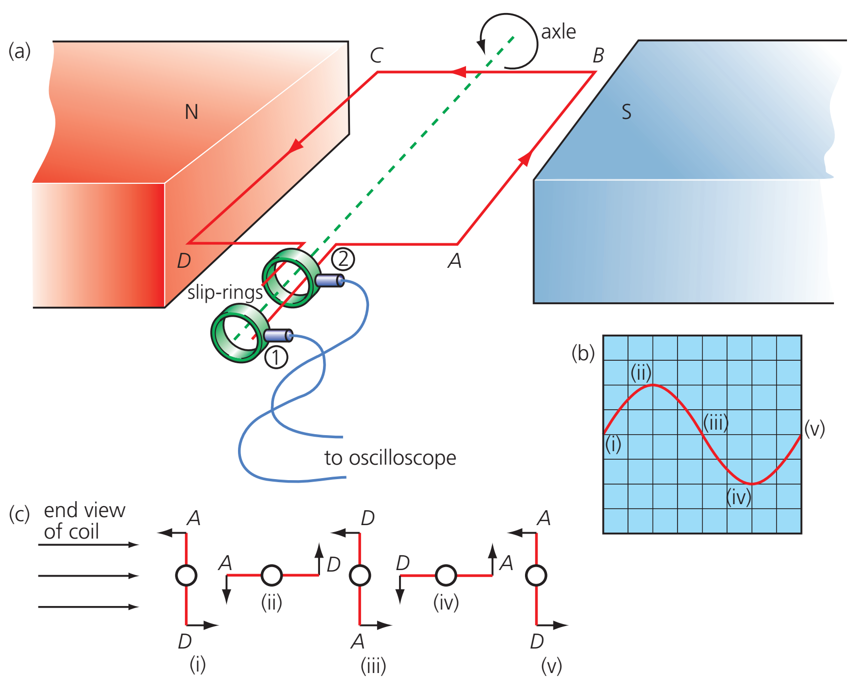
Figure 5.35(b) shows how the induced p.d. varies with time. This waveform can be displayed on an oscilloscope. Figure 5.35(c) shows the position of the coil at various times.

i) The coil is vertical. In this position the sides AB and CD are moving parallel to the field and no p.d. is induced.

ii) The coil is horizontal. In this position the sides AB and CD are cutting through the field at the greatest rate. The induced p.d. is at its maximum.

iii) The coil is again vertical and the induced p.d. is zero.

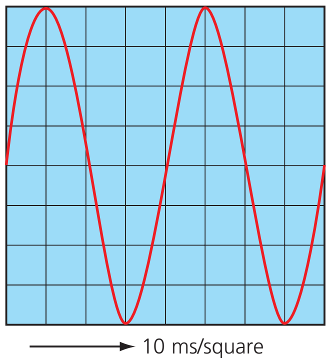
iv) The coil is again horizontal, but the sides AB and CD are moving in the opposite direction in comparison with position ii). The induced p.d. is again at its maximum, but now in the opposite direction.



▲ **Figure 5.35** Design of a simple electricity generator

The size of the induced p.d. can be made larger by:

- rotating the coil faster
- using stronger magnets
- using more turns of wire
- wrapping the wire round a soft iron core.

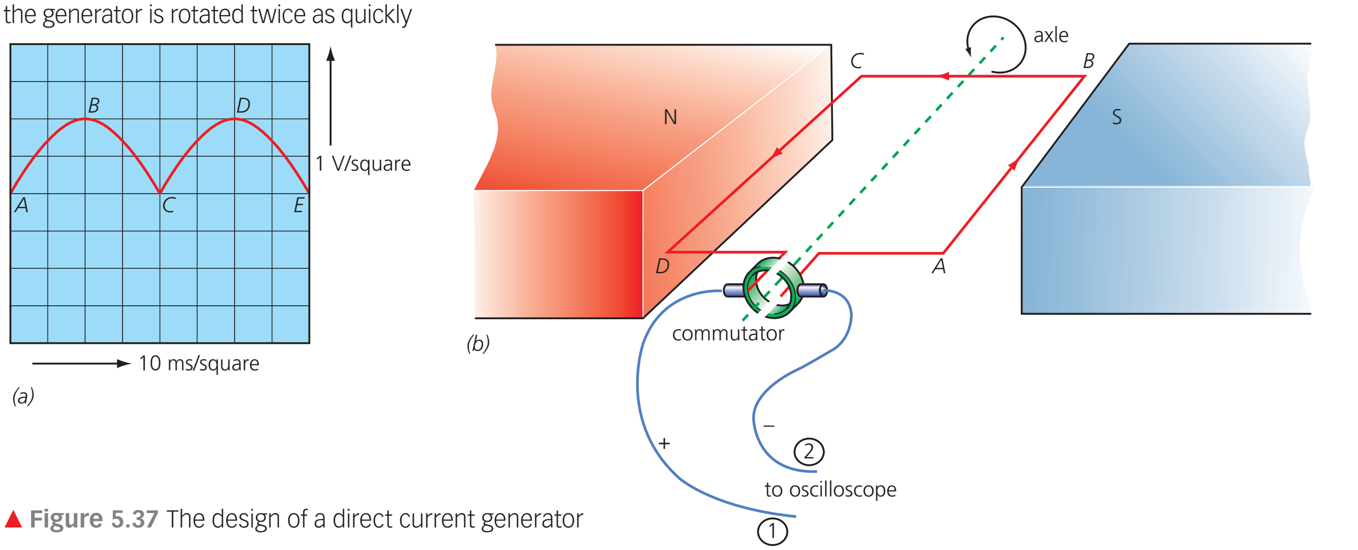


▲ **Figure 5.36** The voltage waveform when the generator is rotated twice as quickly

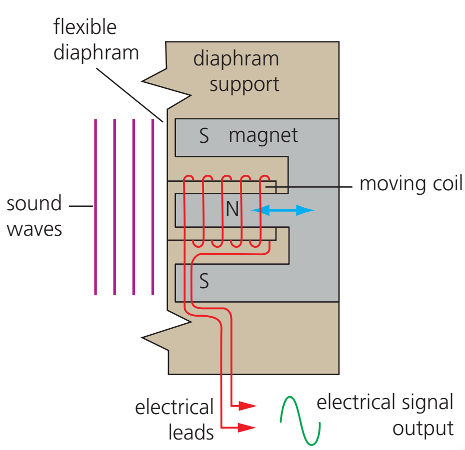
Figure 5.36 shows the voltage waveform when the generator is rotated twice as quickly. There are two effects: the maximum voltage is twice as large and the frequency is doubled, i.e. the interval between the peaks is halved.

The dynamo

Figure 5.37 shows the design of a direct current generator. This is called a dynamo. The design of a dynamo is similar to that of an alternator. However, a dynamo has a split ring commutator rather than two separate slip rings. Now it does not matter which side, AB or CD, moves upwards, the induced current always flows in the same direction.



▲ **Figure 5.37** The design of a direct current generator



▲ **Figure 5.38** How a moving coil microphone works

Microphones

Figure 5.38 shows how a moving coil microphone works. When sound waves reach the diaphragm they cause it to vibrate. The diaphragm is attached to a small moving coil, which then vibrates inside a strong magnetic field. In this way a p.d. is induced across the end of the coil.

When we use a microphone with a sound system the induced p.d. is amplified and a current can then drive a loudspeaker, which enables an audience to hear the sound.

Show you can...

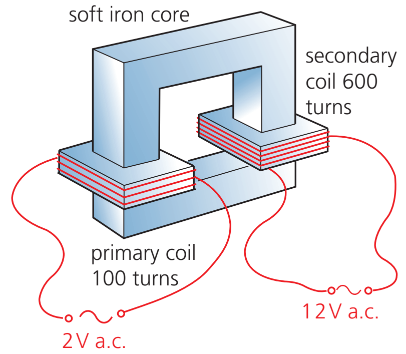
Show you understand how an alternator works by completing this task.

Explain how a coil and magnets can be used to generate alternating current. How can you make the induced current as large as possible?

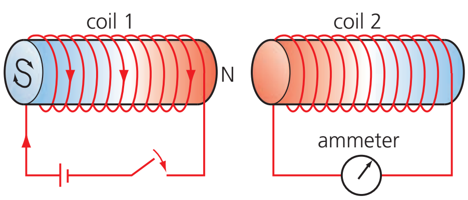
Test yourself

22 This question refers to the dynamo output shown in Figure 5.37.
  a) State the position of the coil for each of the times A, B, C, D and E.
  b) Copy the graph and add further graphs to show what happens to the p.d. after each of these separate changes.
    i) The direction of the coil rotation is reversed.
    ii) An extra turn of wire is added.
    iii) The coil is rotated at twice the speed.

23 This question refers to the microphone shown in Figure 5.38. Explain why a larger p.d. is induced when the sound is louder.



▲ **Figure 5.39** A step up transformer



▲ **Figure 5.40** Two coils placed close to each other

Transformers

A transformer is made by putting two coils of wire onto an iron core, as shown in Figure 5.39.

Transformers only work using an ac supply. When an alternating current is supplied to the primary coil, a changing magnetic field is produced. The iron core becomes magnetised and carries the changing magnetic field to the secondary coil. The changing magnetic field passes through the secondary coil where an alternating p.d. is induced.

When a direct current is supplied to the primary coil, the magnetic field is constant. Then no p.d. is induced in the secondary coil.

Changing currents and fields

Figure 5.40 shows two coils placed close to each other. Coil 1 can be connected to a battery, coil 2 is connected to a sensitive ammeter.

- When the current is switched on the ammeter in the second circuit moves to the right.
- When the current in coil 1 flows steadily the ammeter reads zero.
- When the current is turned off in coil 1, the ammeter moves to the left.

Why does this happen?

This is rather like moving a magnet into a solenoid, then leaving the magnet stationary in the solenoid, then moving the magnet out of the solenoid again. A p.d. is induced one way when the magnet moves in and the other way when it moves out.

You can increase the size of the induced current further by putting an iron rod between the coils. Now the current in the first coil produces a larger changing magnetic field, which induces a larger current in the second coil.

▲ **Figure 5.41** Without transformers we could not transmit electricity over large distances.

Step-up and step-down transformers

Transformers are useful because they allow us to change the p.d. of a supply. The transformer in Figure 5.39 is an example of a step-up transformer. The input p.d. is increased from 2 V to 12 V.

- When there are more turns on the secondary coil than the primary coil, the p.d. is increased. This is a **step-up** transformer.
- When there are fewer turns on the secondary coil than the primary coil, the p.d. is decreased. This is a **step-down** transformer.

The rule for calculating the potential differences in a transformer is as follows:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

where

V_p is the p.d. across the primary coil

V_s is the p.d. across the secondary coil

n_p is the number of turns in the primary coil

n_s is the number of turns in the secondary coil.

Example

An a.c. power supply has a p.d. of 230 V. This is applied to a transformer with 5000 turns in its primary coil, and 250 turns in its secondary coil. Calculate the potential difference across the secondary coil. Is this a step-up or step-down transformer?

Answer

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

$$\frac{230}{V_s} = \frac{5000}{250}$$

$$\frac{230}{V_s} = 20$$

$$\text{So } V_s = \frac{230\text{ V}}{20} = 11.5\text{ V}$$

This is a step-down transformer.

Power in transformers

We use transformers to transfer electrical power from the primary coil to the secondary coil. Most transformers do this very efficiently and there is little loss of power in the transformer itself. For a transformer that is 100% efficient we can write:

power supplied to the primary coil = power provided by the secondary coil.

$$V_p \times I_p = V_s \times I_s$$

where I_p is the current in the primary coil

and I_s is the current in the secondary coil

V_p is the p.d. across the primary coil

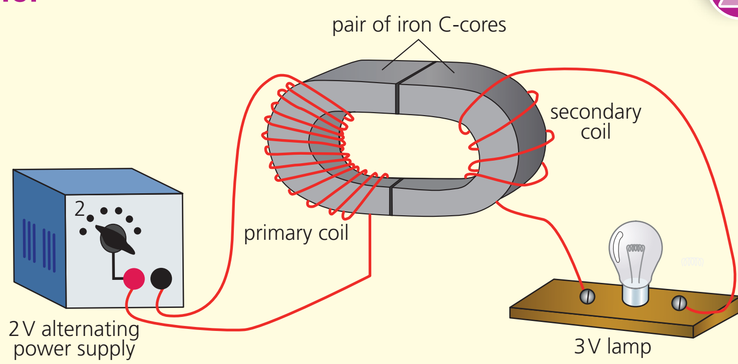
V_s is the p.d. across the secondary coil

Practical

Investigating your own transformer

You can make and investigate your own transformer by wrapping two coils of insulated wire around iron C-cores. Connect one coil, the primary, to a 2V alternating power supply. Connect the second coil, the secondary, to a 3V lamp.

Without changing the number of turns on the primary coil or the potential difference across the primary coil wrap more turns onto the secondary coil.

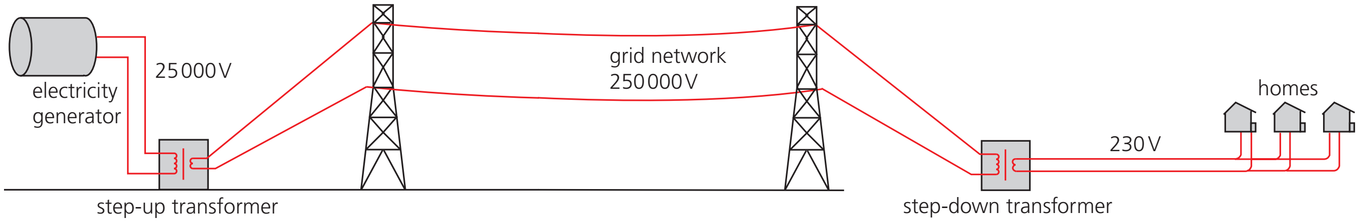


▲ Figure 5.42

1. What happens to the brightness of the lamp as more turns are wrapped onto the secondary coil?
2. Why must the number of turns on the primary coil and the potential difference across the primary coil be kept constant?
3. What is the independent variable in this investigation?
4. Why should the number of turns on the secondary coil not go too far above the number of turns on the primary coil?

The National Grid

Figure 5.43 shows how electricity generated in a power station is distributed around the country through the National Grid.



▲ **Figure 5.43** How electricity generated in a power station is distributed around the country through the National Grid

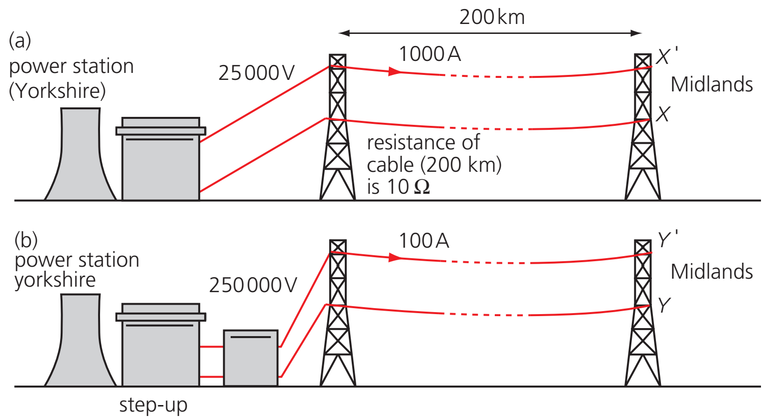
Power is transmitted around the country at voltages as high as 400 000 V. There is a very good reason for this. It makes the whole process much more efficient.

The following calculations explain why.

Figure 5.44 suggests two ways of transmitting 25 MW of power from a Yorkshire power station to the Midlands.

a) The 25 000 V supply from the power station could be used to send 1000 A down the power cables.

b) The potential difference could be stepped up to 250 000 V and 100 A could be sent along the cables.



▶ **Figure 5.44** Two ways of transmitting 25 MW of power from a Yorkshire power station to the Midlands

How much power would be wasted in heating the cables in each case given that 200 km of cable has a resistance of 10 Ω?

a) power lost = potential difference along cable x current

$= IR \times I$

$= I^2 R$

$= (1000)^2 \times 10$

$= 10\,000\,000$ W or 10 MW

b) power lost $= I^2 R$

$= (100)^2 \times 10$

$= 100\,000$ W or 0.1 MW

By stepping up the potential difference to a very high level, power is transmitted using much lower currents. When a high current flows through a wire, energy is used to heat the wire up. By keeping the current low, less energy is wasted and the whole system is much more efficient.

TIP

Electricity is transmitted at a very high potential difference and low currents to reduce energy loss and improve efficiency.

Show you can...

Show you understand about the transmission of electricity around the country by explaining why we use a.c. electricity in our homes, rather than d.c. electricity supplies.

Test yourself

24 In Figure 5.40 (on page 21) when the switch is opened the ammeter flicks to the left, describe what happens to the ammeter during each of the following:

- **a)** The switch is closed and left closed so that a current flows through coil 1.
- **b)** The coils are pushed towards each other.
- **c)** The coils are left close together.
- **d)** The coils are pulled apart.

25 This question refers to the transformer shown in Figure 5.39 (on page 21).

- **(a)** Calculate the power used in the secondary circuit.
- **(b)** Now calculate the current being supplied to the primary circuit.

26 Table 5.1 gives some information about four transformers. Copy the table and fill in the gaps.

Table 5.1

Primary turns	Secondary turns	Primary voltage in volts	Secondary voltage in volts	Step-up or step-down
100	20		3	
400	10 000	10		
	50	240	12	
	5 000	33 000	11 000	

27 Give three examples of where transformers are used at home to step the mains voltage of 230 V down to a lower level.

28 Explain why a transformer does not work using a dc supply.

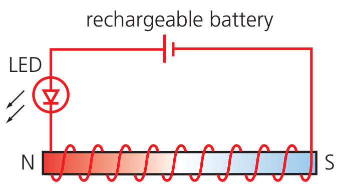
29 Why is an ac supply necessary to make a transformer work?

30 Explain why very high voltages are used to transmit electrical power over long distances.

Chapter review questions

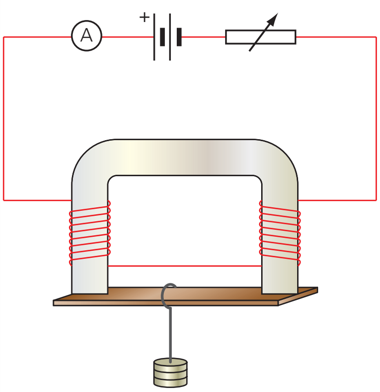
1 a) Draw accurately the magnetic field pattern around a bar magnet.
  b) Explain how you would use a compass to plot this magnetic field pattern.

2 Draw carefully the shape of a magnetic field close to:
  a) a long wire b) a long solenoid
  when each is carrying a current.



▲ **Figure 5.48**

3 Figure 5.48 is a circuit diagram for a 'shake-up' torch. A magnet is placed in a coil of wire, which is linked to a rechargeable battery and a light-emitting diode (LED). The magnet is free to slide backwards and forwards, inside the coil.
  a) What is a light-emitting diode?
  b) Explain why a LED is used in the charging circuit.
  c) Explain how the battery is recharged.



▲ **Figure 5.49** An experimental arrangement to investigate the action of an electromagnet

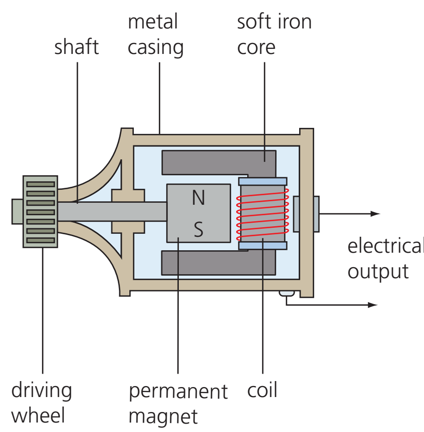
4 Figure 5.49 shows an experimental arrangement to investigate the action of an electromagnet. Coils of wire have been wound round a C-shaped soft iron core.
  At the bottom of the C-core, a soft iron bar stays in place because of the attraction of the electromagnet.
  The strength of the electromagnet is measured by increasing the weight hanging on the bar until it falls off.
  Table 5.3 shows some results for this experiment.

Table 5.3

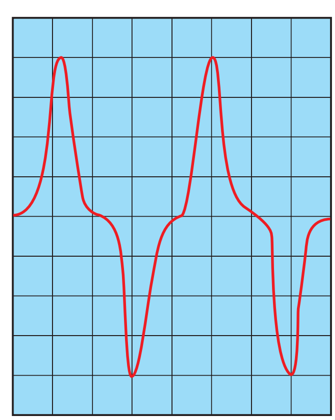
Maximum weight on the iron bar in N	0	0.6	1.2	1.8	2.3	2.7	3.0	3.2	3.3	3.4	3.4
Current in the magnet coils in A	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0

  a) Plot a graph of the maximum weight supported by the electromagnet (*y*-axis) against the current in the magnet coils (*x*-axis).
    A second student does the same experiment, but uses more turns of wire on her electromagnet.
  b) Sketch a second graph, using the same axes, to show how the maximum load supported changes with the current now.

5 Figure 5.50(a) shows a bicycle dynamo. When a bicycle wheel moves it turns the driving wheel of the dynamo. The driving wheel is attached to a permanent magnet which rotates inside a fixed coil.
  The output terminals of the dynamo are connected to a data logger, which displays the voltage shown in Figure 5.50(b).



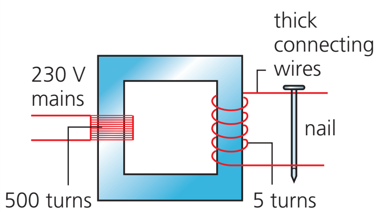
▲ **Figure 5.50** (a)


▲ **Figure 5.50** (b)

When the potential difference looks as it does in Figure 5.50(b), the drive wheel is rotating 10 times each second.

a) Copy Figure 5.50(b) and add to it a second trace to show the potential difference when the wheel rotates 5 times each second.

b) Explain why a bicycle lamp attached to the dynamo does not light when the bicycle is stationary.



▲ **Figure 5.51** A laboratory demonstration of how a transformer may be used to produce very large currents.

6 Figure 5.51 shows a laboratory demonstration of how a transformer may be used to produce very large currents. Here the current is used to melt a nail.

a) Use the information in the diagram to show that the potential difference across the nail is 2.3 V

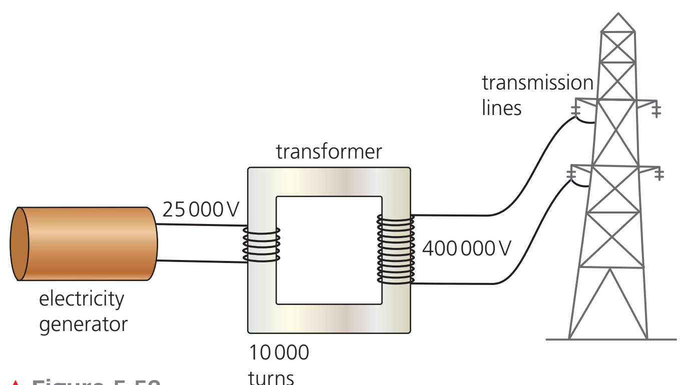
b) The nail has a resistance of 0.02 Ω. Calculate the current in the secondary circuit.

c) Show that the power in the secondary circuit is 265 W.

The nail melts when 15 000 J of energy have been transferred to its thermal store.

d) Calculate how long it takes for the nail to melt.

7 The generator in a power station produces electricity at a potential difference of 25 000 V. A transformer steps this up to 400 000 V, for the electricity to be transmitted on the national grid. See Figure 5.52 below.



▲ **Figure 5.52**

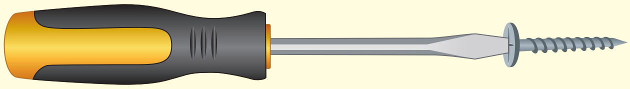
a) Use the information in the diagram to calculate the number of turns in the secondary coil of the transformer.

b) The current in the primary coil is 800 A. Calculate the current in the transmission lines.

c) Why are high potential differences used to transmit current on the national grid?

Practice questions

1 The diagram shows a magnetic screwdriver that has picked up and is holding a small metal screw.



▲ **Figure 5.53** Diagram of a magnetic screwdriver

a) What type of material is the screw made from? [1 mark]

aluminium copper steel

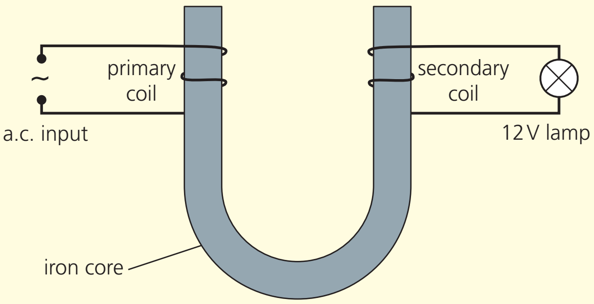
b) The magnetic force between the screw driver and screw is an example of a non-contact force.

Which **one** of the following is also a non-contact force? [1 mark]

air resistance friction gravity

c) Explain how you can use a bar magnet to show that an unmarked bar of material is either a bar magnet or an unmagnetised bar of iron. [3 marks]

2 Figure 5.54 represents a simple transformer used to light a 12 V lamp. When the a.c. input is supplied to the primary coil, the lamp is dim.



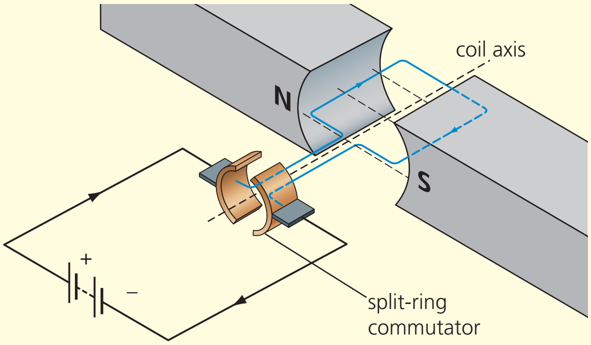
▲ **Figure 5.54** A simple transformer used to light a 12 V lamp

a) Copy and complete the sentences below. [5 marks]

The alternating current input in the _________ coil produces an continuously changing _______ _____ in the iron core and therefore through the secondary coil. This ________ an alternating potential difference across the ends of the secondary coil. If the secondary coil is part of a complete circuit, _______ will be induced in the __________ coil.

b) Suggest three ways to increase the potential difference across the lamp without changing the power supply. [3 marks]

3 Figure 5.55 shows a diagram of an electric motor. As the current flows from the battery, the coil and split-ring commutator spin.



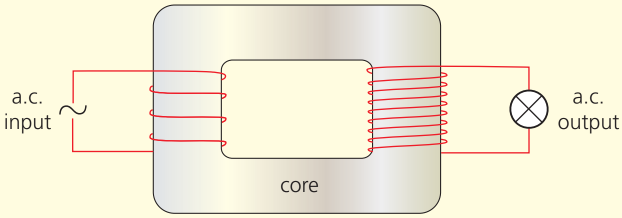
▲ **Figure 5.55** Diagram of an electric motor

a) Explain why the coil spins when a current flows through it. [3 marks]

b) Without changing the coil, give two ways in which it could be made to spin faster. [2 marks]

c) Give two ways in which the coil could be made to spin in the opposite direction. [2 marks]

4 Figure 5.56 shows a simple transformer.



▲ **Figure 5.56** A simple transformer

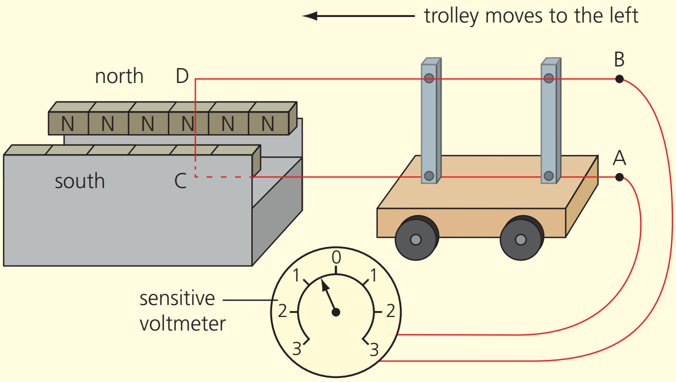
a) Is the transformer being used as a step-up or step-down transformer? [1 mark]

b) Why must the wire used to make the coils be insulated? [1 mark]

c) i) What material is the core made from?

ii) Why must the core be made from this material? [2 marks]

5 Figure 5.57 shows some apparatus that is being used to investigate the factors which affect the potential difference induced when the wire CD moves through a magnetic field. The potential difference is measured by a sensitive voltmeter which reads zero when the pointer is in the middle of the scale.



▲ **Figure 5.57**

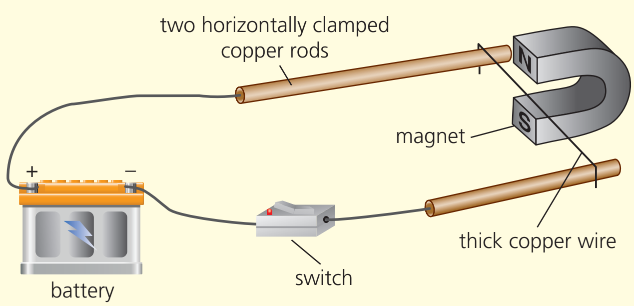
The trolley is moving to the left and the sensitive voltmeter records a reading to the left of zero.

a) State *two* separate changes you could make, so that the voltmeter records a reading to the right of zero. [2 marks]

b) State *two* separate changes you could make, so that the induced potential difference is greater. [2 marks]

c) What does the voltmeter record when the wire CD is stationary between the magnets? [1 mark]

6 a) A student investigates how a thick copper wire can be made to move in a magnetic field. Figure 5.58(a) shows the apparatus.



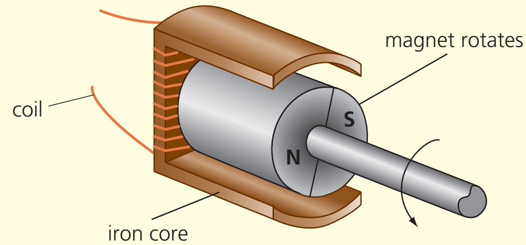
▲ **Figure 5.58** (a)

The wire is placed between the poles of the magnet.

i) Use the information in the diagram to predict the direction of motion of the wire. [1 mark]

ii) Explain what happens to the motion of the wire when the magnet is turned so the N pole is below the wire. [2 marks]

b) Figure 5.58(b) shows a model generator.

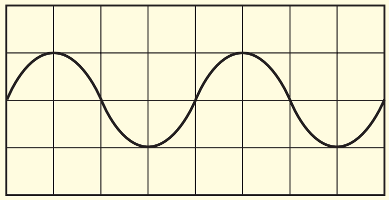


▲ **Figure 5.58** (b)

i) Explain why a potential difference is induced across the ends of the coil when the magnet rotates. [2 marks]

ii) Explain why the potential difference is alternating. [1 mark]

c) The ends of the coil are connected to a cathode ray oscilloscope (CRO). Figure 5.58(c) shows the trace on the screen as the magnet rotates.



▲ **Figure 5.58** (c)

Copy the diagram and draw new traces for each of the following changes using the same scale. The settings of the oscilloscope remain the same.

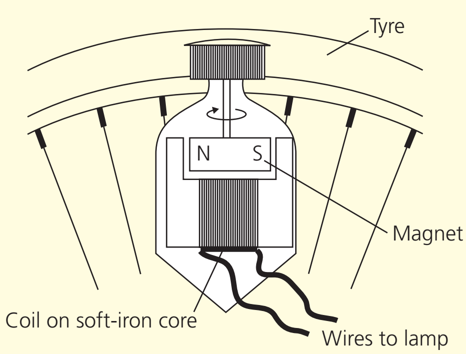
i) The magnet rotates at the same speed, but in the opposite direction. [1 mark]

ii) The magnet rotates at the same speed, in the same direction as the original, but the number of turns of the coil is doubled. [2 marks]

iii) The magnet rotates at twice the speed, in the same direction, with the original number of turns of the coil. [2 marks]

d) Explain why iron is used as the core in the model generator. [1 mark]

7 Figure 5.59 shows part of a bicycle dynamo which is in contact with the wheel.



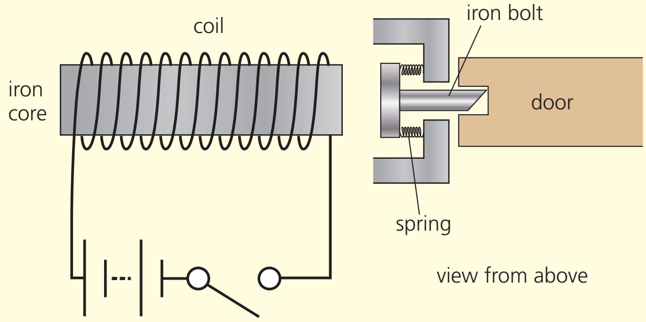
▲ **Figure 5.59** Part of a bicycle dynamo, which is in contact with the wheel

a) Explain fully why a current flows through the lamp when the bicycle wheel turns. [3 marks]

b) Why does the lamp get brighter as the cycle moves faster? [2 marks]

c) Why does the lamp not work when the bicycle is stationary? [1 mark]

8 Figure 5.60 shows a type of door lock.

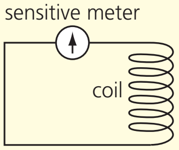


▲ **Figure 5.60**

a) Explain how closing the switch allows the door to be opened. [3 marks]

b) The door bolt is changed, and a thicker, stronger piece of iron is used. When the switch is closed, the lock does not open. Without changing the bolt, suggest two changes that could be made, each of which would make the lock work again. [2 marks]

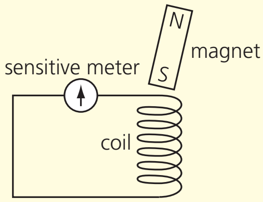
9 Figure 5.61(a) shows a coil connected to a sensitive meter. The meter is a 'centre zero' type: the needle is in the centre when no current flows.



▲ **Figure 5.61** (a) a coil connected to a sensitive meter

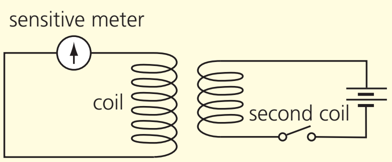
A student does two experiments.

In the first experiment, shown in Figure 5.61(b), the magnet is pushed into the coil. Then the magnet is removed. The meter only reads a current when the magnet is moving.



▲ **Figure 5.61(b)**

In the second experiment, shown in Figure 5.61(c), a second coil is brought close to the first. The student switches the current on and off in the second coil. The needle deflects for a brief time each time the current is turned on or off.



▲ **Figure 5.61(c)**

a) In the first experiment:

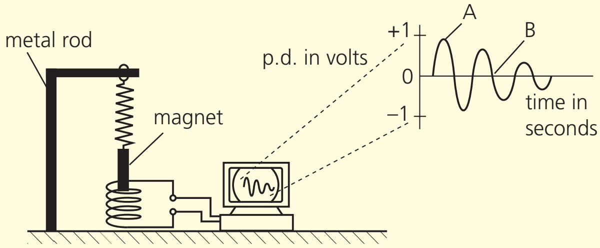
i) What is happening in the coil while the magnet is moving? [1 mark]

ii) How does the deflection of the needle as the magnet is pushed towards the coil compare with the deflection of the needle as the magnet is pulled away? [1 mark]

iii) State three ways in which the student could increase the deflection on the meter, when the magnet is moved. [3 marks]

b) Use the second experiment to help explain why transformers only work with alternating current. [3 marks]

10 The waves from earthquakes are detected by instruments called seismometers. Figure 5.62 shows a simple seismometer.



▲ **Figure 5.62**

It consists of a bar magnet suspended on a spring. The spring hangs from a metal rod that transmits vibrations from the Earth. When there is an earthquake, the magnet moves in and out of the coil. A computer monitors the potential difference across the coil.

a) Explain why a p.d. is induced in the coil. [1 mark]

b) Why is the induced p.d. alternating? [1 mark]

c) Describe the movement of the magnet when the induced p.d. has its greatest value at the point labelled A. [1 mark]

d) Describe the movement of the magnet when the induced p.d. is zero, as at point B. [1 mark]

e) Suggest *two* ways in which the seismometer could be made more sensitive so that it can detect weaker earthquakes. [2 marks]

Working scientifically

Technological applications of science; the implications

The discovery of the principles of electromagnetic induction by Michael Faraday led to the development of the d.c. dynamo. The dynamo was the first machine capable of generating electricity for industrial processes.

Further scientific work led to the development of the a.c. generator. This, combined with the invention of the transformer, resulted in dynamos being replaced by a.c. generators for electricity generation and power distribution.

Easy access to electricity has led to more appliances, devices and gadgets being invented that use electricity. However, easy access to electricity is not a reality for everyone. For about 1.6 billion people in the world, life without electricity is a reality. There is no flicking a switch for light, pressing a button to work the microwave, or putting dirty clothes in a washing machine.

Having electricity is not just about being rich or poor. It is about a country having the resources to generate electricity or the money to pay for electricity. The use of the world's resources to provide some people with a comfortable lifestyle whilst others go without raises **ethical issues**.

The application of science to everyday life and to technology may also have certain personal, social, economic and environmental implications. Consider the examples of the clockwork radio and water bottle lighting system.

Questions

1 Why was the invention of the transformer important in developing the electrical power distribution systems used today?

2 Why does the increased use of electricity in developed countries raise ethical issues?

KEY WORD

Ethical issues An ethical issue involves a consideration of what is good or bad for both individuals and society as a whole. For many ethical issues there may be no single right or wrong answer.

The clockwork radio

The clockwork radio was invented by Trevor Baylis in 1989. The radio was developed for use in countries where affordable energy is either rare or does not exist. The original radios had no batteries and did not need to be plugged into the mains electricity supply. Turning the handle powered a small internal clockwork generator. This provided the electricity to work the radio.

Most people turning a generator like the one in the wind-up radio are able to develop about 5 watts of power. This is an energy input to the generator of 5 joules every second.

Table 5.2 shows the energy required to operate a few devices for just 1 minute.

▲ Figure 5.64 A photograph of a clockwork radio

Table 5.2

Device	Energy to operate for 1 minute in joules
MP3 player	60
mobile phone	120
desktop computer	12 000
electric kettle	180 000

Questions

3 Suggest what the personal and social implications of developing a clockwork radio may be.

4 Explain why it is unlikely that a wind-up desktop computer or electric kettle would be developed.

The water bottle lighting system

Using a plastic bottle filled with water (and a little bleach) to light up a dark room is a new idea that uses simple physics.

▲ Figure 5.65 A plastic bottle filled with water provides about the same amount of light as a 50W bulb.

The water bottle fits into a hole made in the roof of the building. Sunlight enters the bottle from above, is refracted and then spreads into the room. It is a simple device that, for a small cost, lets people with no electricity, or little money to pay for electricity, see inside a room that has no other source of daylight.

Question

5 Suggest one economic and one environmental implication of using this water bottle lighting system.

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