# 45 Electromagnets

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## Oersted's discovery

In 1819 Oersted accidentally discovered the magnetic effect of an electric current. His experiment can be repeated by holding a wire over and parallel to a compass needle that is pointing N and S (Figure 45.1). The needle moves when the current is switched on. Reversing the current causes the needle to move in the opposite direction.

Evidently around a wire carrying a current there is a magnetic field. As with the field due to a permanent magnet, we represent the field due to a current by **field lines** or **lines of force**. Arrows on the lines show the direction of the field, i.e. the direction in which a N pole points.

Different field patterns are given by differently shaped conductors.

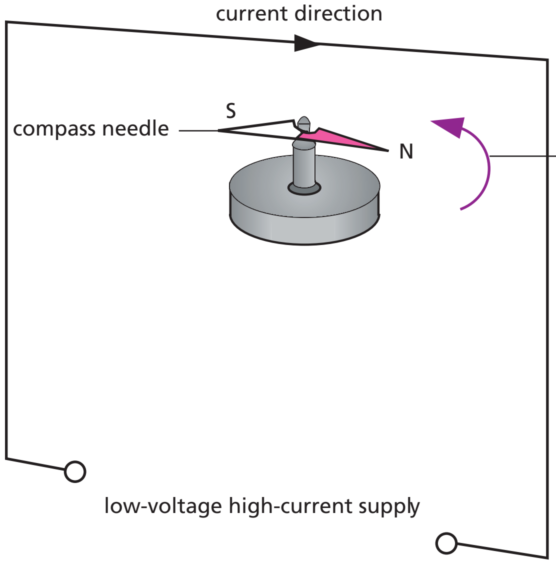



**Figure 45.1** An electric current produces a magnetic effect.

## Field due to a straight wire

If a straight vertical wire passes through the centre of a piece of card held horizontally and there is a current in the wire (Figure 45.2), iron filings sprinkled on the card settle in concentric circles when the card is gently tapped.

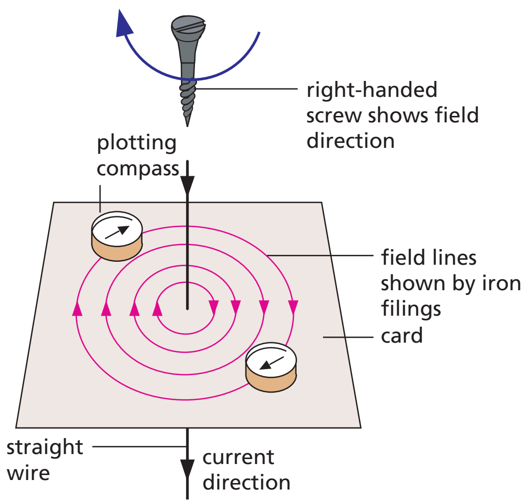



**Figure 45.2** Field due to a straight wire

Plotting compasses placed on the card settle along the field lines and show the direction of the field at different points. When the current direction is reversed, the compasses point in the opposite direction showing that the direction of the field reverses when the current reverses.

If the current direction is known, the direction of the field can be predicted by the **right-hand screw rule**:

> If a right-handed screw moves forwards in the direction of the current (conventional), the direction of rotation of the screw gives the direction of the field.

# Field due to a circular coil

The field pattern is shown in Figure 45.3. At the centre of the coil the field lines are straight and at right angles to the plane of the coil. The right-hand screw rule again gives the direction of the field at any point.

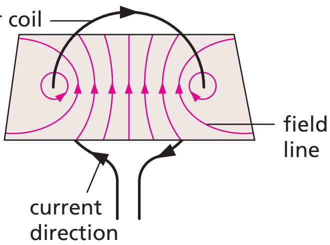



**Figure 45.3** Field due to a circular coil

# Field due to a solenoid

A **solenoid** is a long cylindrical coil. It produces a field similar to that of a bar magnet; in Figure 45.4a, end A behaves like a N pole and end B like a S pole. The polarity can be found as before by applying the right-hand screw rule to a short length of one turn of the solenoid. Alternatively the **right-hand grip rule** can be used. This states that if the fingers of the right hand grip the solenoid in the direction of the current (conventional), the thumb points to the N pole (Figure 45.4b). Figure 45.4c shows how to link the end-on view of the current direction in the solenoid to the polarity.

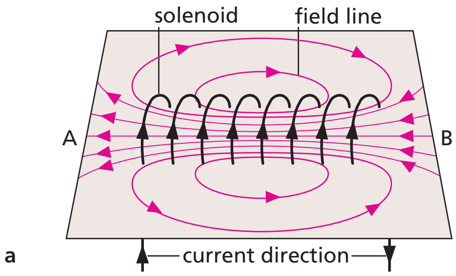



**Figure 45.4a** Field due to a solenoid

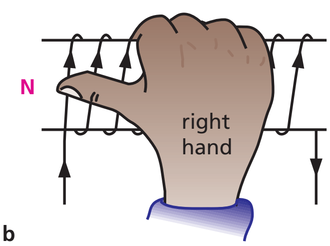



**Figure 45.4b** The right right-hand grip rule

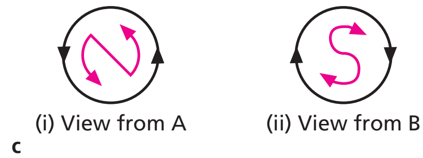



**Figure 45.4c** End-on views

Inside the solenoid in Figure 45.4a, the field lines are closer together than they are outside the solenoid. This indicates that the magnetic field is stronger inside a solenoid than outside it.

The field inside a solenoid can be made very strong if it has a large number of turns or a large current. Permanent magnets can be made by allowing molten ferromagnetic metal to solidify in such fields.

# Magnetisation and demagnetisation

A ferromagnetic material can be magnetised by placing it inside a solenoid and gradually increasing the current. This increases the magnetic field strength in the solenoid (the density of the field lines increases), and the material becomes magnetised. Reversing the direction of current flow reverses the direction of the magnetic field and reverses the polarity of the magnetisation. A magnet can be demagnetised by placing it inside a solenoid through which the current is repeatedly reversed and reduced.

## Practical work

### Simple electromagnet

An **electromagnet** is a coil of wire wound on a soft iron core. A 5 cm iron nail and 3 m of PVC-covered copper wire (SWG 26) are needed.

**(a)** Leave about 25 cm at one end of the wire (for connecting to the circuit) and then wind about 50 cm as a single layer on the nail. **Keep the turns close together and always wind in the same direction.** Connect the circuit of Figure 45.5, setting the rheostat at its maximum resistance.
Find the number of paper clips the electromagnet can support when the current is varied between 0.2 A and 2.0 A. Record the results in a table. How does the 'strength' of the electromagnet depend on the current?

**(b)** Add another two layers of wire to the nail, winding in the *same direction* as the first layer. Repeat the experiment. What can you say about the 'strength' of an electromagnet and the number of turns of wire?

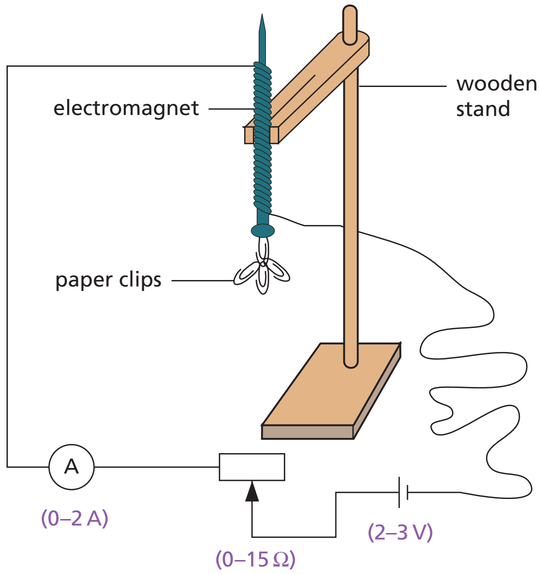



Figure 45.5

**(c)** Place the electromagnet on the bench and under a sheet of paper. Sprinkle iron filings on the paper, tap it gently and observe the field pattern. How does it compare with that given by a bar magnet?
**(d)** Use the right-hand screw (or grip) rule to predict which end of the electromagnet is a N pole. Check with a plotting compass.

## Electromagnets

The magnetism of an electromagnet is *temporary* and can be switched on and off, unlike that of a permanent magnet. It has a core of soft iron which is magnetised only when there is current in the surrounding coil.

The strength of an electromagnet increases if

**(i)** the **current** in the coil increases,
**(ii)** the **number of turns** on the coil increases,
**(iii)** the poles are moved **closer together**.

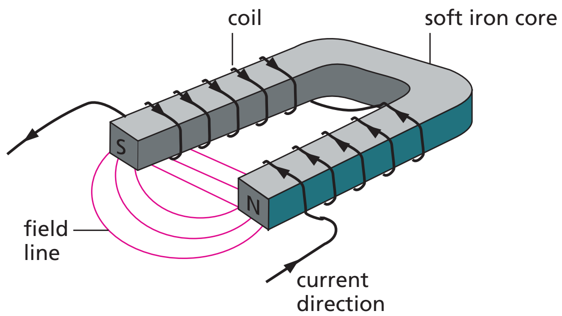



Figure 45.6 C-core or horseshoe electromagnet

In C-core (or horseshoe) electromagnets condition **(iii)** is achieved (Figure 45.6). Note that the coil on each limb of the core is wound in *opposite* directions.

As well as being used in cranes to lift iron objects, scrap iron, etc. (Figure 45.7), electromagnets are an essential part of many electrical devices.

Figure 45.7 Electromagnet being used to lift scrap metal

## Electric bell

When the circuit in Figure 45.8 is completed, by someone pressing the bell push, current flows in the coils of the electromagnet which becomes magnetised and attracts the soft iron bar (the armature).

The hammer hits the gong but the circuit is now broken at the point C of the contact screw.

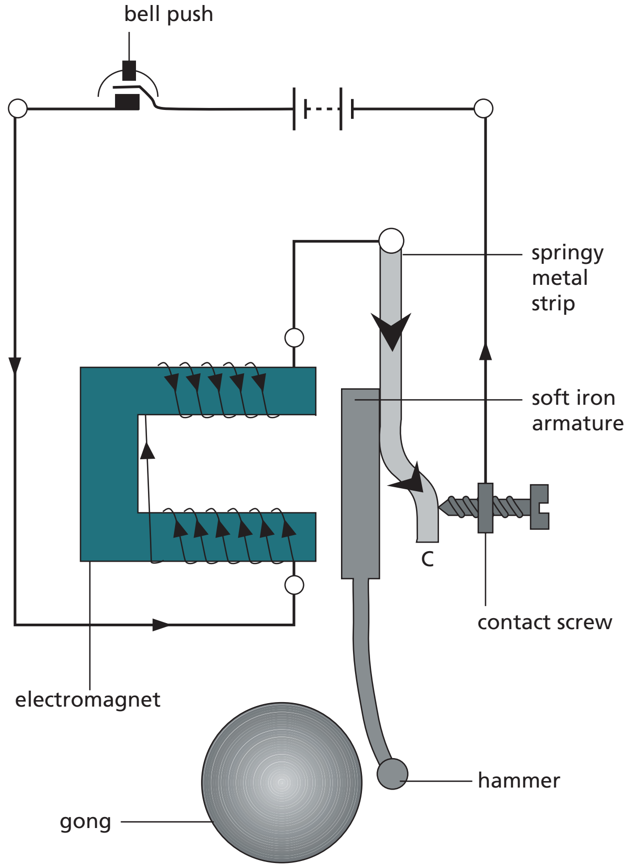



**Figure 45.8** Electric bell

The electromagnet loses its magnetism (becomes demagnetised) and no longer attracts the armature. The springy metal strip is then able to pull the armature back, remaking contact at C and so completing the circuit again. This cycle is repeated so long as the bell push is depressed, and continuous ringing occurs.

# Relay, reed switch and circuit breaker

## a) Relay

A **relay** is a switch based on the principle of an electromagnet. It is useful if we want one circuit to control another, especially if the current and power are larger in the second circuit (see question 3, p. 214). Figure 45.9 shows a typical relay. When a current is in the coil from the circuit connected to AB, the soft iron core is magnetised and attracts the L-shaped iron armature. This rocks on its pivot and closes the contacts at C in the circuit connected to DE. The relay is then 'energised' or 'on'.

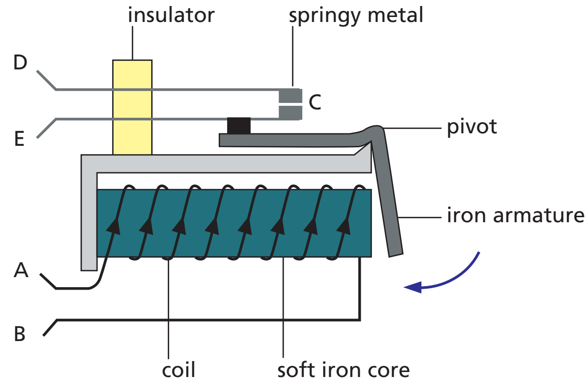



**Figure 45.9** Relay

The current needed to operate a relay is called the **pull-on** current and the **drop-off** current is the smaller current in the coil when the relay just stops working. If the coil resistance, $R$, of a relay is $185\,\Omega$ and its operating p.d. $V$ is 12 V, then the pull-on current $I = V/R = 12/185 = 0.065\,\text{A} = 65\,\text{mA}$. The symbols for relays with normally open and normally closed contacts are given in Figure 45.10.

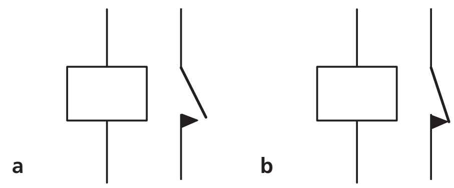
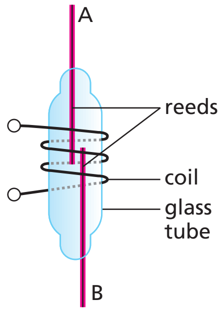



**Figure 45.10** Symbols for a relay: **a** open; **b** closed

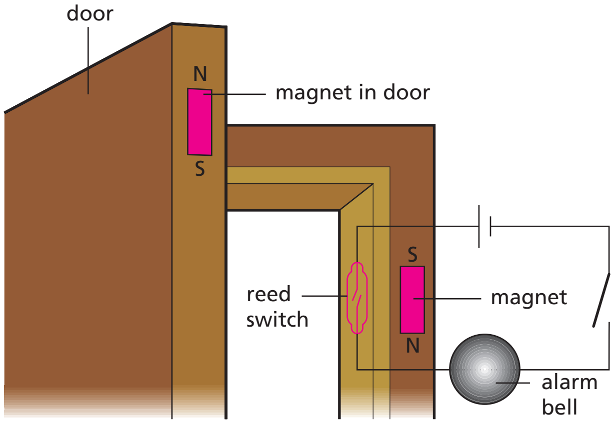
Some examples of the use of relays in circuits appear in Chapter 41.

## b) Reed switch

One such switch is shown in Figure 45.11a. When current flows in the coil, the magnetic field produced magnetises the strips (called **reeds**) of magnetic material. The ends become opposite poles and one reed is attracted to the other, so completing the circuit connected to AB. The reeds separate when the current in the coil is switched off. This type of reed switch is sometimes called a **reed relay**.




**a Reed switch**




**b Burglar alarm activated by a reed switch**

**Figure 45.11**

Reed switches are also operated by permanent magnets. Figure 45.11b shows the use of a normally open reed switch as a burglar alarm. How does it work?

## c) Circuit breaker

A **circuit breaker** (p. 181) acts in a similar way to a normally closed relay; when the current in the electromagnet exceeds a critical value, the contact points are separated and the circuit is broken. In the design shown in Figure 40.11, when the iron bolt is attracted far enough towards the electromagnet, the plunger is released and the push switch opens, breaking contact to the rest of the circuit.

# ● Telephone

A telephone contains a microphone at the speaking end and a receiver at the listening end.

## a) Carbon microphone

When someone speaks into a carbon microphone (Figure 45.12), sound waves cause the diaphragm to move backwards and forwards. This varies the pressure on the carbon granules between the movable carbon dome which is attached to the diaphragm and the fixed carbon cup at the back. When the pressure increases, the granules are squeezed closer together and their electrical resistance decreases. A decrease of pressure has the opposite effect. The current passing through the microphone varies in a similar way to the sound wave variations.

## b) Receiver

The coils are wound in opposite directions on the two S poles of a magnet (Figure 45.13). If the current goes round one in a clockwise direction, it goes round the other anticlockwise, so making one S pole stronger and the other weaker. This causes the iron armature to rock on its pivot towards the stronger S pole. When the current reverses, the armature rocks the other way due to the S pole which was the stronger before becoming the weaker. These armature movements are passed on to the diaphragm, making it vibrate and produce sound of the same frequency as the alternating current in the coil (received from the microphone).

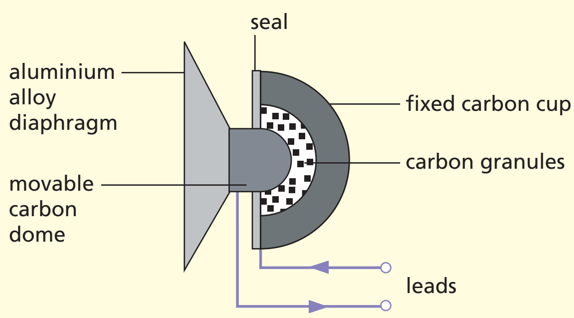



**Figure 45.12** Carbon microphone

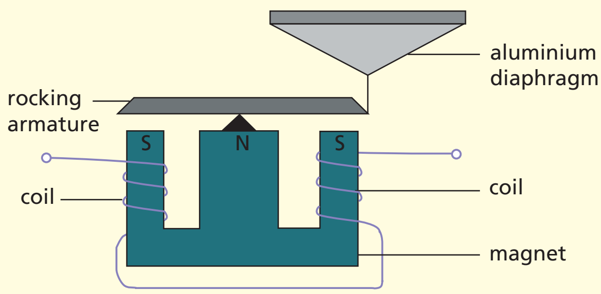



**Figure 45.13** Telephone receiver

## Questions

1 The vertical wire in Figure 45.14 is at right angles to the card. In what direction will a plotting compass at A point when
  a there is no current in the wire,
  b the current direction is upwards?

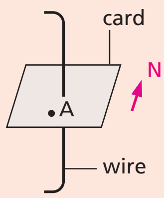



**Figure 45.14**

2 Figure 45.15 shows a solenoid wound on a core of soft iron. Will the end A be a N pole or S pole when the current is in the direction shown?

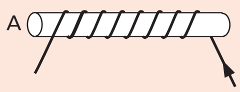



**Figure 45.15**

3 Part of the electrical system of a car is shown in Figure 45.16.
  a Why are connections made to the car body?
  b There are *two* circuits in parallel with the battery. What are they?
  c Why is wire A thicker than wire B?
  d Why is a relay used?

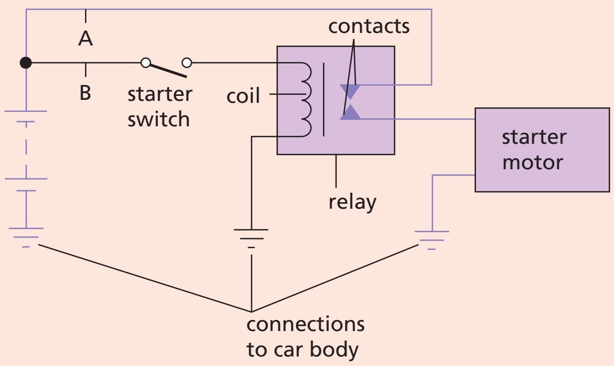



**Figure 45.16**

## Checklist

After studying this chapter you should be able to

- describe and draw sketches of the magnetic fields round current-carrying, straight and circular conductors and solenoids,
- recall the right-hand screw and right-hand grip rules for relating current direction and magnetic field direction,
- describe the effect on the magnetic field of changing the magnitude and direction of the current in a solenoid,
- identify regions of different magnetic field strength around a solenoid,
- make a simple electromagnet,
- describe uses of electromagnets,
- explain the action of an electric bell, a relay, a reed switch and a circuit breaker.