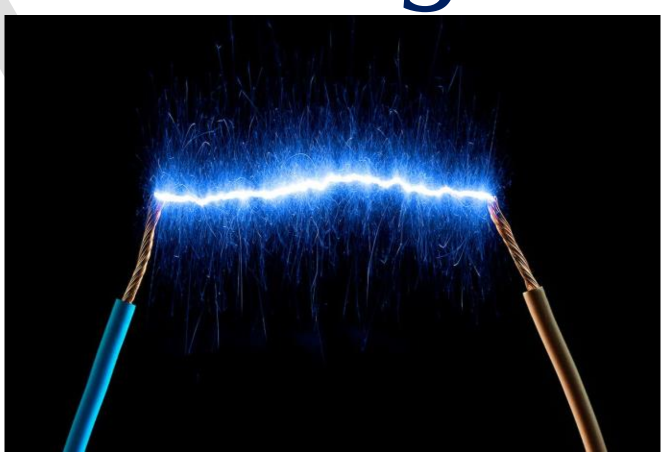
Edexcel IGCSE

Physics

CODE: (4MA1)

Unit 6

Magnetism and Electromagnetism



6.1 Magnetism and magnetic materials

Magnets can attract objects made from magnetic materials such as iron, steel, nickel and cobalt. Magnets cannot attract objects made from materials such as plastic, wood, paper or rubber. These are non-magnetic materials.

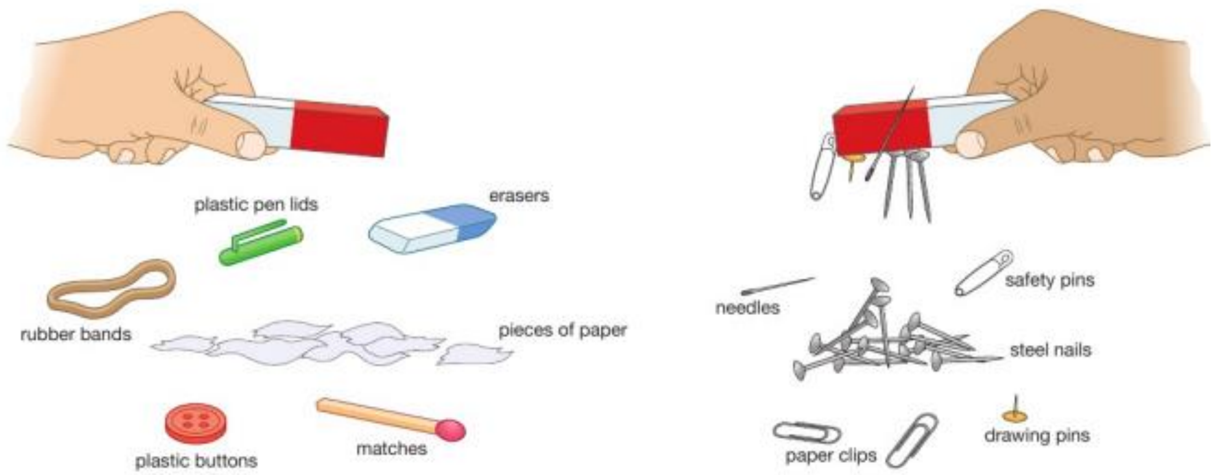


Figure 20.2 Magnets attract some objects and not others.

Magnets

The strongest parts of a magnet are called its poles. Most magnets have two poles. These are called the north pole and the south pole.

If two similar poles are placed near to each other they repel. If two dissimilar (opposite) poles are placed near to each other they attract.

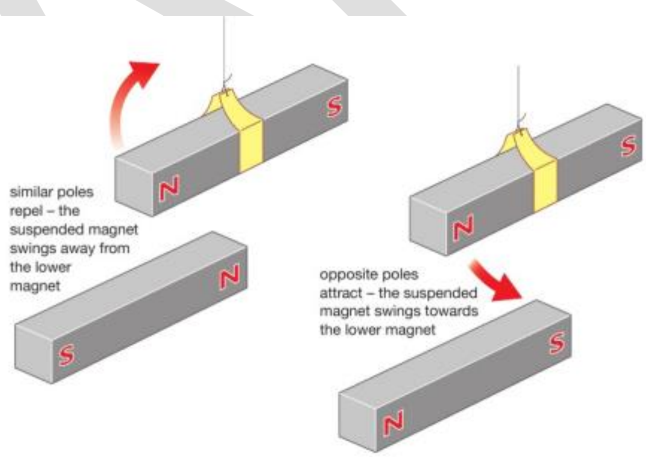


Figure 20.3 Similar poles repel and opposite poles attract.

Magnetic fields

Around every magnet there is a volume of space where we can detect magnetism. This volume of space is called a **magnetic field**.

We draw magnetic fields like that in Figure 20.5 using magnetic field lines. Magnetic field lines don't really exist, but they help us to visualize the main features of a magnetic field.
The magnetic field lines:

■ Show the shape of the magnetic field

■ Show the direction of the magnetic force - the field lines 'travel' from north to south

■ Show the strength of the magnetic field - the field lines are closest together where the magnetic field is strongest.

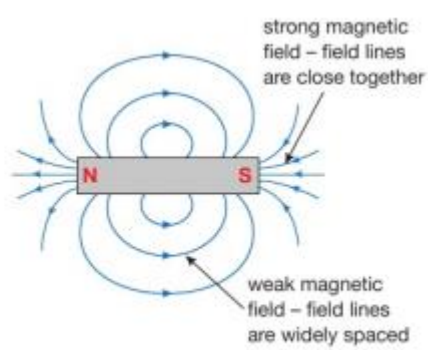


Figure 20.5 The magnetic field around a bar magnet follows a pattern like this.

Overlapping magnetic fields

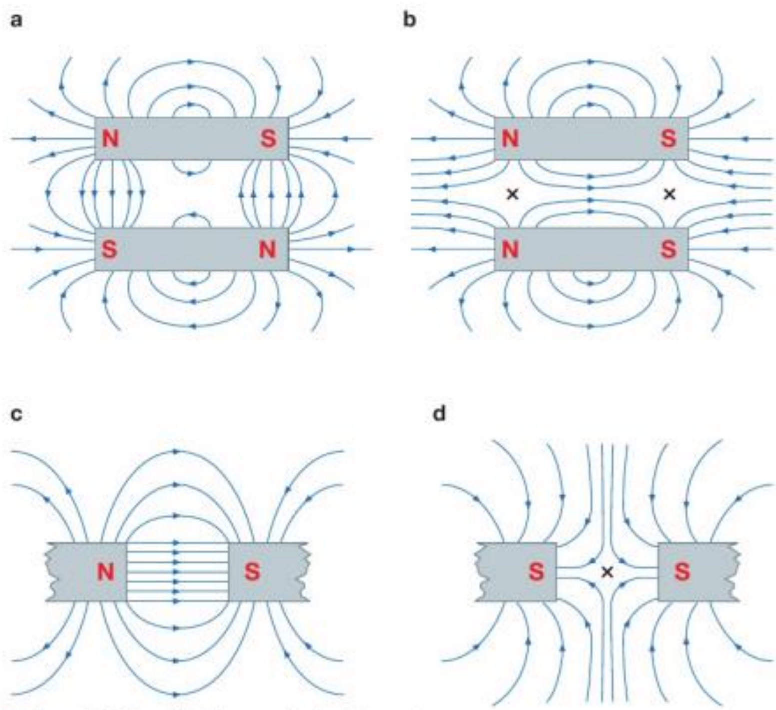
If two magnets are placed near each other, their magnetic fields overlap and affect each other. We can investigate this using iron filings or plotting compasses. Figure 20.6 shows the different field patterns we would see.

Creating a uniform magnetic field

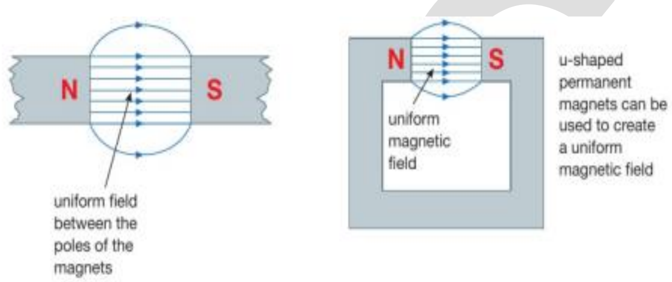
A uniform magnetic field, consisting of straight lines evenly spaced between the north and south poles of two magnets, is highly useful, as its strength and direction remain consistent across all points. (figure 20.7)

Induced magnetism

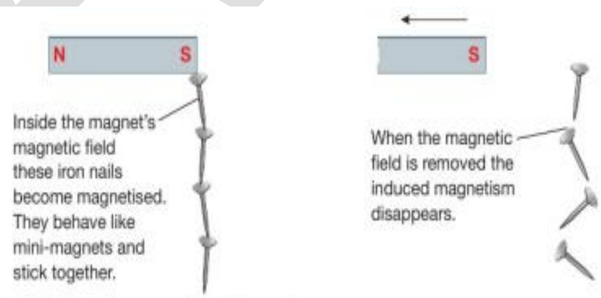
Magnetism is induced in an object made from a magnetic material, such as an iron nail, which is temporary and disappears if the magnet is removed, while hard materials retain some magnetism. (figure 20.8)



▲ Figure 20.6 Magnetic fields around pairs of magnets



▲ Figure 20.7 Two examples of uniform magnetic fields



▲ Figure 20.8 Introducing magnetism in iron nails

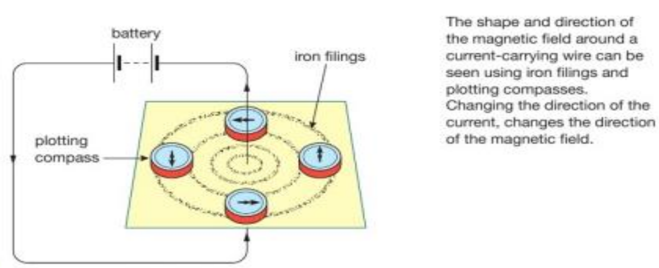
Electromagnetism

When there is a current in a wire a magnetic field is created around it. This is called electromagnetism. The field around the wire is quite weak and circular in shape.

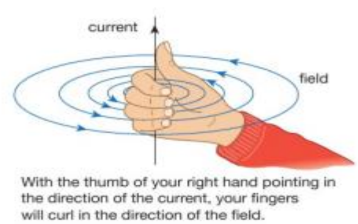
If the wire is made into a flat, single-turn coil (circular wire), the magnetic field around the wire changes shape and is as shown in Figure 20.11.

The strength of the magnetic field around a current-carrying wire can be increased by:

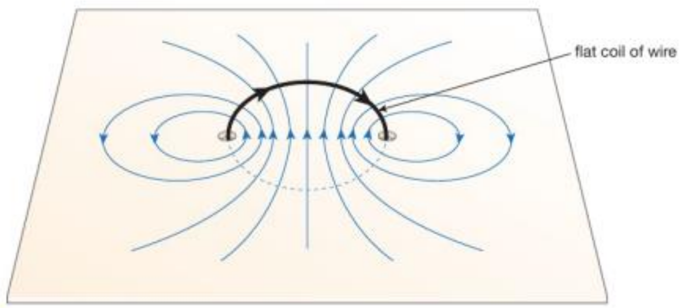
1. increasing the current in the wire
2. wrapping the wire into a coil or solenoid (a solenoid is a long coil). (figure 20.12)



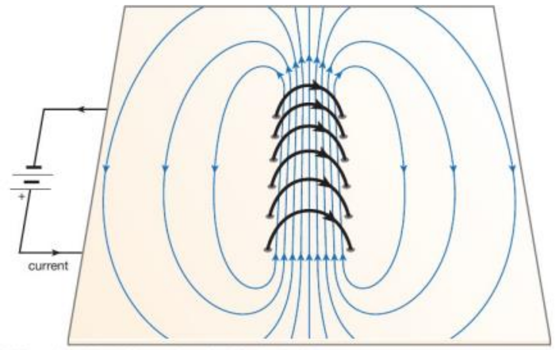
▲ Figure 20.9 A current-carrying wire has a magnetic field around it.



▲ Figure 20.10 You can work out the direction of the field using the right-hand grip rule (for fields).



▲ Figure 20.11 The magnetic field around a flat coil

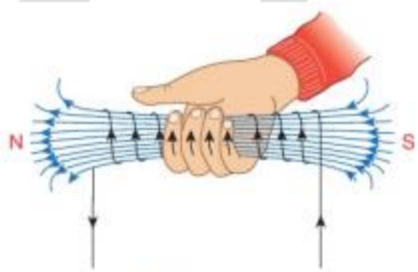


▲ Figure 20.12 The field around a solenoid looks like this.

The shape of the magnetic field around a solenoid is the same as that around a bar magnet.

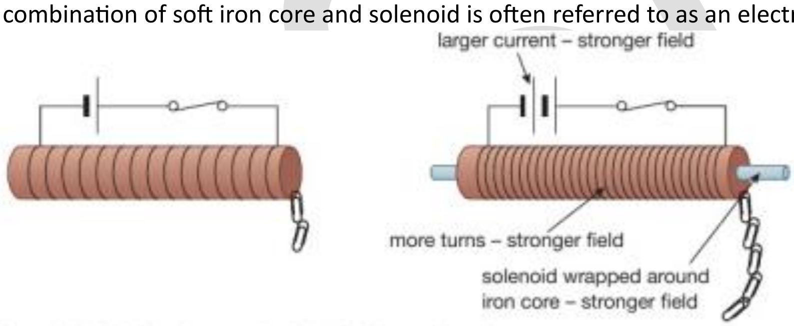
The shape of the magnetic field around a solenoid is the same as that around a bar magnet.

The strength of the field around a solenoid can be increased by:
1. increasing the current in the solenoid
2. increasing the number of turns on the solenoid
3. wrapping the solenoid around a magnetically soft core such as iron.



▲ Figure 20.13 You can work out the **polarity** of the solenoid by imagining that your right hand is wrapped around it. Your fingers point in the direction of the current and your thumb points to the north pole of the solenoid. This is the right-hand grip rule (for poles).

This combination of soft iron core and solenoid is often referred to as an electromagnet.



▲ Figure 20.14 Altering the strength of the field around an electromagnet

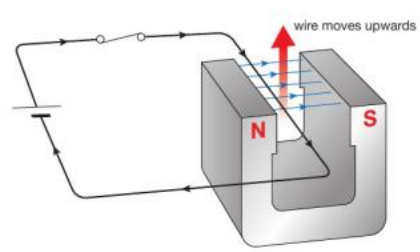
6.2 electric motors and electromagnetic induction

Movement from electricity

Charged particles in a magnetic field experience force, as demonstrated by electrons passing along a wire in a magnetic field, attempting to move upwards when the switch is closed.

Overlapping magnetic fields

We can explain this motion by looking at what happens when the switch is closed, and the two magnetic fields overlap.
The two diagrams in Figure 21.3 show the shapes and directions of the magnetic fields a across the poles of the magnet, and b around the current- carrying wire before they overlap.



▲ Figure 21.2 The wire moves where there is a current in it.

If the wire is placed between the poles of the magnet, the two fields overlap.

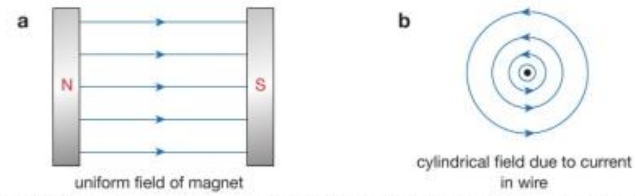


Figure 21.3 a Magnet's uniform magnetic field b Magnetic field around a current carrying wire

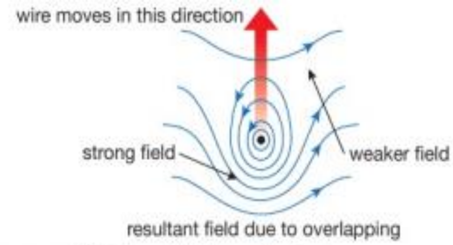


Figure 21.4 The new magnetic field created by overlapping

The motor effect occurs when a wire experiences a force pushing it upwards due to the overlapping of two magnetic fields, which creates a strong magnetic field below the wire and a weaker field above it, causing motion.

A stronger force will be produced if the magnetic field is stronger or if the current is increased.

If we change the direction of the current or the magnet's field, a different overlapping pattern is created, and we will see the wire move in the opposite direction.

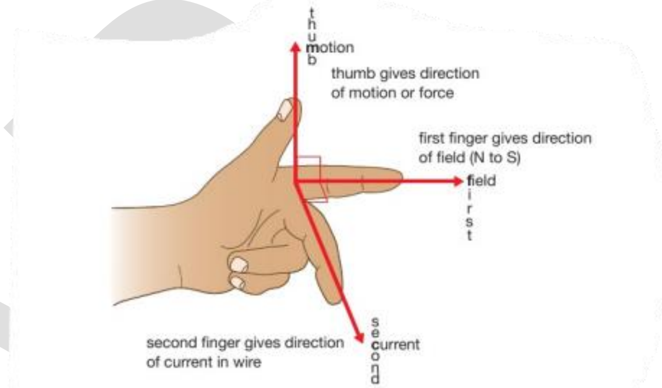


Figure 21.5 Fleming's left-hand rule helps you to work out the direction of the force.

The moving – coil loudspeaker

The moving-coil loudspeaker uses the motor effect to transfer electrical energy to sound energy.

■ Electric currents from a source, such as a radio, pass through the coils of a speaker.

■ These currents, which represent sounds, are always changing in size and direction, like vibrating sound waves.

■ The fields of the coil and the permanent magnet are therefore creating magnetic field patterns which are also always changing in strength and direction.

■ These fields in turn apply rapidly changing forces to the wires of the coil, which cause the speaker cone to vibrate.

■ These vibrations create the sound waves we hear.

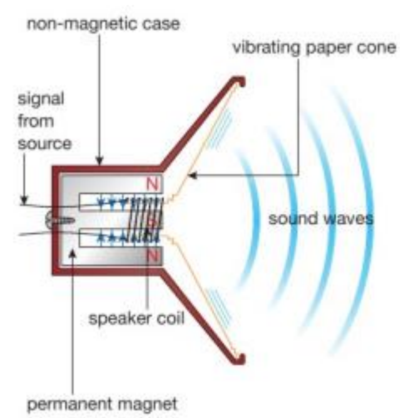


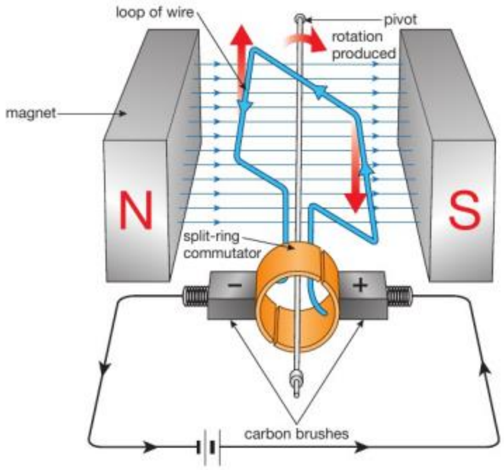
Figure 21.6 A loudspeaker transfers electrical energy to sound energy.

The electric motor

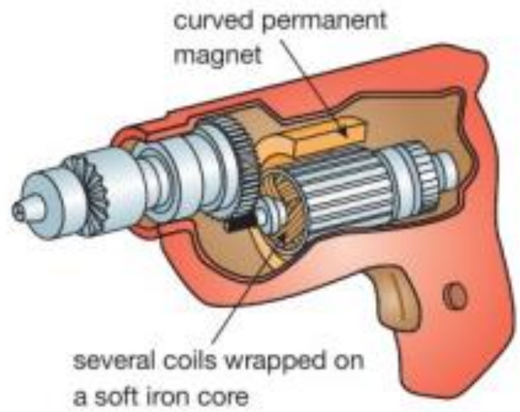
The electric motor is one of the most important uses of the motor effect. Figure 21.7 shows the most important features of a simple d.c. electric motor.

A wire loop rotates due to current, with one side experiencing upward and the other downward forces. As it reaches the vertical position, the loop's momentum changes. To reverse the rotation, a split ring is used to connect the wire loop to the electrical supply. As the loop passes the vertical position, connections change, current direction changes, and the loop rotates continuously.

To increase the rate at which the motor turns we can:
1. Increase the number of turns or loops of wire, making a coil
2. Increase the strength of the magnetic field
3. Increase the current in the loop of wire.



▲ Figure 21.7 A simple electric motor



▲ Figure 21.8 A real electric motor

Electromagnetic induction

Motors use electricity to produce movement. Generators and alternators are machines that use motion to produce electricity. They use a process called electromagnetic induction.

The workers shown in Figure 21.9 need electricity for their machines and their lights. Instead of connecting into the mains supply, as we do at home, the workers have their own generator, which produces the electrical energy they need. In fact, the mains supply itself is produced by large generators in power stations.

▲ Figure 21.9 Transportable generators are used to produce electricity for the lights and machinery used on roadworks.

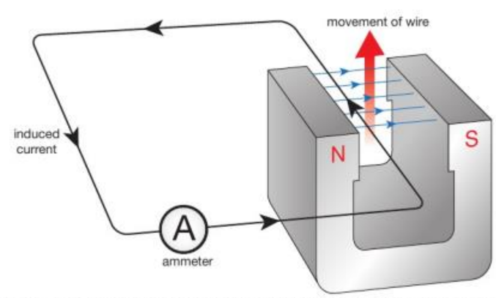
Demonstrating electromagnetic induction

If we move a wire across a magnetic field at right angles, as shown in Figure 21.10, a voltage is induced or generated in the wire. If the wire is part of a complete circuit, there is a current. This event is called electromagnetic induction.

The size of the induced voltage (and current) can be increased by:
1. Moving the wire more quickly

2. Using a stronger magnet so that there are more field lines 'cut'

3. Wrapping the wire into a coil so that more pieces of wire move through the magnetic field.

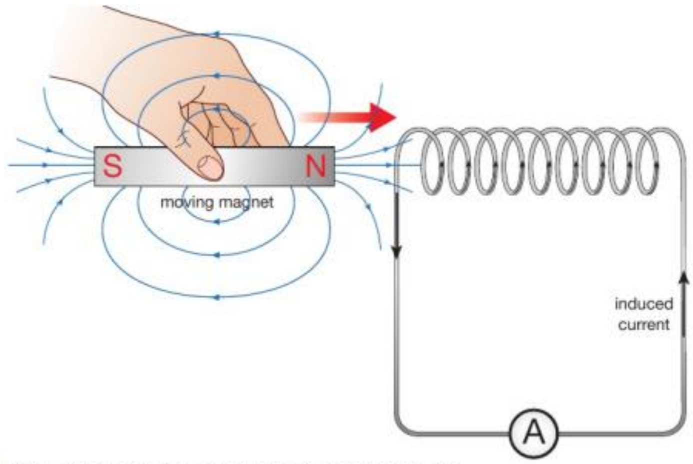


▲ Figure 21.10 When a wire moves across a magnetic field a voltage is generated in the wire.

Pushing a magnet into a coil can generate voltage and current, with the cutting action between wires and field lines generating voltage. If there's no cutting, no voltage is generated, as shown in Figure 21.10.

This experiment also shows us that the size of the induced voltage (and current) can be increased by:

1. Moving the magnet more quickly
2. Using a stronger magnet
3. Using a coil with more turns.



▲ Figure 21.11 A magnet moving in a coil will generate electricity.

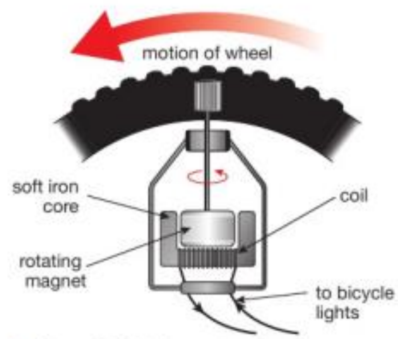
We can summarise all the discoveries from these experiments by saying:

- A voltage is induced when a conductor cuts through magnetic field lines
- A voltage is induced when magnetic field lines cut through a conductor
- The faster the lines are cut the larger the induced voltage.

Generators

Figure 21.12 shows a small generator or dynamo used to generate electricity for a bicycle light.

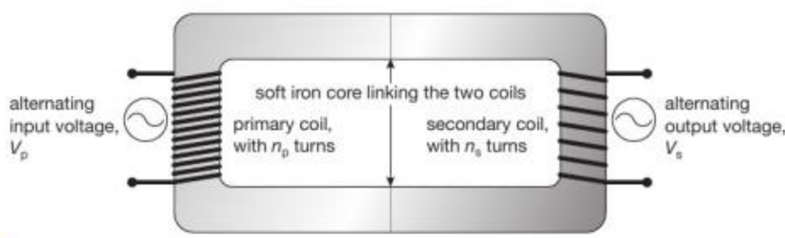
As the cyclist pedals, the wheel rotates and makes a small magnet within the dynamo turn around. As this magnet turns, its magnetic field turns too. The field lines cut through the coil inducing a current in it. This current can be used to work the cyclist's lights.



▲ Figure 21.12 A dynamo is a simple generator.

The transformer

A transformer is a system where alternating current in a coil generates a magnetic field that changes size as the current increases and decreases. This field passes through a second coil, causing a voltage induced across the wires of the second coil. The voltage applied to the primary coil produces the voltage across the secondary coil.



▲ Figure 21.14 The size of the voltage generated in the secondary coil of a transformer depends on the voltage in the primary coil and the numbers of turns on each coil.

Using transformers to change voltages

A **transformer** changes the size of an alternating voltage by having different numbers of turns on the input and output sides.
The relationship between the voltages across each of the coils is described by the equation:

$$\frac{\text{input voltage, } V_p}{\text{output voltage, } V_s} = \frac{\text{number of turns on primary coil, } n_p}{\text{number of turns on secondary coil, } n_s}$$

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

Energy in transformers

If a transformer is 100% efficient then the electrical energy entering the primary coil each second equals the electrical energy leaving the secondary coil each second: Another way of saying this is:

input power, V_pI_p = output power, V_sI_s

$$V_pI_p = V_sI_s$$

Transformers and national grids

National Grids are networks of wires and cables that transport electrical energy from power stations to consumers. However, currents in long wires can lose energy due to heat losses. Transformers help reduce heat losses by reducing current in wires and transmitting electricity as low currents and high voltages. Step-up transformers increase voltage to 400 kV, while step-down transformers decrease voltage to 230 V and increase current.

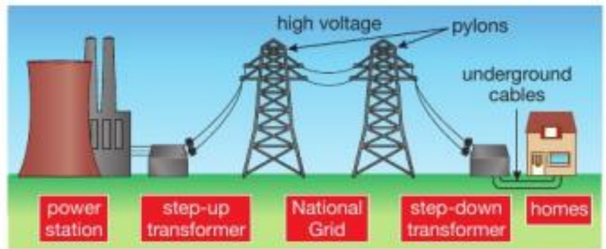
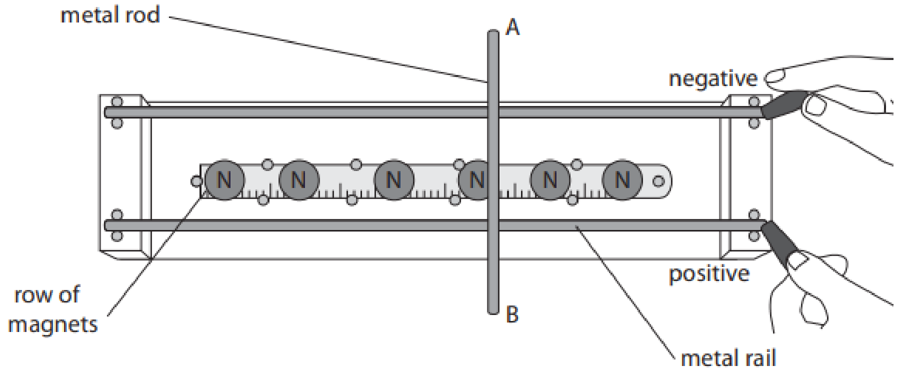


Figure 21.16 Transformers are used in National Grids.

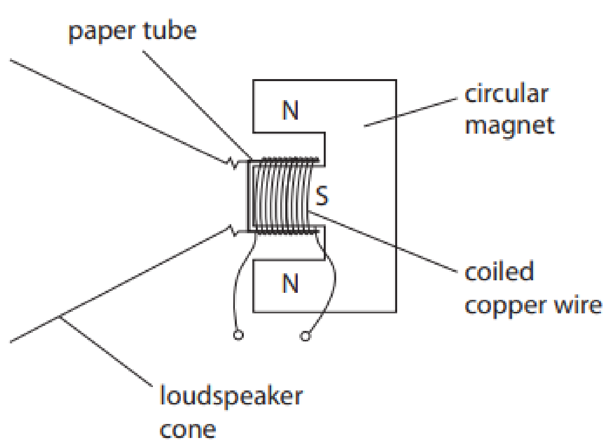
Revision questions

(1) (a) A student uses this apparatus to investigate what happens to a current-carrying conductor in a magnetic field



The student connects the two parallel horizontal metal rails to the positive and negative terminals of a power supply.
The metal rod AB rests across the rails and is free to move.
Explain what happens to the metal rod AB.

(b) This diagram shows the construction of a simple loudspeaker.
A coil of wire is wrapped around a paper tube attached to the loudspeaker cone.

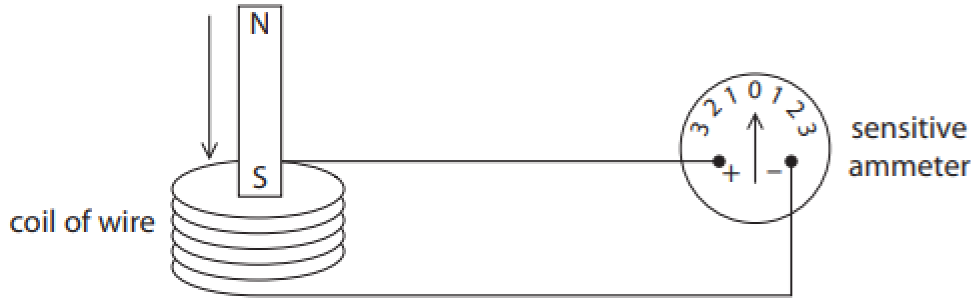


When there is an alternating current in the coil, the cone moves.

Describe how the alternating current generates a sound wave.

You may draw a diagram if it helps your answer

(2) (a) A student uses this apparatus to investigate electromagnetic induction.



When the S pole of the magnet is moved into the coil, the pointer on the sensitive ammeter moves to the left.

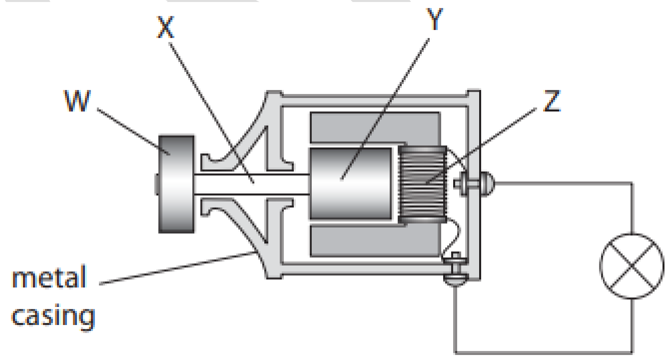
Describe two ways that the student can make the pointer move to the right

(b) The student has a bicycle with a dynamo (generator) that supplies electricity for its lights. The diagram shows the dynamo.

The friction wheel, W, presses against the bicycle tyre. When the student pedals, the friction wheel turns and causes part Y to rotate

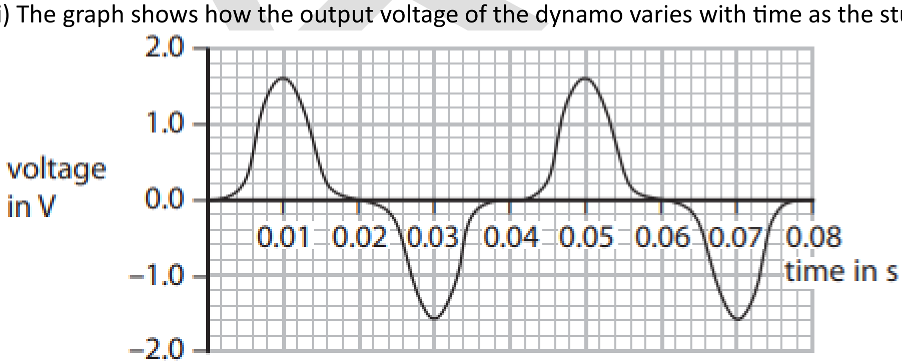
Key

W	friction wheel
X	axle
Y	
Z	



(i) Complete the key for the diagram by giving the names of parts Y and Z.

(ii) The graph shows how the output voltage of the dynamo varies with time as the student pedals steadily.



State the maximum output voltage of the dynamo.

(iii) Calculate the frequency of the output voltage

(iv) Apart from changing the speed of the friction wheel, suggest how the output voltage of the dynamo can be increased.

(3) Magnetic fields can have different shapes.
(a) (i) describe and experiment to show the shape of magnetic field around a bar magnet.
(ii) The diagram shows a bar magnet.
Complete a diagram to show the shape of the field around the magnet.

(b) The diagram shows the two bar magnets.
They produce a uniform magnetic field.
On the diagram, sketch the part of the field that is uniform and label the poles.

(4) Diagram 1 shows some of the apparatus used to investigate the force on a current-carrying wire, XY, in a magnetic field.

(a) Diagram 2 shows the poles of the magnet viewed from above. Draw the uniform magnetic field between the poles.

Diagram 2

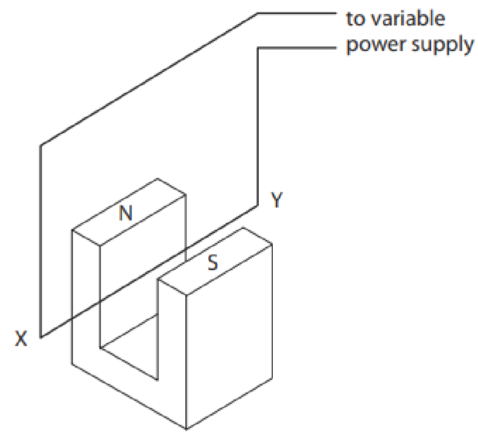
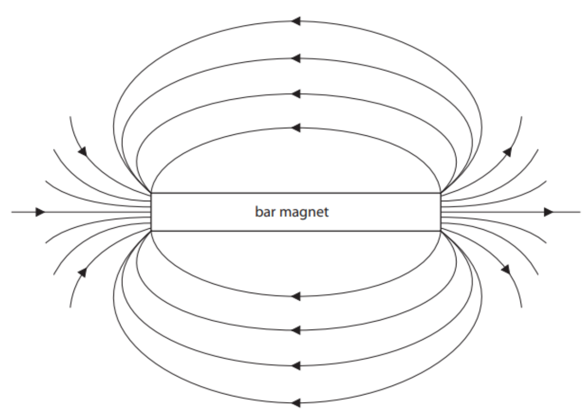


Diagram 1

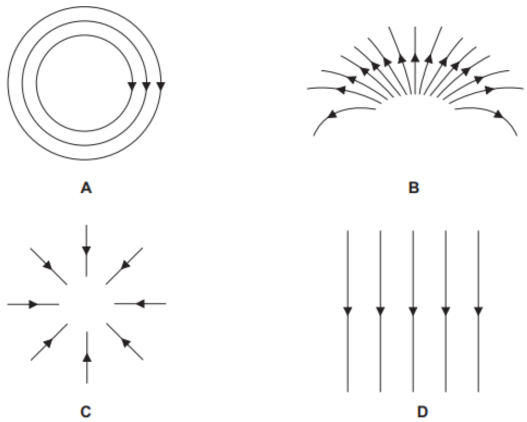
(b) The current-carrying wire XY is at right angles to the magnetic field. The current in the wire is 10 A.
(i) Suggest why the wire used in this investigation must be thick
(ii) Explain why the wire XY experiences a force when there is a current in the circuit.
(iii) State two ways in which this force can be reduced

(5) The diagram shows the magnetic field pattern around a bar magnet

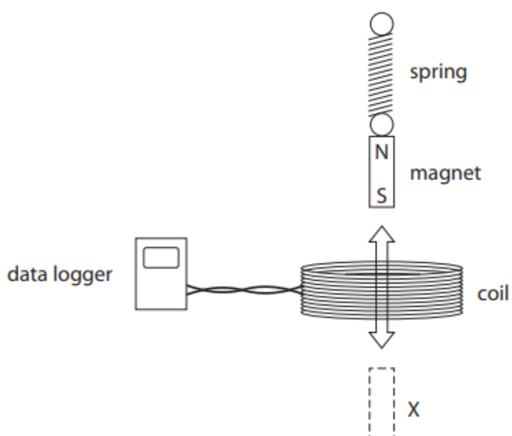


(a) Complete the diagram above by labelling the poles on the bar magnet
(b) Describe an experiment to investigate the shape of the magnetic field pattern of a bar magnet.
You may draw a diagram to help your answer

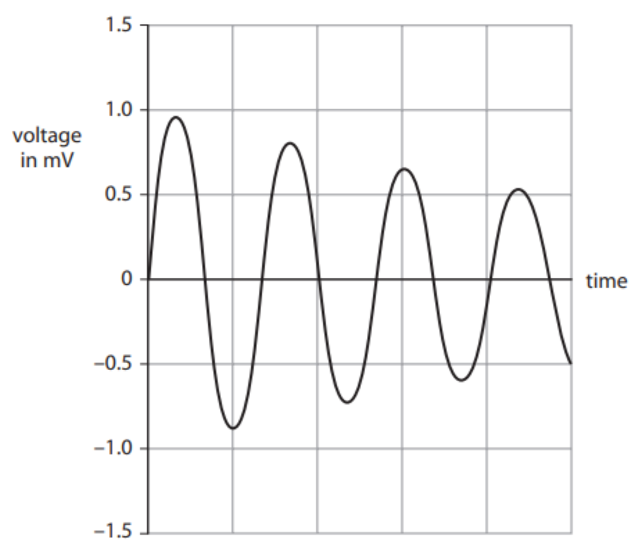
(6) A magnetic field pattern can be shown using lines.
(a) The diagram shows some magnetic field patterns.
(b) Explain how to produce a uniform magnetic field.



(c) A student investigates how to produce a voltage. He hangs a magnet from a spring, above a coil that is connected to a data logger.



(a) The student pulls the magnet through the coil to X and then releases it. The magnet moves up and down through the coil. The data logger produces this graph of voltage against time.
(i) Explain why the data logger records a varying voltage
(ii) Which feature of the graph shows that the voltage is alternating?
(iii) Suggest why the voltage changes as shown by the graph.

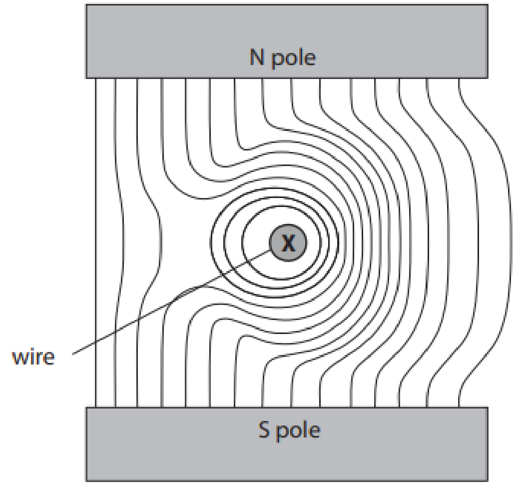


(7) Magnetic field lines show the shape and direction of a magnetic field.

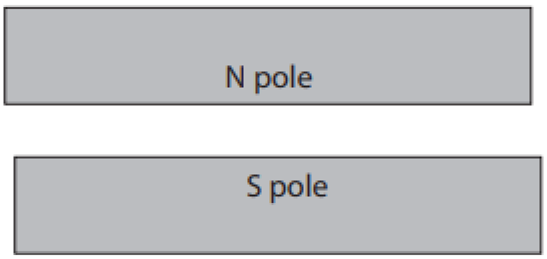
(a) The diagram shows a cross-section through a wire placed between two magnetic poles. The wire carries electric current into the page at X. The shape of the magnetic field is shown.

(i) Add arrows to two of the magnetic field lines to show the direction of the magnetic field.

(ii) Draw an arrow on the diagram to show the direction of the force on the wire. Label this arrow F



(b) The wire is removed and the magnetic field between the poles changes. Sketch the new magnetic field



(c) Explain how you could use a plotting compass to investigate the magnetic field around a bar magnet. You may draw a diagram to help your answer.

(8) This photograph shows an electromagnetic device used to keep a door open

The electromagnet attracts the metal plate to hold the door open. The electromagnet is connected to a fire alarm circuit. When the fire alarm sounds, the door is released, and it closes.

(a) State why the metal plate is made of iron

(b) Describe the construction of an electromagnet. You may draw a diagram to help your answer

(c) Describe the changes that allow the electromagnet to release the door when the fire alarm sounds.