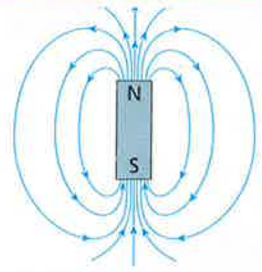
Electromagnets
Magnetism *and* Electromagnetism

Ideas you have met before

Magnetic fields

Magnetic forces act at a distance; they are non-contact forces.

A magnet produces a magnetic field.



Magnetic attraction and repulsion

Magnets have two poles.

Two magnets will attract or repel each other, depending on which poles are facing.

Magnetic materials are attracted by a magnet. There are several magnetic materials, including iron and steel, but most metals are not magnetic.

Explaining electric circuits

Components in circuits can be arranged in series, in parallel or in both. These arrangements have different effects on the voltage and current, and provide different applications.

Current depends on the 'push' given by the battery, known as the voltage.

Circuits and components

The brightness of a lamp or the volume of a buzzer is associated with the number and voltage of cells used in the circuit.

Symbols can be used to represent a simple circuit in a diagram.

In this chapter you will find out

Magnetic fields

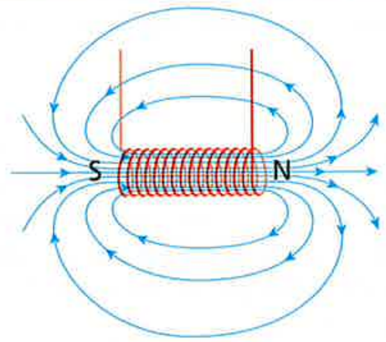
- Magnetic materials, electromagnets and the Earth create magnetic fields which can be described by drawing field lines to show the strength and direction.

Magnetic attraction and repulsion

- The stronger the magnet, and the smaller the distance from it, the greater the force a magnetic object in the field experiences.

Explaining electromagnets

- A current flowing through a wire causes a magnetic field. Its strength depends on the current, the core and the number of coils in the solenoid.
- When a coil of wire is placed in a magnetic field and a current is passed through it, the coil moves. This is because the coil of wire acts as a magnet itself – an electromagnet.



Using electromagnets

- Electromagnetism is the basis of the motors used in power tools, mixers and cars.
- In an electromagnet it is possible to switch the magnetic field off. Metal-recycling plants use electromagnets to separate iron and steel from aluminium.

Forces and fields

We are learning how to:

- Recall the laws of magnetic attraction.
- Explain how a magnetic field can be represented by field lines.
- Apply ideas about attraction to magnetic materials placed in a field.

This toy uses magnetism. The shallow box has a transparent lid and a picture of a face on the lower surface. In the box are some iron filings. By using a magnet, a child can position the filings to add hair, eyebrows, a beard and a moustache. It works because the magnetic field of the bar magnet extends into the box if the magnet is close.

FIGURE 2.2.1a: Fun with magnets.

Attract and repel

Magnets apply forces. These forces don't work on everything, but they do work on other magnets and also on magnetic materials. If you have a box of steel paperclips you can pick them up using a magnet. The magnet has two **poles**, north and south, but it doesn't matter which you use. It's always a force of attraction.

Magnetism is a good example of a **non-contact** force (other examples are gravity and static electricity). The magnet doesn't have to touch the paper clips to move them. It just has to be near them.

If you bring one magnet near to another one, however, you soon find that which pole you use does matter. If two magnets get close, you will learn that opposite poles **attract** and like poles **repel**. Two norths (or two souths) push away from each other, whereas a north and a south attract. We can say that:

- Like poles repel.
- Unlike poles attract.

1. If a magnet had a paper sleeve over it so you couldn't see the labels on the poles, how could you work out which was which if you had another magnet?
2. If you had a magnet and a piece of magnetic metal, both with paper sleeves over them, how could you use a magnet to work out which was which?

Did you know...?

Magnetism was first discovered when naturally occurring magnets, called lodestones, were found. No-one knows how they became magnetised as the Earth's magnetic field is too weak. One explanation is that it was as a result of lightning bolts.

The idea of a field

If you were to hold a steel paper clip near to a bar magnet, you would feel it being attracted. This force would be there whether you held the clip on either side of the magnet, above it or below it. In other words, the magnet has produced a **field** and anything magnetic in that field will be affected.

We can show this field by drawing lines. The lines always start at a north-seeking pole and go to a south-seeking pole. They can never cross and where they are closer together, the field is stronger.

This is what the field looks like for a bar magnet.

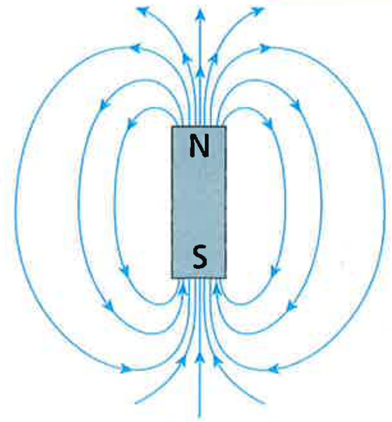


FIGURE 2.2.1b: Field lines of a bar magnet.

3. Whereabouts is the field strongest?
4. Where is it weaker?
5. Figure 2.2.1b shows the field on either side of the magnet and around the ends, but which part of the field does it not show?

Applying ideas about forces and fields

Imagine an experiment with a toy car rolling down a ramp. The car has a body made of steel, so it is magnetic. Halfway down the ramp is a magnet. It's near to where the car will pass but isn't in the way. Alex and her team are trying to work out what will happen. They have several ideas:

- 'The magnet will push the car away as it comes down the ramp.'
- 'The magnet will speed the car up as it gets near and slow it down as it goes on past but the car won't change direction.'
- 'If the magnet is near enough it will attract the car and stick to it.'
- 'The magnet won't affect the car. Once it gets going, the car will accelerate, just as if the magnet wasn't there.'

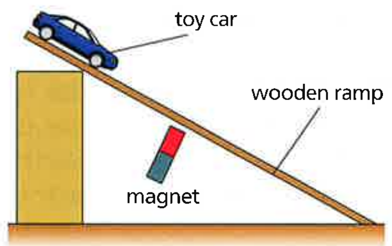


FIGURE 2.2.1c: How will the magnet affect the car?

6. Decide which of these predictions you agree with and say why.
7. Now select one of the others and explain why you think it's wrong.
8. Identify the variables in this experiment and suggest how if the values were changed it might make one of the other predictions true.

Know this vocabulary

pole
non-contact
attract
repel
field

Using ideas about fields

We are learning how to:

- Describe key features of the Earth's magnetic field.
- Explain why fields vary in strength.
- Explore the fields around combinations of magnets.

Finding your way through a bleak and wild landscape can be difficult enough, but if the fog comes in it will be several times worse. Neither the shape of the landscape or the fog, however, will stop a compass from working. It will always detect the Earth's magnetic field, and indicate which way you are facing.

FIGURE 2.2.2a: Using magnetism to help you find your way.

Exploring the Earth's magnetic field

The Earth has a magnetic **field**. It works as if there was a giant bar magnet inside the Earth. The lines of magnetic force follow the same pattern as those of a bar magnet. The field is the same shape.

Of course, it's a huge field, thousands of kilometres long and stretching out into space in all directions. It can be detected anywhere around the Earth.

The other interesting thing about it is that the south **pole** of this giant bar magnet is close to the Earth's north pole. It's as if the magnet is the wrong way around. What this means, of course, is that it will attract the north pole of a **compass**. Unlike poles attract.

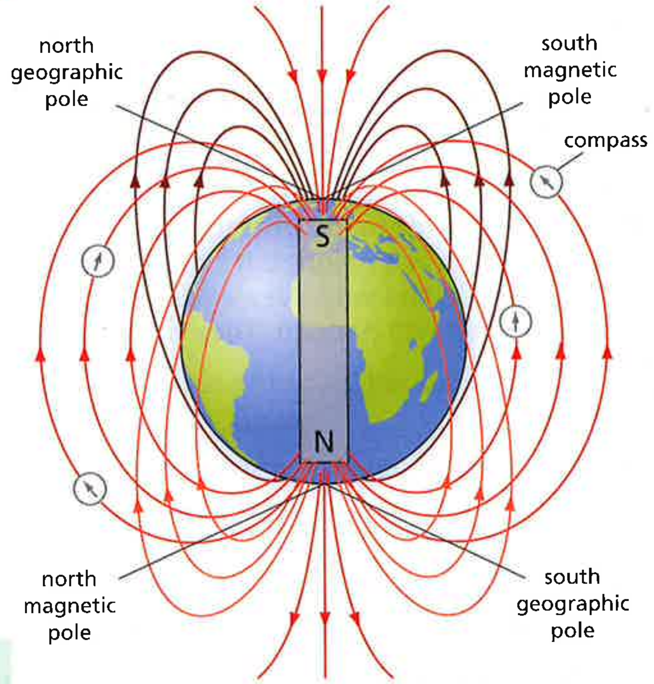


FIGURE 2.2.2b: The Earth's magnetic field.

1. Why is a compass useful for navigation?
2. Why are compasses used more at sea and in wild areas than in built-up areas?
3. How is a compass like a bar magnet?

Factors affecting fields

Magnetic fields aren't all the same strength. If you hold a paper clip near a magnet you will know that the force of attraction varies. There are two things it depends upon.

It is affected by the strength of the magnet. A stronger magnet produces a stronger field.

It is also affected by distance. The further away the magnet is, the weaker the field becomes.

4. Some cupboard doors have magnetic catches. How can you tell from these that magnetic fields are weaker further from the magnet?
5. How does the field diagram for a bar magnet indicate that the field is weaker further from the magnet?

FIGURE 2.2.2c: Using the Earth's magnetic field.

Combinations of magnets

If we bring two magnets close to each other, the space in between will be affected by both of them.

If the magnets are arranged so that a north pole on one is facing the south pole on the other, then the effect is as shown in Figure 2.2.2d. Lines of force leave the north pole and travel to the south pole but, as we can see, it doesn't need to be the south pole of the same magnet. This produces a very concentrated field.

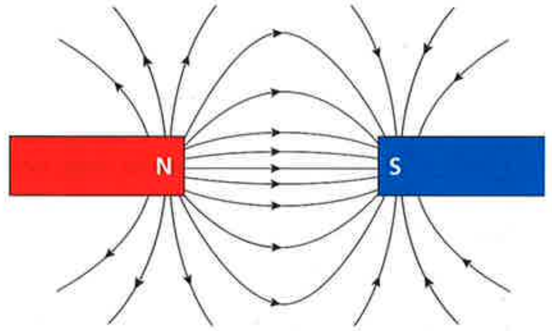


FIGURE 2.2.2d: Field diagram for two opposite magnetic poles placed near each other.

If we bring two like poles near to each other the effect is quite different. Lines of force leave both north poles and curve away from each other (see Figure 2.2.2e).

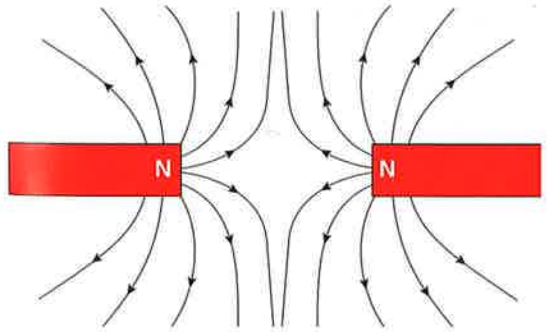


FIGURE 2.2.2e: Field diagram for two magnetic poles that are the same placed near each other.

FIGURE 2.2.2f: A horseshoe magnet.

6. Sketch the shape of the magnetic field between two south poles that are brought close to each other.
7. How can we tell from the diagram that if a north pole of one magnet is brought close to the south pole of another that the area in between is very concentrated?
8. Sketch the shape of the magnetic field around the poles of a horseshoe magnet (see Figure 2.2.2f).

Did you know...?

Compasses were used for many years on wooden sailing ships very effectively for navigation but as soon as iron was used to make the hull this affected the accuracy. One early solution was to put the compass on a 5 m tall pole!

Know this vocabulary

field
pole
compass

Investigating electromagnetism

We are learning how to:

- Describe what an electromagnet is.
- Investigate the factors affecting the strength of electromagnets.

If you pass a current through any wire, a weak magnetic field is produced. This link between electricity and magnetism has been thoroughly investigated, enabling us to make very powerful, controllable electromagnets.

What is an electromagnet?

In 1820, a Danish scientist, Hans Oersted, passed a **current** through a single wire. Placing a compass near the wire, he noticed that the needle moved, proving that a **magnetic field** was present. When the current was switched off, the needle returned to its normal position. Oersted had taken the first steps towards understanding electromagnetism.

FIGURE 2.2.3a: When the switch completes the circuit, the compass needle moves – the current in the wire is acting like a magnet.

Any wire with a current passing through it will produce a magnetic field. When the current is switched off, the magnetic field disappears. Any magnet that uses electricity to produce a magnetic field is called an **electromagnet.** Such a magnet is a temporary magnet as it only produces a magnetic field when the current flows (whereas a bar magnet is a permanent magnet).

1. How is an electromagnet different from a permanent magnet?
2. Describe two different ways to prove that an electromagnet is magnetic.

Making electromagnets stronger

Oersted made a very weak electromagnet because he used a single wire and a small current.

The strength of an electromagnet can be increased by:

- increasing the current passing through the wire
- making the wire into a coil
- increasing the number of coils in the wire
- putting an iron **core** in the centre of the coil.

Did you know...?

A coil of wire wrapped around a core is known as a **solenoid**. Solenoids are used in car starter motors, computer disk drives and domestic washing machines.

Figure 2.2.3b shows a simple electromagnet consisting of a battery and a coil of wire surrounding an iron nail. The wire is covered by electrical insulation so that it does not connect electrically with the iron nail. When a current is passed through the wire, it causes the iron nail to become magnetic.

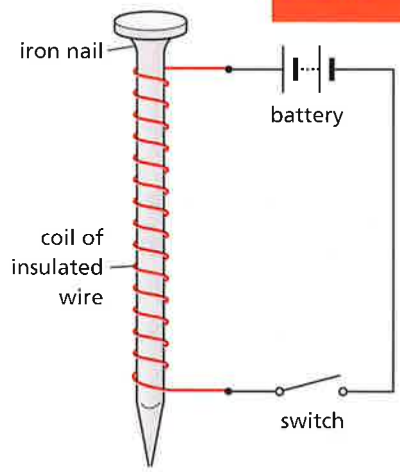


FIGURE 2.2.3b: A simple electromagnet, made using an iron nail.

3. Draw an electromagnet you might use to attract a steel paper clip. Explain how you could modify your electromagnet so that it could attract and lift a car.
4. How would you drop the car?

Magnetic fields around electromagnets

If plotting compasses are placed around a wire with a current flowing through it, they show that the magnetic field shape around the wire is circular, as shown in Figure 2.2.3c. Iron filings can be used to show this.

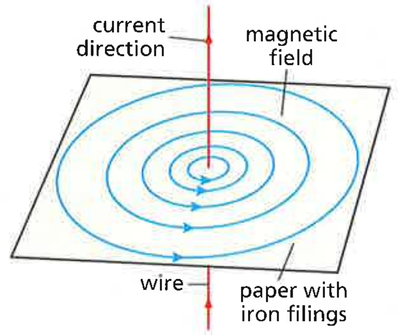


FIGURE 2.2.3c: The shape of the magnetic field around a wire carrying a current.

The shape of the magnetic field around a long coil of current-carrying wire is similar to that of a bar magnet, as shown in Figure 2.2.3d. One end of the coil is the north pole (N) and the other end is the south pole (S). Reversing the direction of the current reverses the magnetic field – the S pole becomes the N pole and vice versa. Increasing the number of coils increases the magnetic field around the loops, resulting in a stronger field. Using a magnetic material, like iron, as a core strengthens the field.

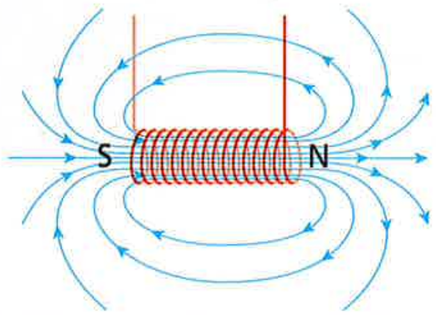


FIGURE 2.2.3d: Coils with many turns of wire are used in electromagnetic devices.

5. Explain the advantages of an electromagnet over a permanent magnet for devices that require a magnet.
6. What would happen to the magnetic field lines if the current in Figure 2.2.3d was increased?
7. Why are the coils of an electromagnet placed in line and not in a random way?
8. Explain why the core is made of iron.

Know this vocabulary

magnetic field
electromagnet
solenoid
core

Using electromagnets

We are learning how to:

- Describe different applications of electromagnets.

The main advantage of using electromagnets over ordinary magnets is that the magnetic field can be switched on or off at will, making them easier to control. This has resulted in a wide range of applications.

Common uses of electromagnets

Electromagnets are used in many different devices.

- In your computer hard drive, tiny electromagnets are used to help store information on a disk.
- Separating iron and steel from non-magnetic metals, such as aluminium and copper, is one of the main uses of electromagnets. Switching the current off allows the magnetic objects to fall from the electromagnet.
- Electromagnets are used in loudspeakers – the magnetic field moves a diaphragm to amplify the sound vibrations.

1. Give two advantages of using electromagnets.
2. Give one disadvantage of using an electromagnet compared to an ordinary magnet in the applications listed above.

FIGURE 2.2.4a: How is this electromagnet being used?

The electric bell

The circuit inside an electric bell is shown in Figure 2.2.4b.

When the switch is closed at A, a current flows. The iron core of the electromagnet at B becomes magnetised.

The iron bar, called the **armature**, at C is attracted to the electromagnet and moves towards it. The hammer, connected to the armature, moves to strike the gong.

The springy steel strip at D moves away from the **contact** screw as the hammer strikes the gong, breaking the circuit.

Because the current no longer flows through the electromagnet, it loses its magnetism. The armature is no longer attracted and moves back to its original place.

Did you know...?

Electromagnets are used to remove tiny pieces of metal that accidentally enter the eye. They offer greater control than ordinary magnets, so there is less risk of injuring the eye.

The steel strip is once again in touch with the contact screw and the circuit will be complete as long as the switch remains pushed.

3. What must be done to stop an electric bell from ringing? Explain your answer.
4. What would happen if the electromagnet in an electric bell was replaced with an ordinary magnet?

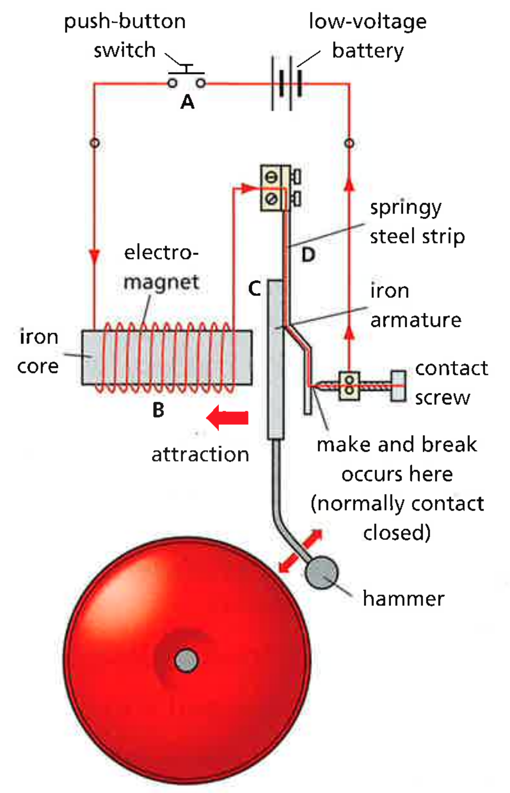


FIGURE 2.2.4b: How an electric bell works.

The circuit breaker

A **circuit breaker** is designed as a safety device. It breaks a circuit if too much current is drawn from the mains, and so protects appliances. Household appliances and lighting are protected with circuit breakers.

Figure 2.2.4c shows how a circuit breaker works. In normal operation, a low current passes through the appliance and the electromagnet. Because the current is low, the electromagnet is weak and so is not strong enough to separate the iron contacts. If the appliance malfunctions and too much current passes through the wire, the electromagnet becomes stronger, attracting the nearest iron contacts. This breaks the connection between the iron contacts and breaks the circuit, protecting the appliance. The spring prevents the contacts from reconnecting.

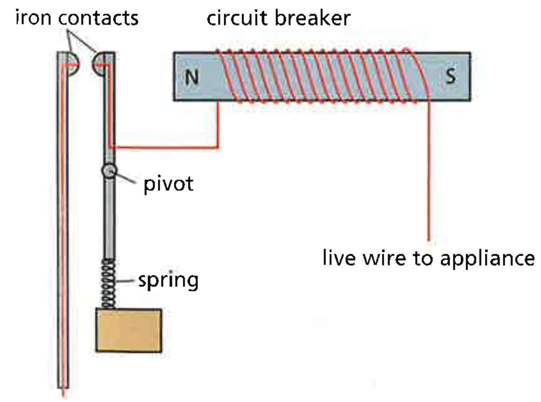


FIGURE 2.2.4c: How an electromagnetic circuit breaker works.

5. In a circuit breaker, why is it important for the contacts, once broken by the electromagnet, to remain unconnected?
6. What advantages do circuit breakers have over ordinary switches?

Know this vocabulary

armature
contact
circuit breaker

Investigating strength of electromagnets

We are learning how to:

- Identify and manage variables.
- Investigate the effect of changing variables.
- Draw conclusions about how the strength of an electromagnet can be controlled.

Making a simple electromagnet is easy – wrap some wire around an iron nail and attach the ends of the wire to a battery. It won't be very strong, though, and the battery won't last long. We can explore how to make something better than that.

Deciding what to change

An electromagnet produces a magnetic field because three things are happening:

- A current is flowing along a piece of wire.
- The wire is wrapped into a coil.
- An iron core is put in the centre of the coil.

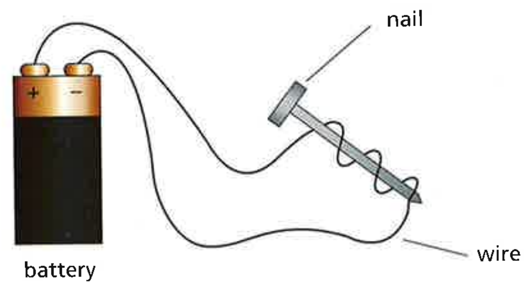


FIGURE 2.2.5a: Making an electromagnet.

The strength of the electromagnet is the outcome of these variables. In other words, by exploring these we can find out how to make an electromagnet stronger.

1. Make a list of the **variables** that could be investigated.
2. For each one, suggest how it could be changed.
3. Suggest what the effect might be of changing each of them.

Did you know…?

One way of making electromagnets much stronger is to cool them to very low temperatures, using liquid helium. At these temperatures there is no resistance in the wires so a huge current flows, generating a very strong magnetic field.

Investigating the variables

Some variables are **discrete** and others **continuous**. A continuous variable is one for which you can select any value. Others are discrete; only certain values are possible.

In this investigation, some of the variables are discrete and others are continuous. The number of turns is a discrete variable as it can only have a whole number value but the current is continuous as it can have any value. The material of the core will be discrete; you will have to select from what is available.

You'll need to choose which values to use for the variable you are altering. It's a good idea to try a few of these out beforehand; it will give you a sense of whether you're working in the right range.

4. Decide on a variable to investigate.
5. Identify whether it is continuous or discrete.
6. Select the values you will use.

Drawing conclusions

By this stage you'll have run the experiment several times, having altered one of the variables. You'll have worked out how to see if your electromagnet changed in strength. This should have produced some data which you can put in a table and, if appropriate, a graph.

7. What **relationship** did you discover between the variable you investigated and the strength of the electromagnet?
8. Did other students who investigated the same variable draw the same conclusion?
9. Sometimes there is a **limit** to a relationship. For example, loading a spring makes it longer but if you overload it, it stretches the spring (and, eventually, snaps the wire) so the pattern breaks down. Do you think there is a limit to the relationship that you've explored?
10. How do you think that your conclusion might be relevant to people who are designing equipment that uses electromagnets?

Know this vocabulary

variable
discrete
continuous
relationship
limit

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills.

Represent magnetic fields using lines to show strength and direction.	Use field lines to help explain how the field around a magnet varies.	Predict the pattern of field lines between two magnets placed near each other.
Explain how the force on a magnetic object is related to the strength of the magnet.	Explain how the force on a magnetic object is related to the distance from the magnet.	Predict the effect of a magnetic field on a magnetic object placed in or rolled through the field.
Describe the forces between like poles and between unlike poles.	Explain how a compass responds to the Earth's magnetic field.	Explain how the Earth's magnetic field can be used to aid navigation.
Recognise that a current flowing through a wire causes a magnetic field.	Explain how the strength of the field depends upon the current flow, the material in the core and the number of coils.	Use a diagram to explain how to change the strength of an electromagnet.
Explain the difference between permanent and non-permanent magnets.	Describe different applications of permanent magnets and electromagnets.	Compare and contrast the use of magnets and electromagnets in different applications, such as a circuit breaker.
Describe how to test the strength of a magnet and an electromagnet.	Design investigations to compare different methods of making magnets and testing the strength of electromagnets.	Explain the variables that affect the strengths of magnets and electromagnets.

Questions

KNOW. Questions 1–5

See how well you have understood the ideas in this chapter.

1. Which of the following determines how magnetic field lines should be drawn? [1]

a) They flow from the south-seeking pole to the north-seeking pole.
b) They flow from the north-seeking pole to the south-seeking pole.
c) They are circular.
d) They flow from one magnet to another.

2. A magnetic paper clip is placed near to a bar magnet. Under which of these situations will the force on the clip be strongest? [1]

TABLE 2.2.7

	Strength of bar magnet	Distance between clip and magnet
A	Weaker	Greater
B	Weaker	Less
C	Stronger	Greater
D	Stronger	Less

3. State two differences between a magnet and an electromagnet. [2]

4. Which of the following uses an electromagnet? [1]

a) a compass
b) a fridge magnet
c) a torch
d) a metal-sorting plant prior to recycling.

5. Which of the following will the make the strongest electromagnet? [1]

a) using one coil with a low current
b) using 100 coils with a low current
c) using 100 coils with a high current
d) using one coil with a high current.

APPLY. Questions 6–8

See how well you can apply the ideas in this chapter to new situations.

6. Which of these statements best explains the reason why a compass points north? [1]

a) The tip of the compass is a south pole and it is attracted by the Earth's north pole.
b) The tip of the compass is a north pole and it is attracted by the Earth's north pole.
c) The Earth's north pole is actually a magnetic south pole and it attracts the north pole of the compass.
d) The north pole on a compass is actually attracted to the Earth's south pole so you have to do the opposite of what the compass says.

7. A magnetic field diagram shows the lines of magnetic force around a magnet. Where is the field strongest? [1]

a) Where the field lines are straightest
b) Where the field lines curve sharpest
c) Where the field lines are closer together
d) Where the field lines are further apart.

8. This electromagnet is being used to pick material up in a scrapyard. [4]

a) What will it pick up?
b) Why is an electromagnet being used instead of a permanent magnet?

FIGURE 2.2.7a: Using an electromagnet in a scrapyard.

EXTEND. Questions 9–10

See how well you can understand and explain new ideas and evidence.

9. Suggest how the poles on these magnets are arranged so that they are suspended above each other. [2]

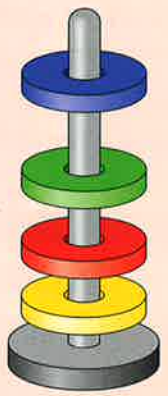


FIGURE 2.2.7b: Suspended magnets.

10. Sketch a diagram to show what you think the pattern of field lines will be between the two bar magnets in Figure 2.2.7c. [2]

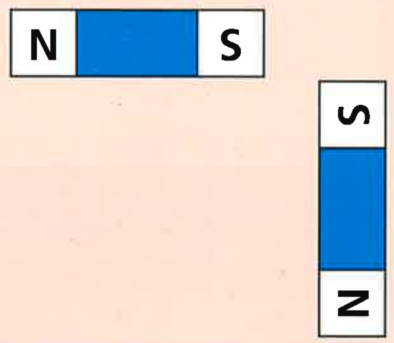


FIGURE 2.2.7c