Magnets

PHYSICS • ELECTRICITY AND CIRCUITS • MAGNETS

Section 1: What Is Magnetism?

• What causes magnetism?

Any moving charge creates a magnetic field around it, and this is the reason that there is a magnetic field around a current carrying wire. However, the source of the magnetic fields generated by materials like permanent magnets, which have no current flowing within them, is due to a property of the particles within the material (their 'magnetic moment'), as well as the motion of electrons within the atoms. Usually these cancel out, but in some materials they can align to produce an overall magnetic field.

• Suggested Film

- What Are Magnets?

A permanent magnet is a piece of metal that possesses a magnetic field

Extension Questions

Q1. What units are used to measure magnetism?

There are various units used to measure magnetism. The strength of a magnetic field is usually measured in tesla; a tesla is a large unit. The Earth's magnetic field is a few hundred thousandths of a tesla and very powerful magnets would have fields of a few tesla. Gauss is an older, smaller unit that is sometimes used; 1 tesla is equal to 10,000 gauss.

Q2. What is a magnetic monopole?

Each magnet always has a north and south pole. It is not possible to isolate one pole. Cutting the magnet in half to separate the poles would result in two magnets, each with a north and south pole. A particle with only one magnetic pole is known as a magnetic monopole. Despite decades of searching, no magnetic monopoles have ever been detected but they are predicted to exist. It is intended that one of the experiments at the Large Hadron Collider will search for evidence of magnetic monopoles.

• What are the different types of magnetism?

Some materials respond to a magnetic field, and we are used to seeing this when some metals, like iron, are attracted to magnets. However, this is only one form of magnetism, ferromagnetism; materials can also be paramagnetic or diamagnetic.

Ferromagnetic materials are strongly attracted by magnetic fields and can retain their magnetic properties even after the field is removed. For this reason permanent magnets are made from ferromagnetic materials. Iron, nickel and cobalt are ferromagnetic.

Paramagnetic materials are weakly attracted by magnetic fields. This effect is usually so weak that it is not noticeable. After the magnetic field is removed paramagnetic material does not retain its magnetic properties.

Diamagnetic materials are repelled by magnetic fields, but the effect is usually very weak. Superconductors can be strongly diamagnetic and this means they can be levitated above powerful magnets.

Extension Questions

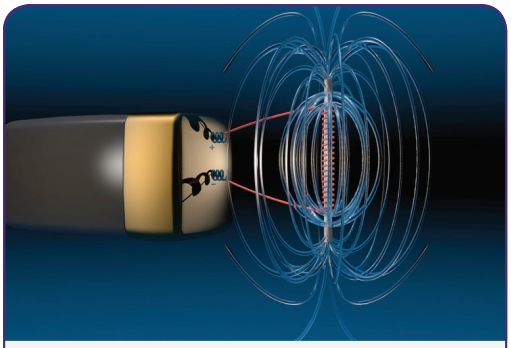
Q3. What is a domain?

Within a ferromagnetic material there are regions where the atoms have their magnetic moments aligned in the same direction. However, each of these regions aligns in a different direction and so the material has no overall magnetic field. These regions are known as domains and a strong magnetic field can cause these domains to align. If the domains stay aligned, even after the magnetic field is switched off, the material will become a 'permanent' magnet. Striking or heating the material can cause the domains to align randomly again, demagnetising the material.

Q4. What is the Curie temperature?

If ferromagnetic materials, like iron, are heated above a certain temperature they lose their magnetism. This is known as the Curie temperature, and for iron is around 770°C. If the material is allowed to cool below the Curie temperature it will again be attracted by magnetic fields.

• How do electromagnets work?



The magnetic field of a simple electromagnet

Any moving charge will generate a magnetic field. For current flowing in wires these are generally very weak unless the current is very large. However, a larger magnetic field can be produced by winding the wire into a coil. In an electromagnet this can be further increased by adding a core of ferromagnetic material such as iron. Electromagnets are useful as the strength of the field can be controlled by increasing or decreasing the current in the wire or changing the number of turns and, unlike permanent magnets, can be switched on and off. Electromagnets have many applications, including in motors, loudspeakers and powered door locks, such as those used in the central locking systems of cars.

Powerful electromagnets can be made by using superconducting wire. This allows very large currents to be used as superconductors have no resistance and so large currents do not cause heating. Unfortunately superconductors only work at very low temperatures.

• Suggested Film

- What Are Electromagnets?

Extension Question

Q5. How are magnets used in particle accelerators?

Electromagnets are often used in particle accelerators. The magnetic field they create is used to make particles follow a curved path. Beams of particles can also be focused using special configurations of electromagnets called quadrupoles. These use two north poles and two south poles, which are arranged around the beam so that each pole is directly across from a similar pole. This produces a magnetic field which increases the further the particles are from the centre of the arrangement, and means the particles are pushed into the centre, focusing the beam.

Section 2: Applications of Magnetism

• How are magnets used in electricity generation?

Electricity is generated by moving an electrical conductor through a magnetic field. In a power station, steam or water is used to turn large turbines and drive generators. These move wires next to magnets (or move magnets next to wires) and the changing magnetic fields cause the electrons in the wires to move, generating electrical currents. In power stations, which use fossil fuels, the coal, oil or gas is burned and the heat is used to boil water. This produces steam to turn the turbine. Similarly, nuclear power stations use the heat generated by the nuclear fuel in the reactor to boil water to produce steam. Hydropower uses water to turn turbines.

• Suggested Film

- How Do Generators Work?

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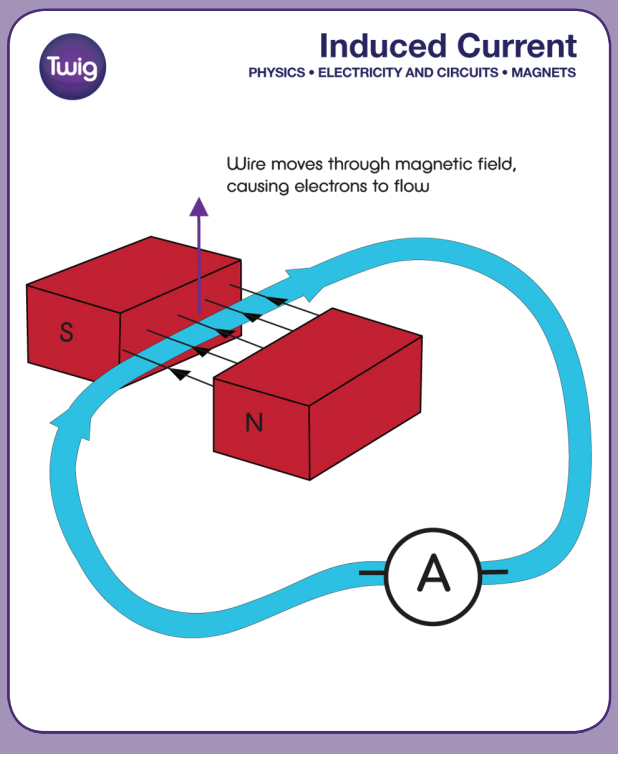

• What is magnetic resonance imaging?

Magnetic Resonance Imaging (MRI) uses powerful magnets to image the human body. It relies on protons in the water molecules within body tissue aligning with a strong magnetic field. When the field is switched off the protons return to their original state, and the energy released when this happens can be detected and used to produce images of tissue inside the body.

Unlike other scans, MRI does not use X-rays and so the patient is not exposed to radiation. However, care has to be taken to check that the patient does not have metal in their body, which could move and cause injury during scanning, or medical implants which could be affected by the magnetic fields.

• Suggested Film

- MRI

Extension Question

Q6. What is a SQUID?

Very weak magnetic fields can be measured using a SQUID (a Superconducting Quantum Interference Device). A SQUID measures the flow of current through a circuit containing two structures known as Josephson junctions (which are made of two superconductors separated by a thin insulator), and the current through this circuit can be affected by magnetic fields. SQUIDs can measure magnetic fields of only a few millionths of a trillionth of a tesla and can be used to measure the very weak magnetic signals due to electrical currents in the brain. It is possible that in the future SQUIDS may be used to build smaller, cheaper MRI machines which use weaker magnetic fields.

Extension Question

Q7. Is blood magnetic?

Blood contains iron so it often assumed that blood is magnetic. In fact, the iron in blood exists as part of a long molecule, haemoglobin, and in this form it is not ferromagnetic and so magnets do not influence blood flow.

- How does magnetic levitation work?

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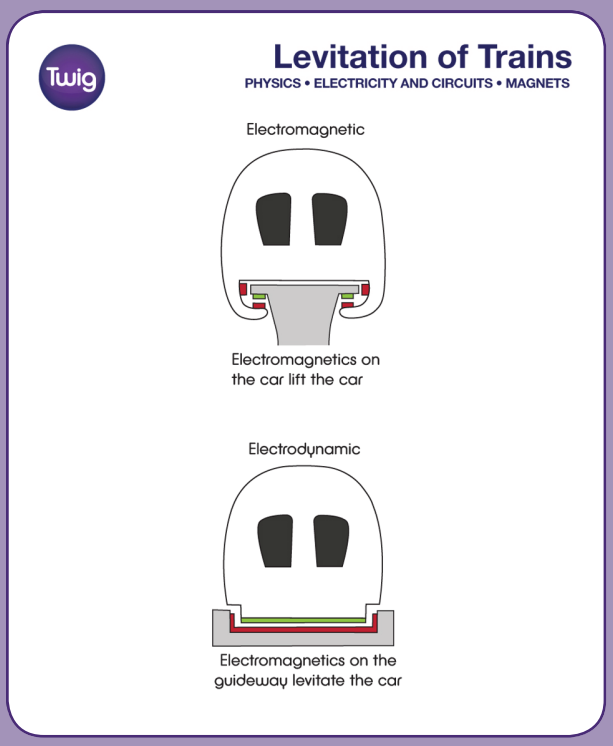


Materials which are diamagnetic are repelled by magnetic fields and so can be made to levitate above magnets, as long as the force of the repulsion is greater that the weight of the object. This is hard to achieve without very powerful magnets or materials which are very strongly diamagnetic. Superconductors are extremely diamagnetic and so can be levitated above magnets relatively easily.

Some trains use magnetic levitation. The train is suspended above the track, which reduces friction and allows it to reach very high speeds. There are two ways to achieve this. In ElectroDynamic Suspension (EDS) superconductors are placed on the train and these are repelled by electromagnets in the track. Alternatively, in ElectroMagnetic Suspension (EMS), electromagnets can be used in an arrangement where part of the train reaches around and under the track. Electromagnets on this part are attracted to coils on the underside of the track. This pulls the train upwards, lifting it off the track.

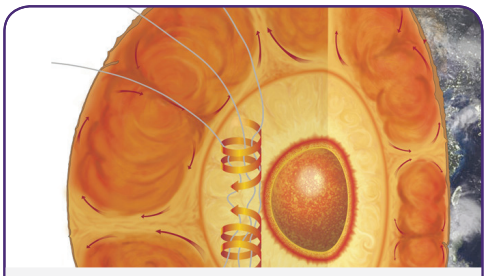
The Shinkansen bullet train can reach top speeds of 443km/h

- **Suggested Film**
  - **Maglev Trains**

Section 3: The Earth's Magnetic Field

- What causes the Earth's magnetic field?

The Earth has a magnetic field which protects us from the solar wind, a stream of charged particles which emanate from the Sun. It is caused by the flow of molten iron in the Earth's outer core. The Earth's magnetic field lets us navigate using a compass, a small magnet which is free to move and so will orient itself in the direction of the field. The end of the magnet, which points north, is called the north pole. However, as opposite poles attract, this means that the magnetic pole which is found in the north is actually the south pole of the Earth's magnetic field.



The Earth's magnetic field is caused by the flow of molten iron in the outer core

Extension Questions

Q8. Do other planets have magnetic fields?

Many of the other planets in the Solar System have a magnetic field. Mars doesn't, presumably because the required movement in its molten core has ceased. At one point in the past Mars did have a magnetic field, and the reasons it has now been lost are not well understood.

The Moon has almost no magnetic field. The very weak magnetic field it does have appears to be due to rocks in its crust which have become magnetised. It is possible that the Moon did have a magnetic field early in its history when currents were still flowing in its core.

Q9. What are the Northern Lights?

As charged particles from the Sun reach the Earth they interact with the Earth's magnetic field. As this magnetic field accelerates the particles, they collide with molecules in the air and excite them. These molecules then emit light and this can cause spectacular light displays in the night sky. These are usually only visible in the far north, where they are known as the Northern Lights or Aurora Borealis, and in the far south, where they are known as the Aurora Australis. Similar effects have been observed on other planets and moons in our Solar System.

Q10. How does a compass work?

A compass contains a magnet which is allowed to turn and align with an external magnetic field. This is done by supporting the magnet at its centre while still allowing it to rotate. The magnet will align with the Earth's field and, as this is directed from north to south, this will give an indication of the direction of north and south. The north pole of the magnet will point to the Earth's north magnetic pole.

A simple compass containing a magnet supported at its centre could be difficult to read. This is because as the magnet moves it could overshoot the correct position before being pulled back. It would then pass the correct position again and this oscillation could continue for some time. For this reason, compasses are often filled with a liquid like water, which reduces the oscillations and causes the magnet to settle far more quickly.

• What is magnetic pole reversal?

The Earth's magnetic poles move slowly over time and only stay in one orientation for a few hundred thousand years. The last reversal took place almost 800,000 years ago and it is almost impossible to predict when the next will occur, as the periods between reversals typically last a few hundred thousand years but have been known to last much longer. The time taken for the change to complete may also vary from a few years to 10,000 years. It is not clear what the effects of a pole reversal would be but it is clear that life of Earth has survived many reversals in the past.

- **Suggested Film**
  - **Earth's Wandering Poles**

Extension Questions

Q11. What is archaeomagnetic dating?

The age of some artefacts can be determined using our knowledge of the Earth's magnetic field. When magnetic materials are heated the overall alignment of the particles within is lost. When this happens the particles can realign with any external magnetic field which is present, including the Earth's magnetic field. If the material is then allowed to cool this alignment will be 'frozen' and remain as a record of the Earth's magnetic field at the time it was heated.

The way the direction of the Earth's magnetic field has changed over time is known. This means that the age of artefacts which have been heated, such as bricks which have been used in hearths, can be found by measuring the direction of the magnetic field within the material and finding the time at which the Earth's magnetic field was aligned in this direction.

• What are magnetic dip and magnetic declination?

When using a compass it is important to know that the North Pole is not in the same place as the north magnetic pole. For this reason, magnetic north is not the same as true north. In fact, these can differ by several degrees. This is known as the magnetic declination and is often stated on maps to prevent navigational errors.

In addition to this, the Earth's magnetic field is not parallel to the Earth's surface and points upwards in the southern hemisphere and downwards in the northern hemisphere. The magnetic dip (or magnetic inclination) refers to the angle of the Earth's magnetic field relative to the ground.

Compasses align themselves to the Earth's magnetic field

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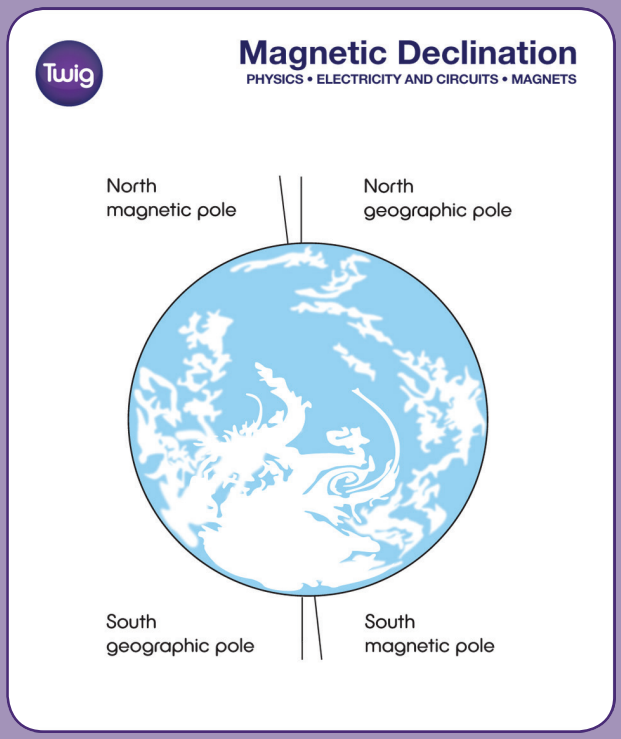

• Quizzes

What Are Magnets?

Basic

• Which of these cannot be used to make a permanent magnet?

A – cobalt

B – nickel

C – copper

D – iron

• How many poles does a magnet have?

A – 1

B – 2

C – 3

D – 4

• What do like poles do?

A – repel

B – attract

C – there is no effect

D – it depends on the type of poles

• Which of these do not use magnets?

A – machines which pick up metal in scrap yards

B – compasses

C – loudspeakers

D – kettles

Advanced

• Which of these is an advantage of electromagnets?

A – they can be switched on and off

B – they can be made of any material

C – their magnetism lasts longer

D – the number of poles the magnet has can be controlled

• Which of the following uses magnetic fields to image the human body?

A – CRT

B – PET

C – MRI

D – thermography

• Why does the Earth have a magnetic field?

A – it has a solid iron core

B – it is electrically charged

C – it has a liquid iron core

D – it has a large gravitational field

• How does a compass work?

A – it aligns with the Earth's magnetic field

B – it contains a magnet with only one pole

C – it aligns with the direction of the Earth's rotation

D – it contains metal which is electrically charged

What Are Electromagnets?

Basic

• Which of these do not use magnets?

A – car starters

B – compasses

C – loudspeakers

D – kettles

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Advanced

• How is an electromagnet created?

A – the junction between two metals is heated

B – current is passed through a coil of wire

C – two charged plates are separated by a small gap

D – a piece of metal is heated in the presence of a magnetic field

• What shape is the magnetic field around a wire?

A – it is directed along the wire

B – it points out from the wire

C – it is circular

D – it is continuously changing

• Which of these does not make an electromagnet stronger?

A – adding an iron core

B – switching the magnet on and off continuously

C – adding more coils of wire

D – increasing the current

• Answers

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