Electricity and Magnetism: Physics Narrative 06

Contents

Magnets everywhere 2
Magnetic materials 3
All materials are magnetic…to some extent! 4
Permanent magnets 5
A little more on magnetic materials and magnets 6
The poles of a magnet 7
Interactions between magnets 10
A model of magnets 11
Putting the model to work 13
Action-at-a-distance and magnetic fields 19
Representing magnetic fields: In theory 20
Representing magnetic fields: In practice 22
How is the strength of a magnetic field measured? 24
The Earth and its magnetism 25
The Earth's magnetic field 27
Magnetic poles in relation to the Earth's poles 29
History, navigation and Gilbert 30

This is the 'Physics Narrative' for this episode, that explains the physics for teachers. To develop your expertise in the episode, work with the 'Teaching and Learning Issues' and the 'Teaching Approaches'. Navigate to any part of the topic using the Topic Menu, or use the tabs below to stay within this episode..

Magnets everywhere

Stop for a moment and think of all of the places where magnets are used in your home. There's the magnetic catches on the kitchen cupboards; the magnetic strip to hold the kitchen knives; all of that stuff stuck on the fridge door; some of the pupils' games work by magnets; electric motors have magnets inside them and isn't there something about not putting computer discs too close to magnets?

In fact you don't need to look too far at all to find magnets in use, but how do they work? If you stop and think for a moment it's a little strange that the magnetic shape will stick at all to the fridge door. How does that work? Normally we need some kind of adhesive to make things stick, but this is not the case with magnets. How come the magnet will stick to the fridge door but not to the stainless steel kitchen sink (try it!)? Is it possible to make a magnet? Are there simple rules that allow us to predict that the magnet will stick to the fridge but not to the sink?

There are lots of questions to be asked about magnets and the pupils that we teach are often very keen to ask them! In this part of the narrative we shall provide the answers to these questions and to a few more that you may not even have considered.

Magnetic materials

It is a commonly-known fact that fridge magnets will stick to some surfaces but not to others. It depends on what material the surface is made from. At a simple level we can say that some materials are magnetic and some are not.

Magnetic materials are those which stick to, or are attracted to, magnets. The most common magnetic materials are iron-based (with other elements added to make iron alloys), along with cobalt and nickel.

Non-magnetic materials are those which do not stick to, or are not attracted to, magnets. Common non-magnetic materials include, wood, glass, PVC, aluminium, stainless steel.

Classifying as magnetic and non-magnetic

Drag the labels to their correct slots.

MAGNETIC	NON-MAGNETIC
Material	Material
Material	Material
Material	Material
Material	Material
Material	Material
	Material
	Material

ALUMINIUM-NICKEL ALLOY	ALUMINIUM-COBALT ALLOY
WOOD	NICKEL
GLASS	PVC
ALUMINIUM	COBALT
IRON	STAINLESS STEEL
WOOL	WATER

CHECK IT

All materials are magnetic…to some extent!

Find out more about the wide range of responses of materials to magnets.

Although the simple classification of magnetic and non-magnetic materials set out above is quite adequate for physics 11-14, you might bear in mind that all materials are magnetic in that they are affected, to a greater or lesser extent, by a magnetic field.

For example, there are dramatic demonstrations showing that a jar of oxygen can be made to move using a powerful magnetic force, and it is possible to levitate water using a strong magnet.

Unusual effects of magnetism

These objects are all floating on a magnet.

Clip 1 | Clip 2 | Clip 3 | Clip 4 | Clip 5 | Clip 6

Permanent magnets

The everyday world of magnets is really all about those magnetic materials that can be magnetised to make permanent magnets. These are the magnets that stick on the fridge door and are used for door catches and all are made from steel with a high iron content. The steel is magnetic because the iron it contains is magnetic.

Permanent magnets can be contrasted with those materials which are attracted to magnets (and are therefore magnetic) but do not themselves retain any magnetism when the magnet is removed. These are temporary magnets.

In the rest of this episode, when we refer to a magnet, we really mean a permanent magnet.

A little more on magnetic materials and magnets

Read more about the ways in which materials interact with other magnets.

The point has been made that permanent magnets retain their magnetism, whilst other materials are attracted to magnets (they are magnetic) but do not themselves become permanent magnets. How can we explain this?

The origin of magnetism lies in circulating electric currents. In atoms these circulating currents arise from the distribution of electric charge around the nucleus. How that charge reacts when it is placed in a magnetic field defines what sort of magnetic behaviour the material it forms will have.

Any material placed in a magnetic field becomes magnetised. Clearly some materials will become more strongly magnetised than others.

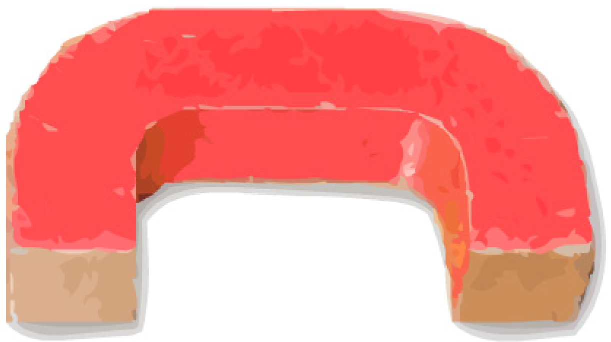
There are not only differences in how much materials become magnetised but also in how they behave when they are placed in the field. There are main three types of behaviour.

In diamagnetic materials the magnetisation is proportional to the magnetic field and in the opposite direction. This means that diamagnetic materials are always repelled by a magnet whose field they are in. Water is an example of a diamagnetic material.

In paramagnetic materials the magnetisation is proportional to the magnetic field and in the same direction. This means that paramagnetic materials are always attracted by a magnet whose field they are in. For example, paperclips are made of a steel alloy which is paramagnetic and a magnet can be used to pick up the clips. The paper clips are attracted to the magnet but do not themselves become magnets.

Ferromagnetic materials behave differently. Their susceptibilities are large, producing high magnetisations in relatively weak magnetic fields. Most significantly, when the field is removed, some ferromagnetic materials retain their magnetisation. These are the permanent magnets that we are familiar with.

In 11-14 physics, when we refer to a magnet, it is short hand for permanent magnet, made from ferromagnetic material (the common one is iron or some alloy containing iron). The magnetic materials we meet in science lessons (and around the home) are essentially paramagnetic – they are always attracted and never repelled by a magnet. It is worth remembering though that, to some extent, all materials respond to a magnetic field when they are placed in one; the manner and magnitude of the reaction depends on the material.



The poles of a magnet

Supposing you take a bar magnet and suspend it freely at its mid-point on a length of thread. Once the magnet stops spinning it takes up a position such that one end points roughly towards the Earth's North Pole and the other towards the South Pole. Set the magnet spinning again and allow it to settle down. The same outcome results, the magnet (and any other magnet) aligns itself along the north/south direction.

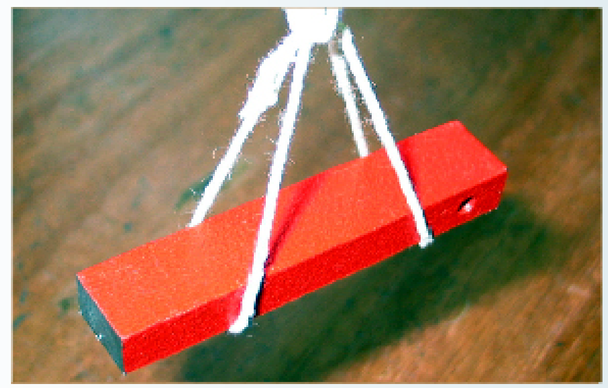
Good use of this property of magnets is made in compasses, where the compass needle is simply a freely suspended bar magnet. If you are caught out on the moors when a mist descends, it is still possible to find your way by using a compass which always points north/south.

The end of the compass which points towards the north is called the north–seeking pole or simply the north pole. The end of the compass which points towards the south is called the south–seeking pole or simply the south pole. In fact the compass does not point directly towards the geographical North Pole, but aligns with what is called the magnetic north. We shall return to this point a little later in discussing the Earth's magnetism.

Freely suspended magents

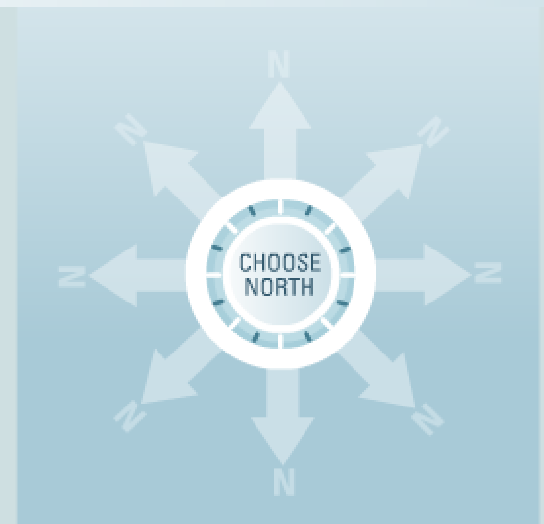
Look at the image, change to the plan view diagram, then choose north.

CHECK IT



A laboratory bar magnet, suspended so that it can swing left and right, but not up and down.

FADE
DIAGRAM
IMAGE



STEP 1 of 3

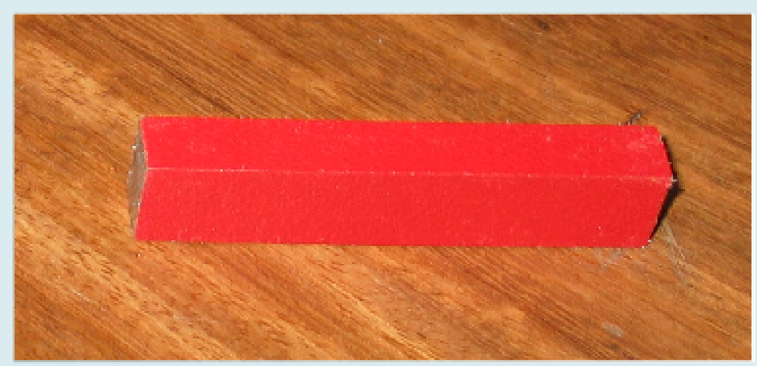
The poles of a magnet

Do all magnets have two poles? Look at these examples, which cover those you are most likely to come across.

So in the lab you'll never get just one pole. But the universe is a much larger place - what about there?

All magnets have two poles

Use the controls to explore the diagram.



BAR MAGNET
DIAGRAM
IMAGE

POLES
SHOW
HIDE

STEP 1 of 6

The poles of a magnet

But what happens if you cut a magnet in half? Do you get a north pole and a south pole?

Well you know that is not the case. If the physics lab bar magnet is cut in half then there will be two magnets, each with a north and a south pole. But then there is the next question:

What happens if you cut it in half loads of times so you are left with just one atom?

The answer is that the atom will still behave as a magnet with a north and a south pole. Although it is possible to know this answer the fundamental question that the student is asking is a very good one: Why can't you get a north pole or south pole on its own? This seems all the more strange since positive and negative charge don't always accompany one another. This difference between electric and magnetic fields is one of the oldest puzzles in physics. Why is it possible to isolate positive and negative electric charges, but not north and south magnetic poles?

In fact finding magnetic poles on their own, or magnetic monopoles, is an idea that was suggested first in 1931 by physicist Paul Dirac. The idea has also been put forward in some modern theories that try to connect all the forces together (grand unified theories). However so far all experimental searches for these elusive particles have proved fruitless.

So, if the question of monopoles is bothering students in class you can assure them it bothers physicists too.

Interactions between magnets

Take a simple bar magnet – the sort that are found in physics lessons – in the form of a rectangular block of steel. Bring another simple bar magnet towards it. The two magnets will either attract or repel each other. Turn one of the magnets around. If they repelled each other before, now they will attract. It is clear that the two ends, or poles of the magnets behave differently and there is a simple rule to describe their interaction:

- IDENTICAL poles (two north or two south) REPEL

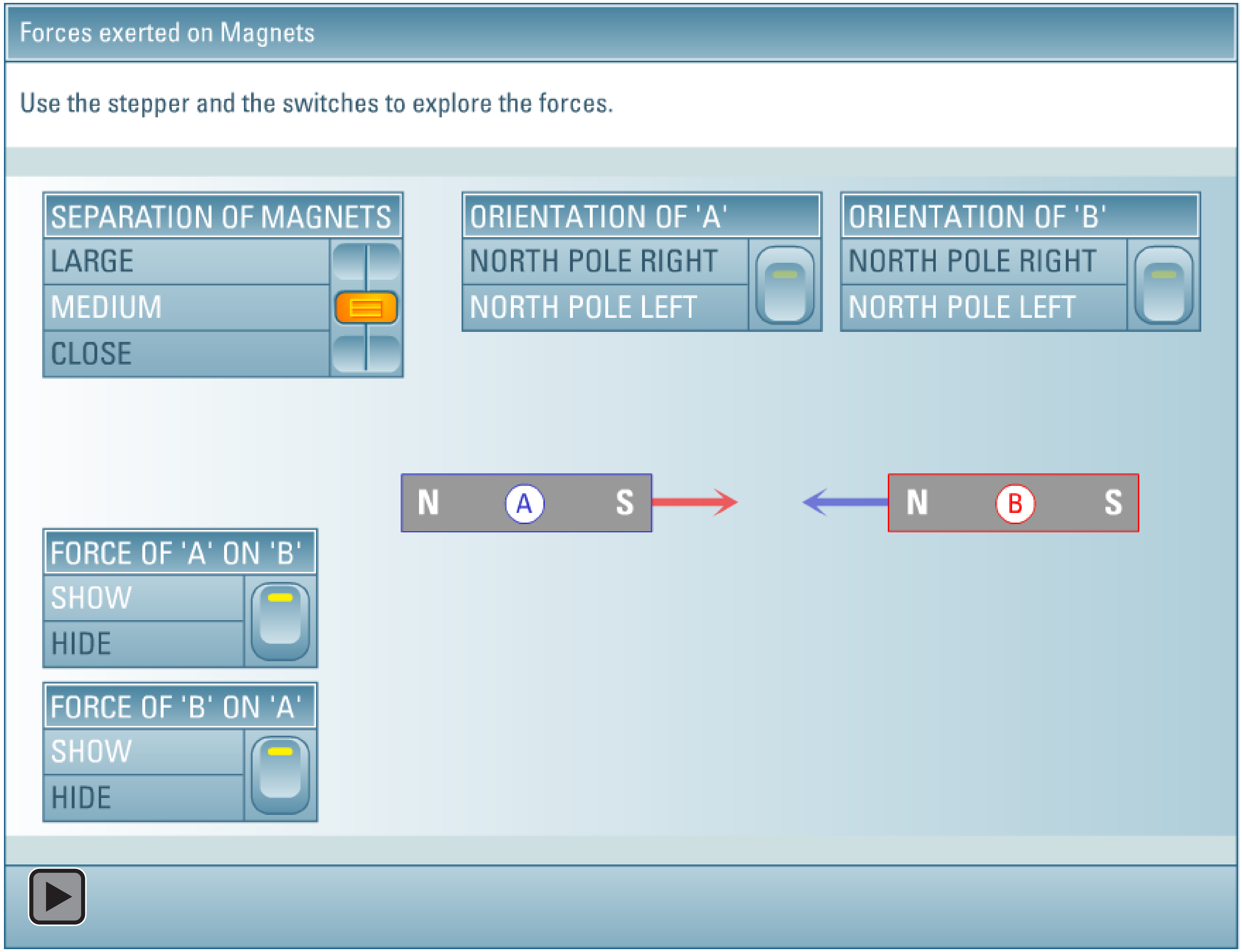
and

- OPPOSITE poles (north and south) ATTRACT,

or

- "Like poles repel and unlike poles attract".

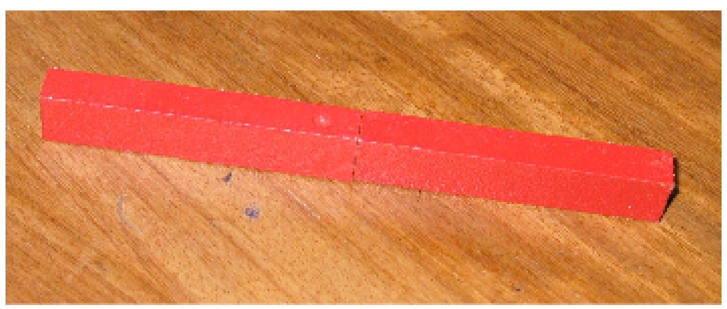
It is important to realise that here we are doing no more than saying what happens and making a simple rule. This is not an explanation of why there is attraction or repulsion. That explanation lies in the two magnets moving to reduce the energy stored between them but that is not a concern of the 11-14 curriculum!

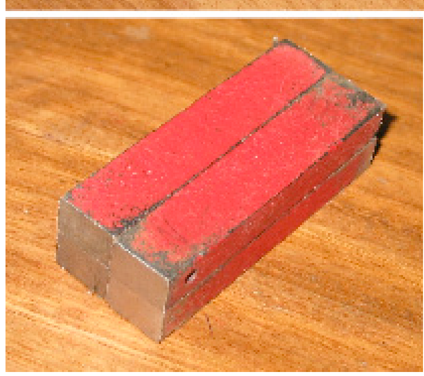


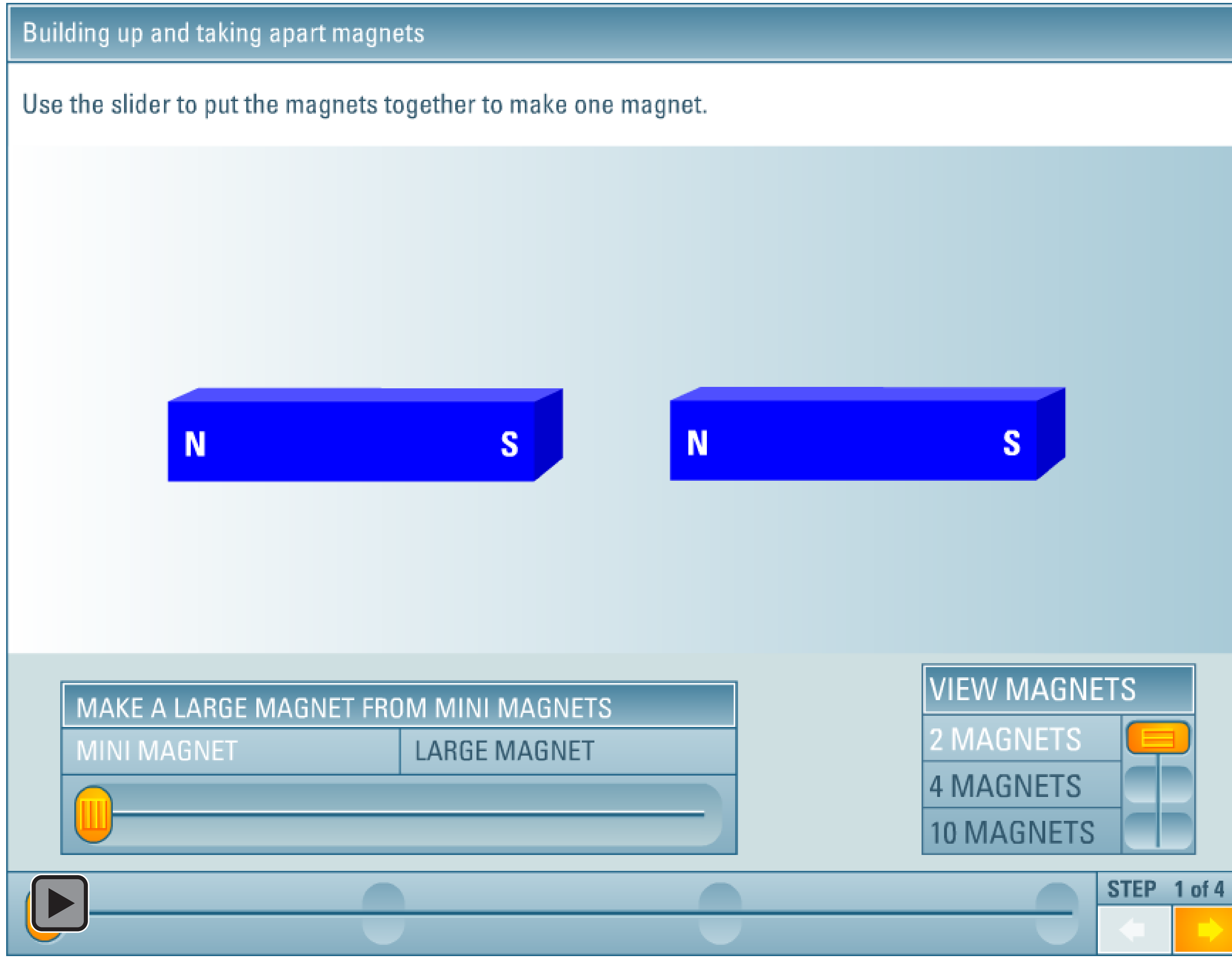
A model of magnets

Imagine two bars of iron placed side-by-side on a table. One of them is a bar magnet, the other is not. From the outside it is impossible to tell which is which, just by looking. How might we imagine the difference between the two (which seem to be identical bars of iron) by thinking about their internal structure?

Inside any magnetic material, such as iron, we can imagine each atom or molecule to be a very small magnet or mini-magnet. So a magnet is made of lots of smaller magnets. You can do this on the bench top, by putting magnets together.







A model of magnets

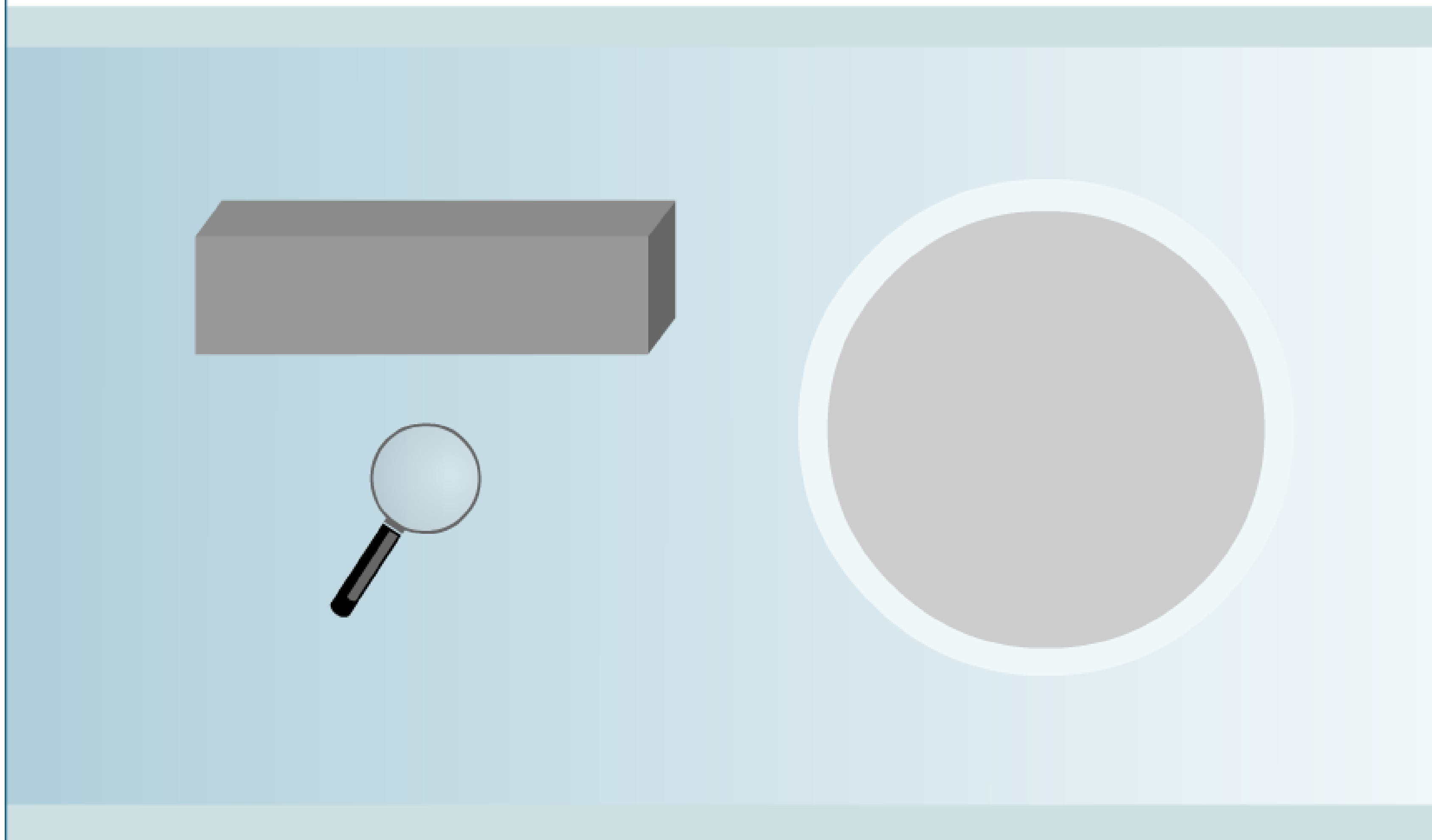
When the material is not magnetised, we can imagine that there is no pattern to the lay-out of the mini-magnets. In other words they point in all directions.

When the material is magnetised, the mini-magnets become aligned so that they all point in the same direction and the object becomes a magnet.

Therefore, the mini-magnets idea offers a model which allows us to think and talk about what is happening during magnetisation. You might use the same model with your pupils and invite them to, "think about it like this!" The sciences are full of such models which allow us to imagine what is happening when we can't see directly. For example we might use the mini-magnet idea to account for the difference between permanent and temporary magnets. We can imagine the permanent magnet where the mini-magnets remain aligned after magnetisation and contrast this with a temporary magnet where the mini-magnets return to a disordered layout after magnetisation.

Modelling the inside of a non-magnet

Drag the magnfying glass over the unmagnetised material to see how you can imagine the insides.



STEP 1 of 2

Putting the model to work

How to make a magnet: Magnetising

Supposing you have an iron nail. The nail is made from iron, a magnetic material, but it is not a magnet at present. How could you turn the nail into a magnet?

Magnetising by stroking

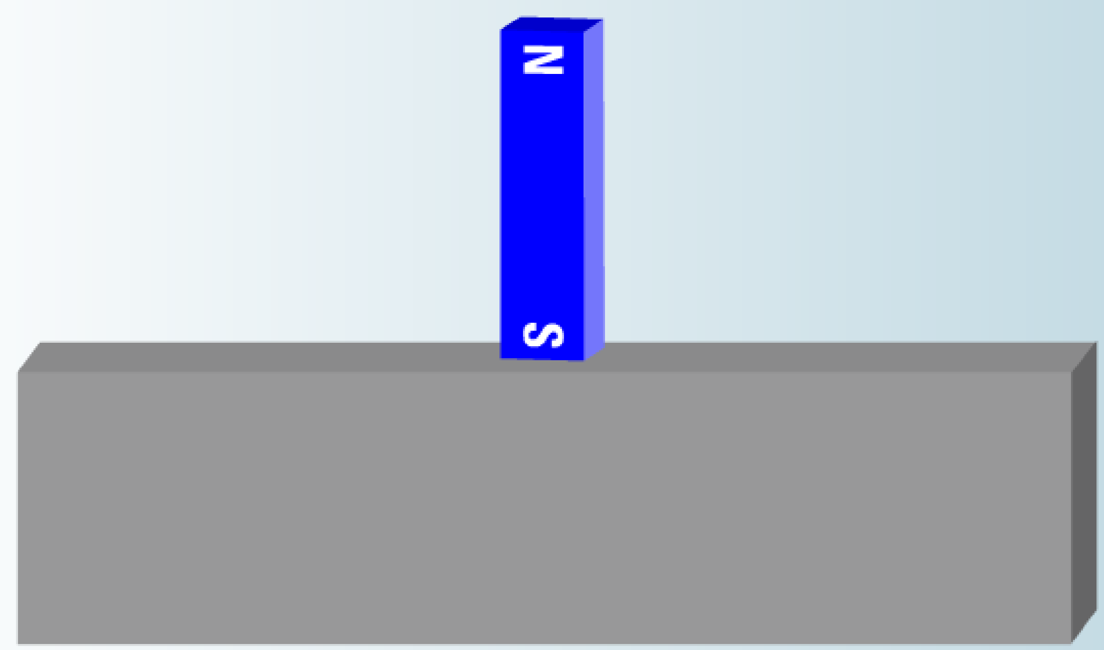
Perhaps the easiest way of turning the nail into a magnet is to take an existing bar magnet and use it to stroke along the length of the nail.

So what is happening inside the nail during stroking?

As the permanent magnet is stroked down the side of the nail the mini-magnets are gradually forced into a line with their north and south poles all pointing in the same direction.

Making a magnet by stroking

This is the action to carry out in order to turn the grey magnetic material into a magnet.



PLAY RESET

AN INTERNAL VIEW
SHOW
HIDE

STEP 1 of 3

Putting the model to work

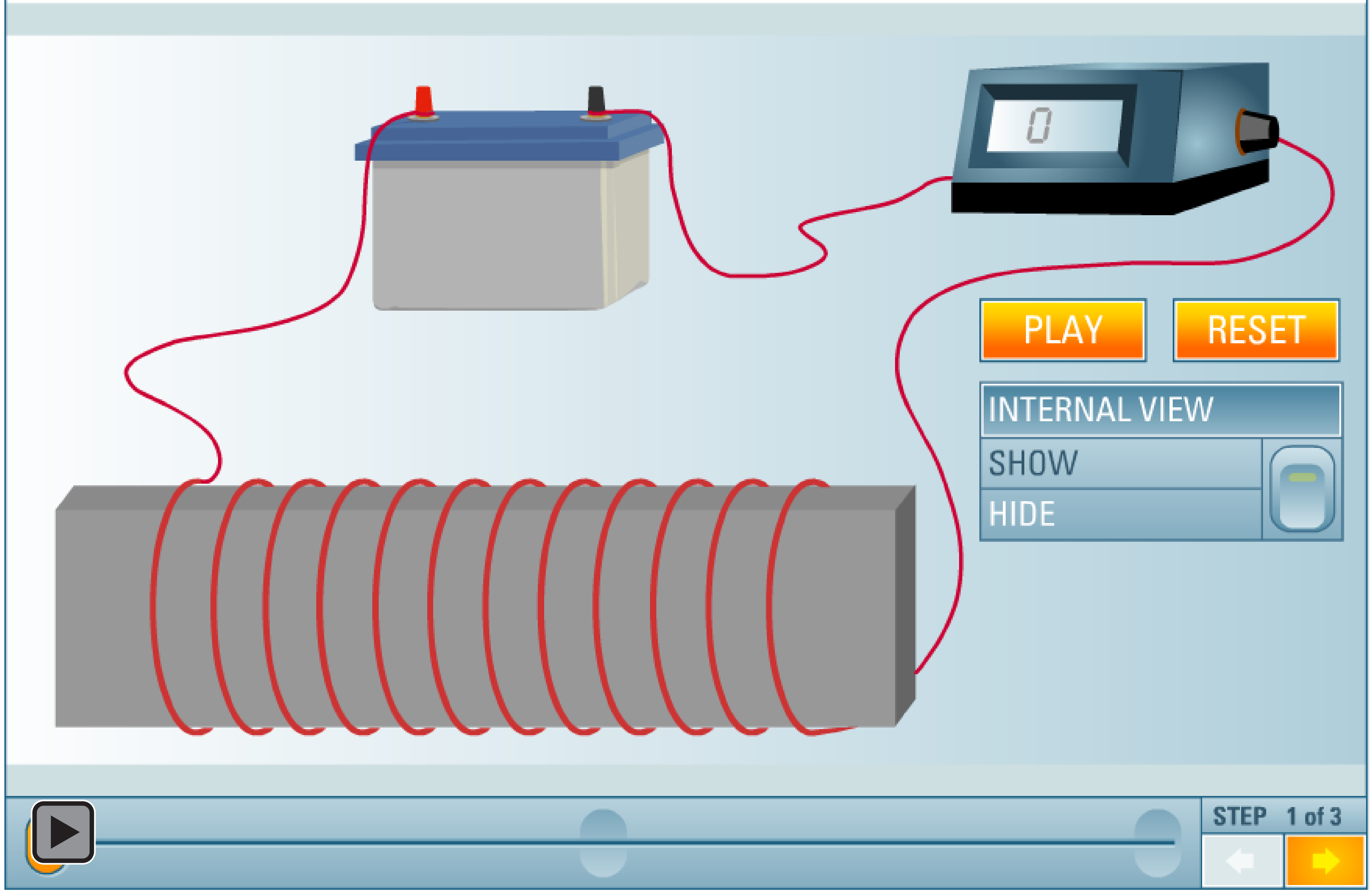
Magnetising by placing in a solenoid with a direct current

If you were making magnets for a living, the stroking technique would not be very economical. Just imagine all of those people stroking bars of iron with a magnet! A far better technique is to place the bar of iron inside a solenoid (a cylindrical coil of wire) and then to send a steady or "direct" (DC) electric current through the turns of wire.

The direct electric current through the solenoid creates a strong, steady magnet field (see episode 7) and the mini-magnets line up in that field.

Making a magnet by by placing in a solenoid

This is the action to carry out to turn the grey magnetic material into a magnet.



Putting the model to work

How to break a magnet: Demagnetising

Supposing you have a piece of magnetised iron. What can you do to remove its magnetic properties so that it is no longer a magnet?

Demagnetising by hitting

Any vibration or rough treatment, such as dropping onto a hard surface or tapping with a hammer, will cause weakening of the magnet

Hitting the magnet makes the mini-magnets become disordered. This, of course, is the reason why physics teachers hate the sound of magnets being dropped on the floor. It's not the clumsiness of the pupils, or the noise produced, but the image of demagnetisation which creates alarm!

Demagnetising by hitting

This is the action to carry out in order to demagnetise the bar.

Putting the model to work

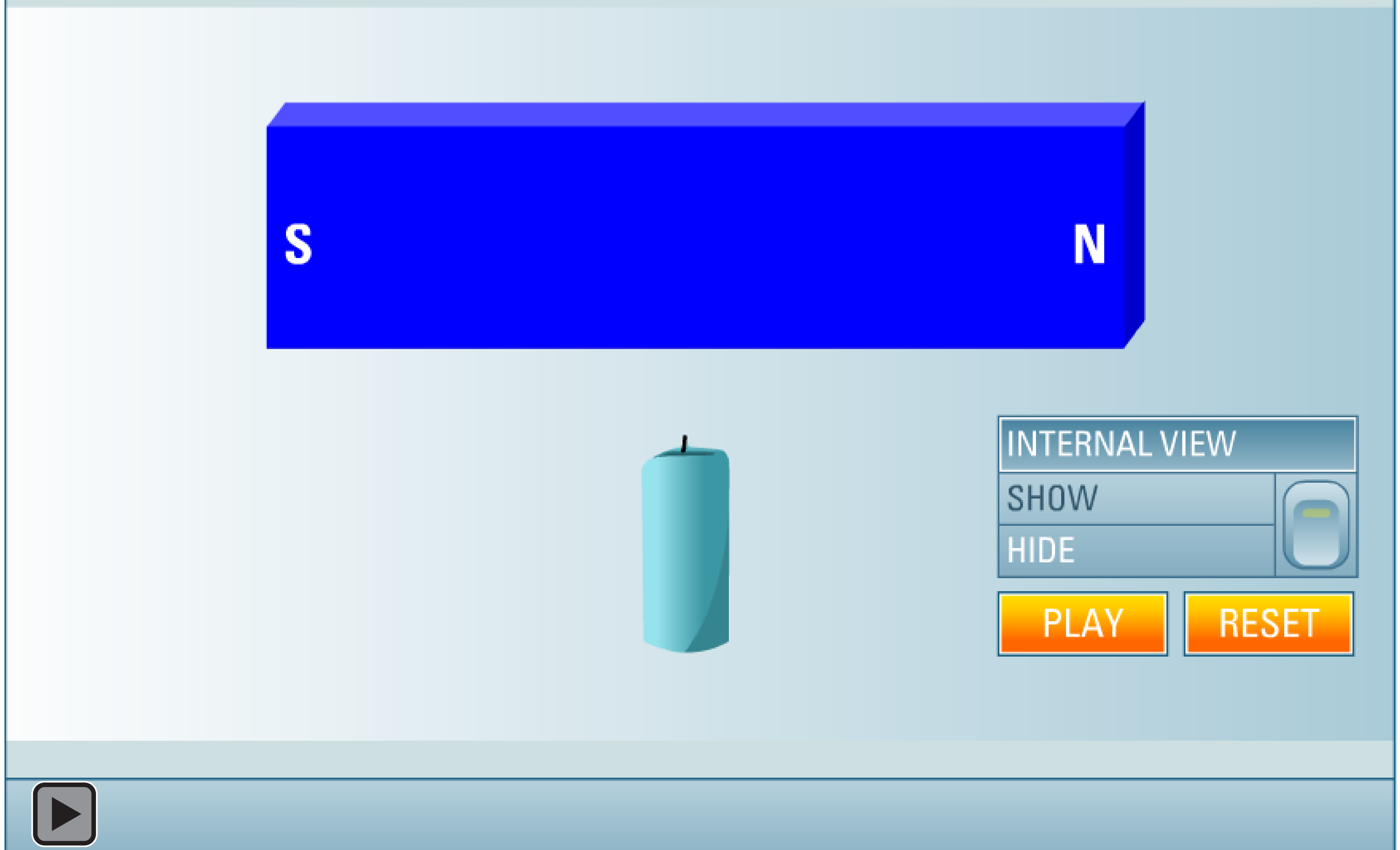
Demagnetising by heating

If a magnet is strongly heated and allowed to cool, it will become demagnetised.

As the magnet is heated there is increased vibration of the molecules and the mini-magnets become disordered.

Demagnetising by heating

This is the action to carry out to demagnetise the bar.



Putting the model to work

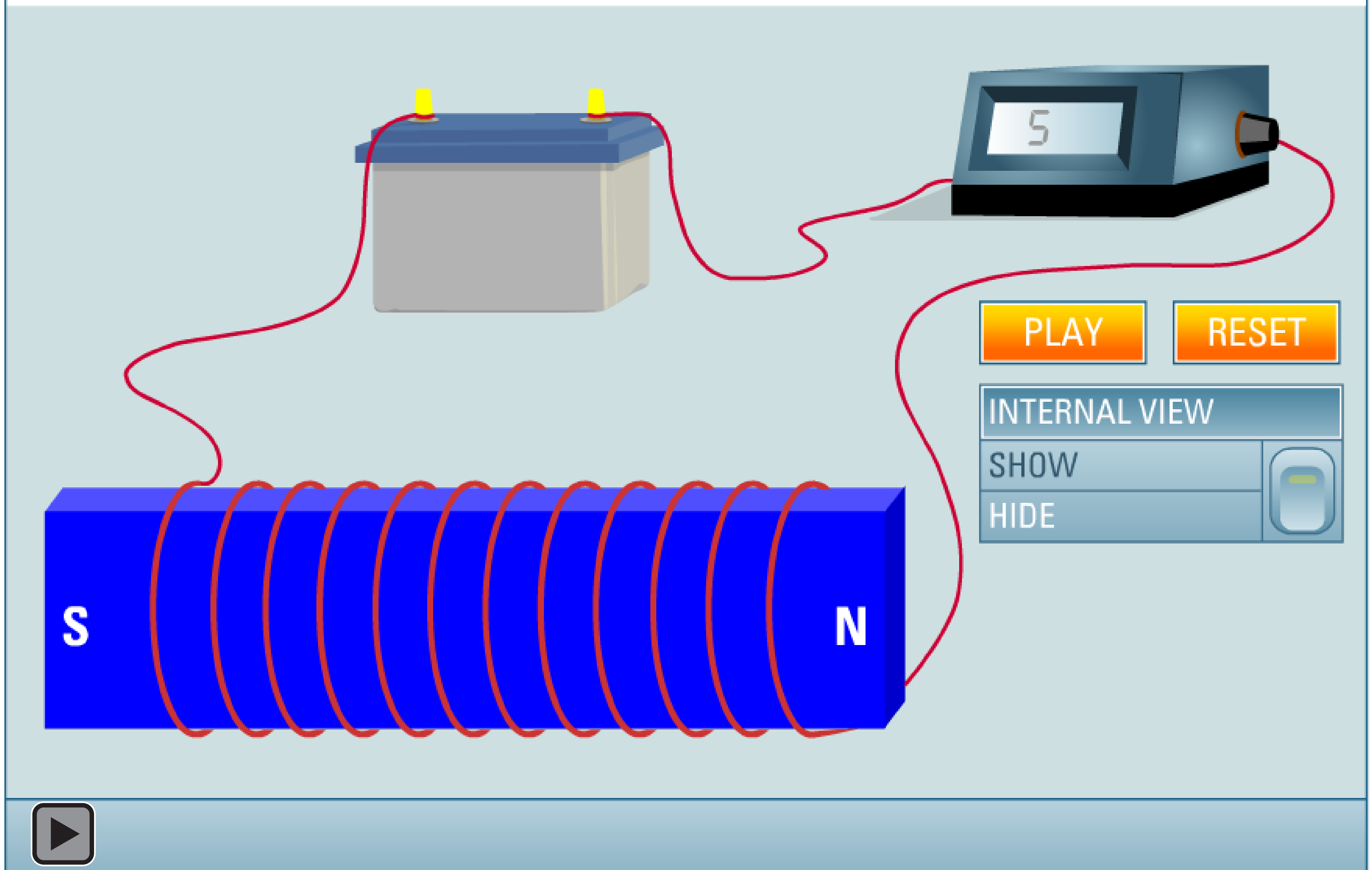
Demagnetising by placing in a solenoid with an alternating current

The best way to demagnetise a magnet is to place it inside a solenoid and then to send an alternating (AC) electric current through the coils.

The alternating current is such that it continuously reverses the direction of flow of charge; the charges pass first in one direction through the coils and then in the opposite direction. As this happens the magnetic field created within the solenoid keeps reversing direction, and this changing field disorders the mini-magnets and so the magnet becomes demagnetised.

Demagnetising by placing in a solenoid

This is the action to carry out in order to demagnetise the bar.



Putting the model to work

Why are magnetic materials attracted to magnets?

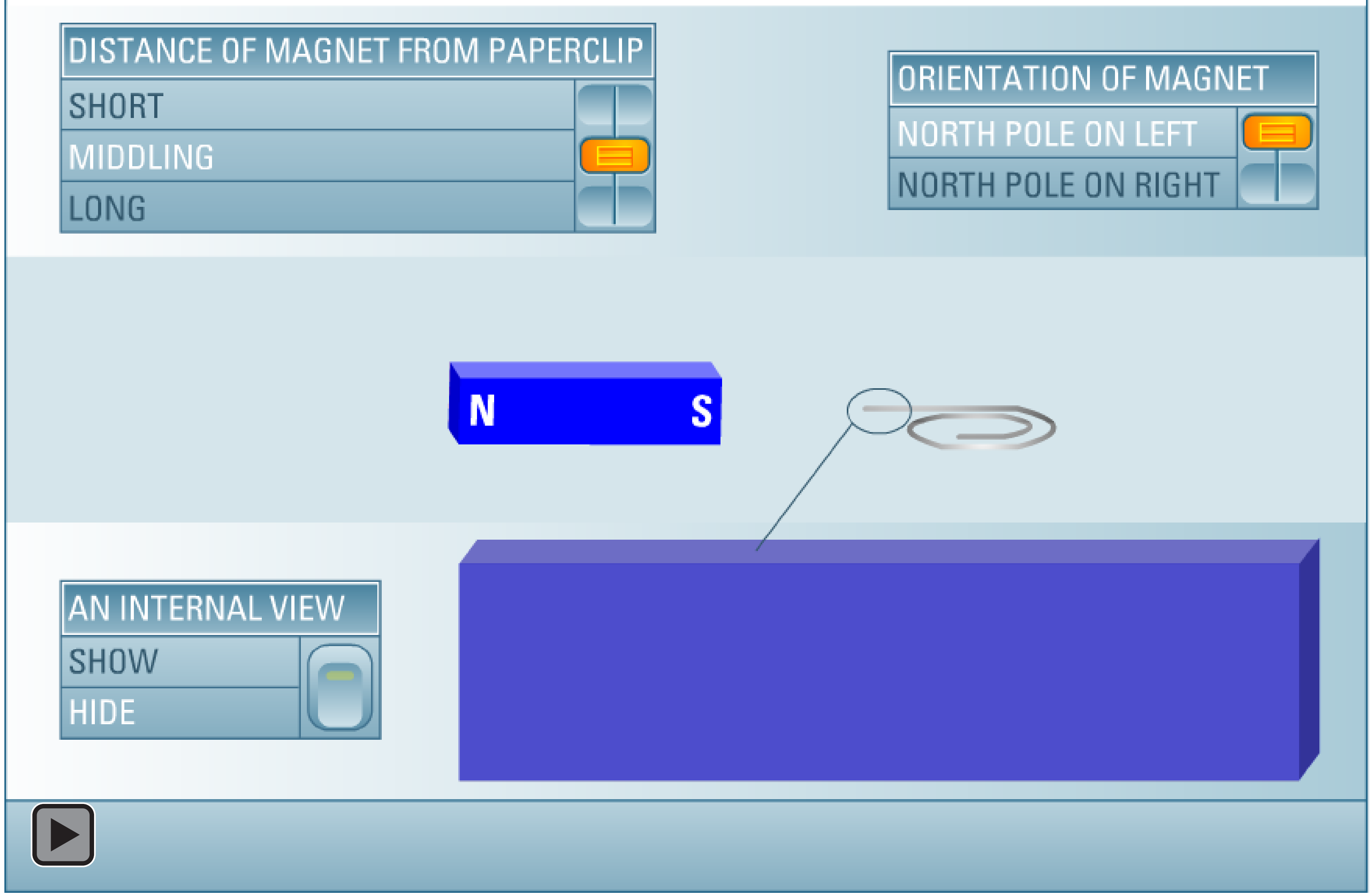
Supposing you have a bar magnet. You move it towards a paper clip (which is made from a magnetic material) and the clip is attracted towards the magnet. You turn the magnet around and try again. The paper clip is attracted to the magnet in exactly the same way. The clip is never repelled (as would be the case with two magnets). How can we explain this?

Our simple model can be used: When the magnet is moved towards the magnetic material (in this case the paper clip), the magnetic material becomes temporarily magnetised. Furthermore, it is magnetised in such a way that the pole nearest the permanent magnet becomes an opposite pole – hence the attractive force.

This process is referred to as magnetic induction: An opposite pole is induced as the magnet is brought near.

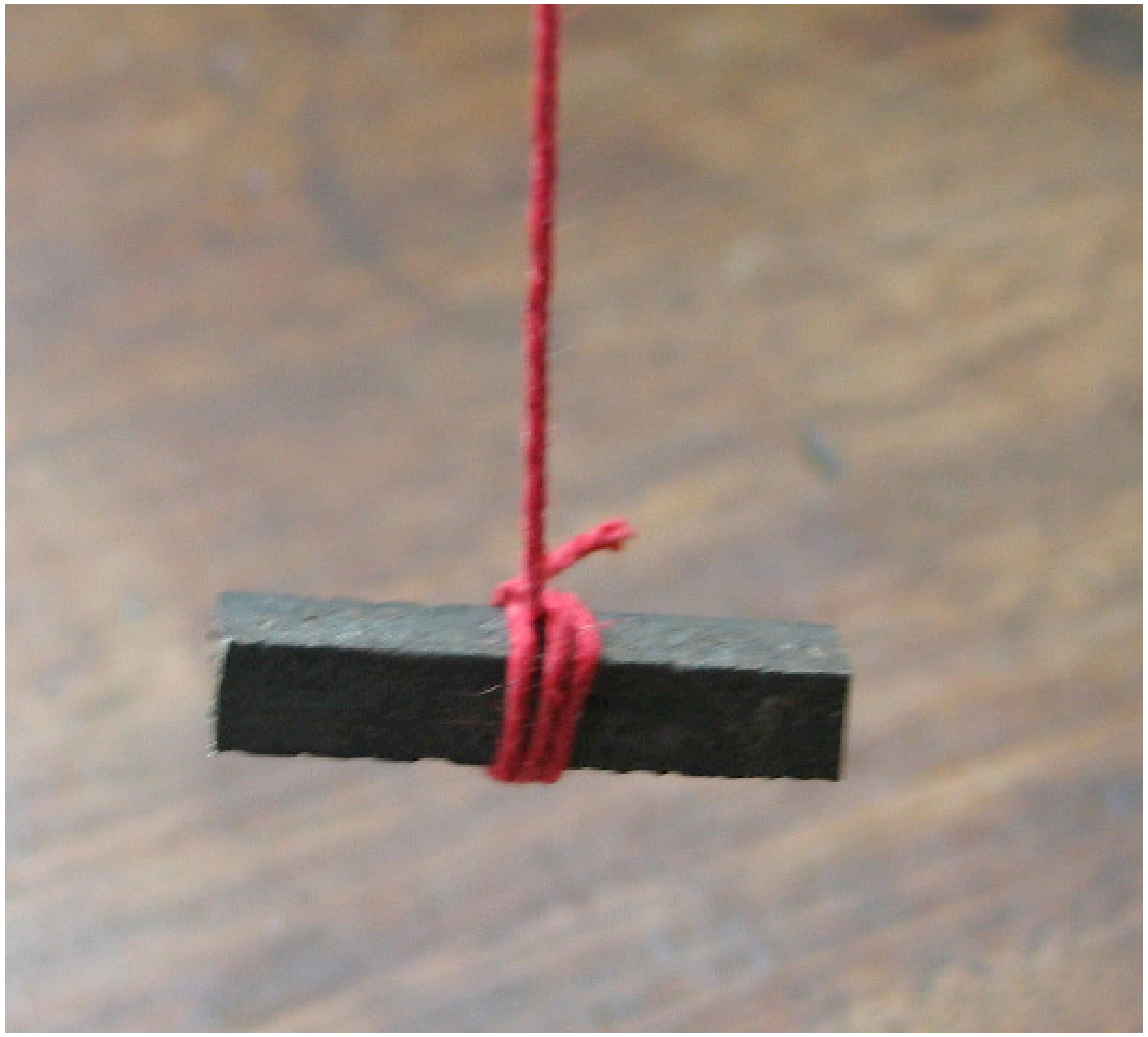
Attracting a paperclip

Use the controls to explore how the model accounts for the attraction.



Action-at-a-distance and magnetic fields

A fascinating feature of the working of magnets is that one magnet can attract or repel another without being in physical contact with it. Because magnets are familiar objects we may take this for granted, but just play with a couple of strong magnets and feel them pushing away at each other “through thin air”. It really is amazing! The magnetic force is one which “acts-at-a-distance”.



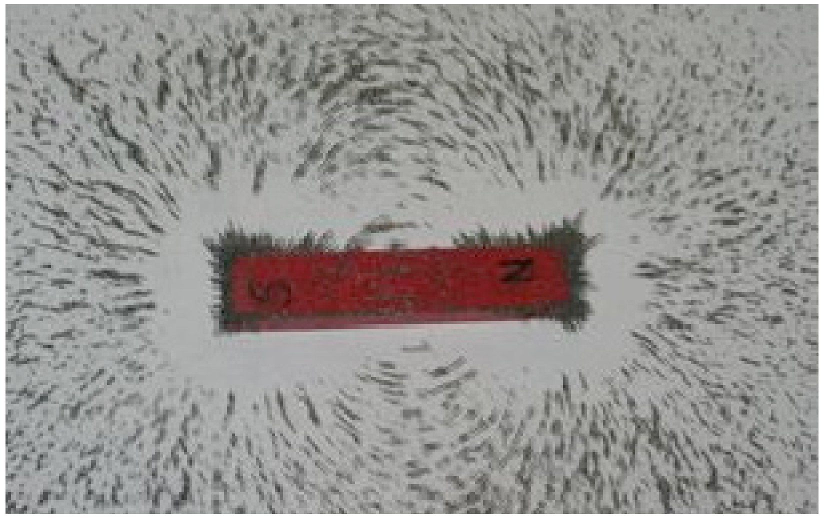
The space around a magnet where the magnetic force acts is called the magnetic field (just as the space around a mass where the gravitational force acts is called a gravitational field). In simple terms a magnetic field exists in a space if a magnet experiences a force when placed in that space. A crude way to make a magnetic field detector would be to suspend a bar magnet on a length of thread. If the suspended magnet is held in a space where there is a magnetic field, the bar magnet will be feel a force and perhaps make a small movement.

It is important to recognise that a magnetic field is not a tangible object (like an iron nail) but a theoretical concept, which we use to describe the physical world. We can point to the space around a magnet and claim (quite correctly) that there is a magnetic field in that space, but of course there is nothing there to actually see!

Other “action-at-a-distance” forces are those associated with gravity and with electric charges (see the forces topic). Since magnetic forces can be attractive or repulsive, they are quite different from gravitional forces which are only attractive, but do have parallels with electric forces which similarly can be attractive or repulsive.

Representing magnetic fields: In theory

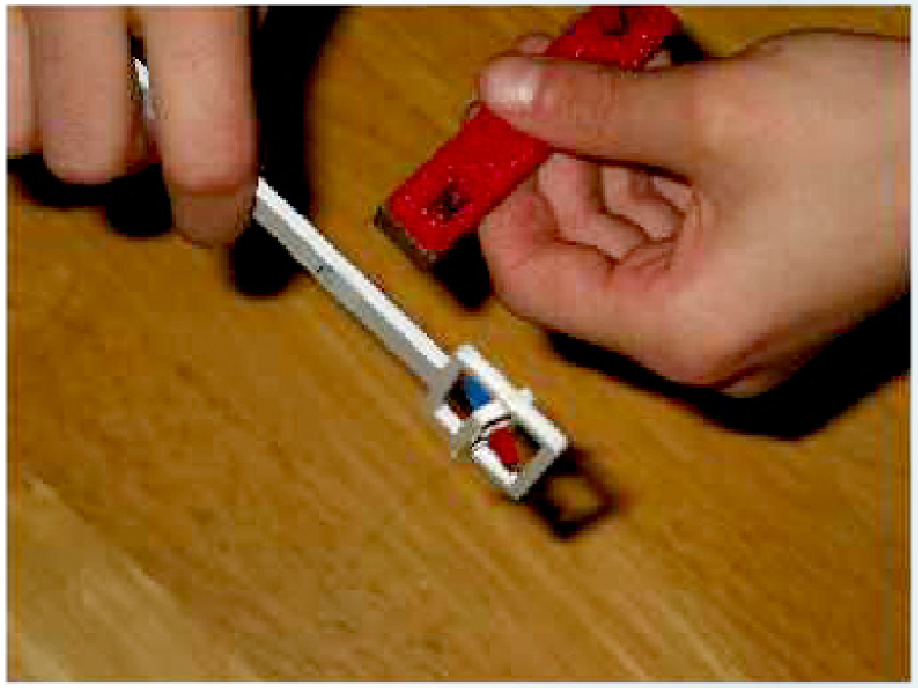
Magnetic fields are represented by diagrams which show patterns of magnetic field lines.



The magnetic field lines show the direction in which the magnetic force is acting at any particular point. The density of the magnetic field lines shows the strength of the magnetic force acting. If the lines are close together the magnetic force is great, if the lines are spread out the force is weak. From the magnetic field pattern you can see that the magnetic field is strongest (greatest magnetic force exerted on any magnetic object) at the poles of a magnet. No two dimensional picture can replace the full understanding that can be gained by exploring the field around a magnet with a carefully gimballed magnet. These images are a poor substitute for trying it for yourself.

Exploring the field around a magnet

Look at the images, then view the diagram in the next step.



EXPLORE THE MAGNETIC FIELD

- POSITION 1
- POSITION 2
- POSITION 3
- POSITION 4
- POSITION 5
- POSITION 6
- POSITION 7
- POSITION 8

STEP 1 of 2

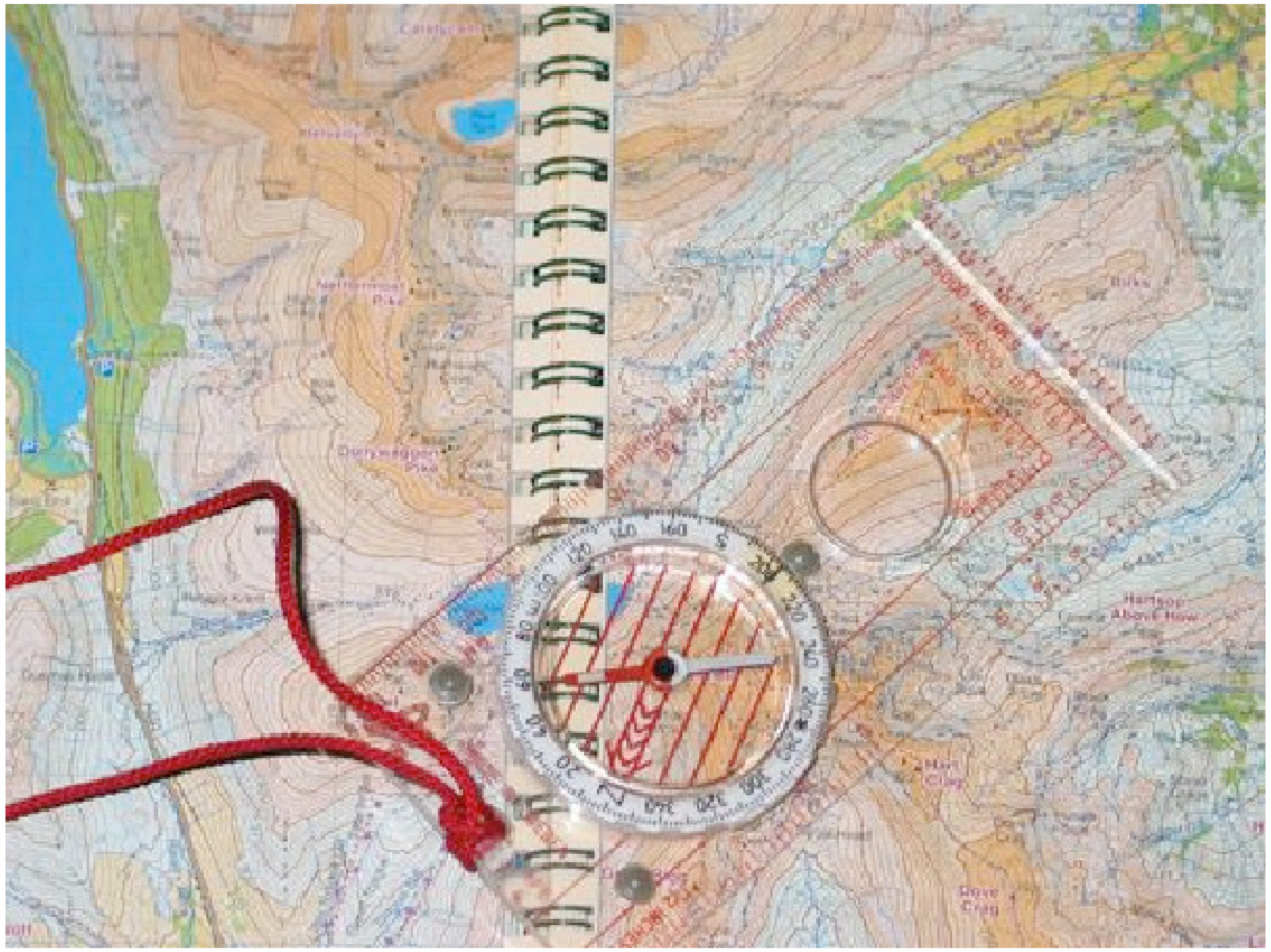
Representing magnetic fields: In theory

The direction of the magnetic field

The arrows on the magnetic field lines show the direction of the magnetic field, but what precisely does this mean?

In the case of gravity we can use any object (with mass) as a field detector, the direction of the field is given by the direction of the force that the object experiences when placed in the field. For example, hold a book in your hand and it is obvious that the gravity field is acting in a downwards direction on the book.

With magnetism, there are two contenders for the role of field detector, north and south poles. Deciding on north or south is a matter of convention, and the convention that is used throughout the world of physics is that the arrow drawn on a magnetic field line shows the direction in which a free north pole would move, that is from north towards south.



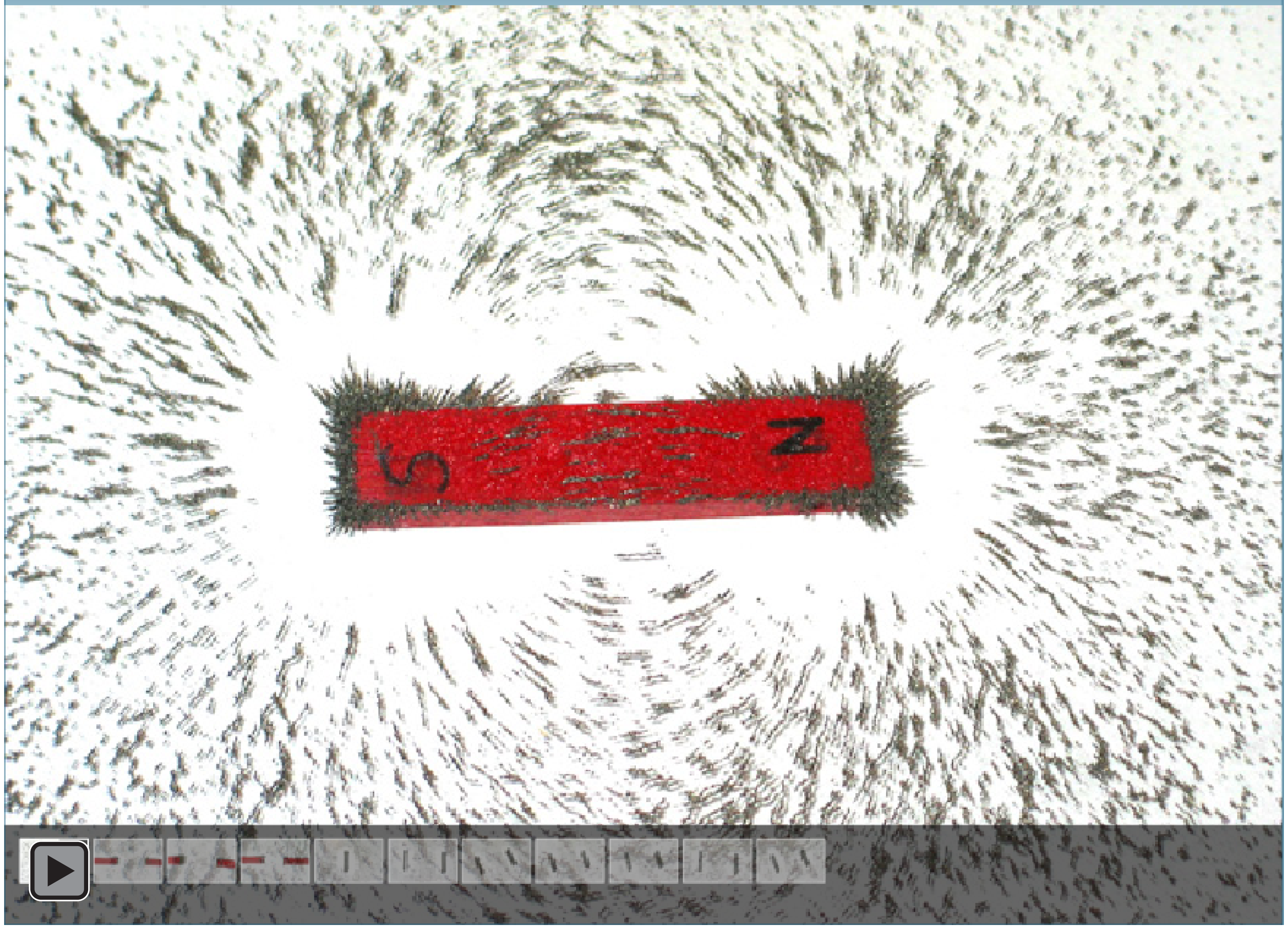
Representing magnetic fields: In practice

With iron filings

A simple way of mapping the rough shape of a magnetic field is to use iron filings. For example, the magnetic field pattern of bar magnet can be detected by covering it with a piece of paper and scattering iron filings over the paper.

As the filings are scattered around the magnet they become temporary magnets (by magnetic induction) and line up end-to-end. The filings tend to clump together around the poles of the magnet, indicating that this is where the magnetic field is strongest. The lines of iron filings give an impression of the lay-out of the magnetic field, but it is important to remember that what you have before you with the iron filings is not a magnetic field pattern. As argued earlier, the magnetic field pattern is a theoretical construction, a kind of graph which can be drawn to plot the layout of magnetic fields.

Magnetic fields with iron filings



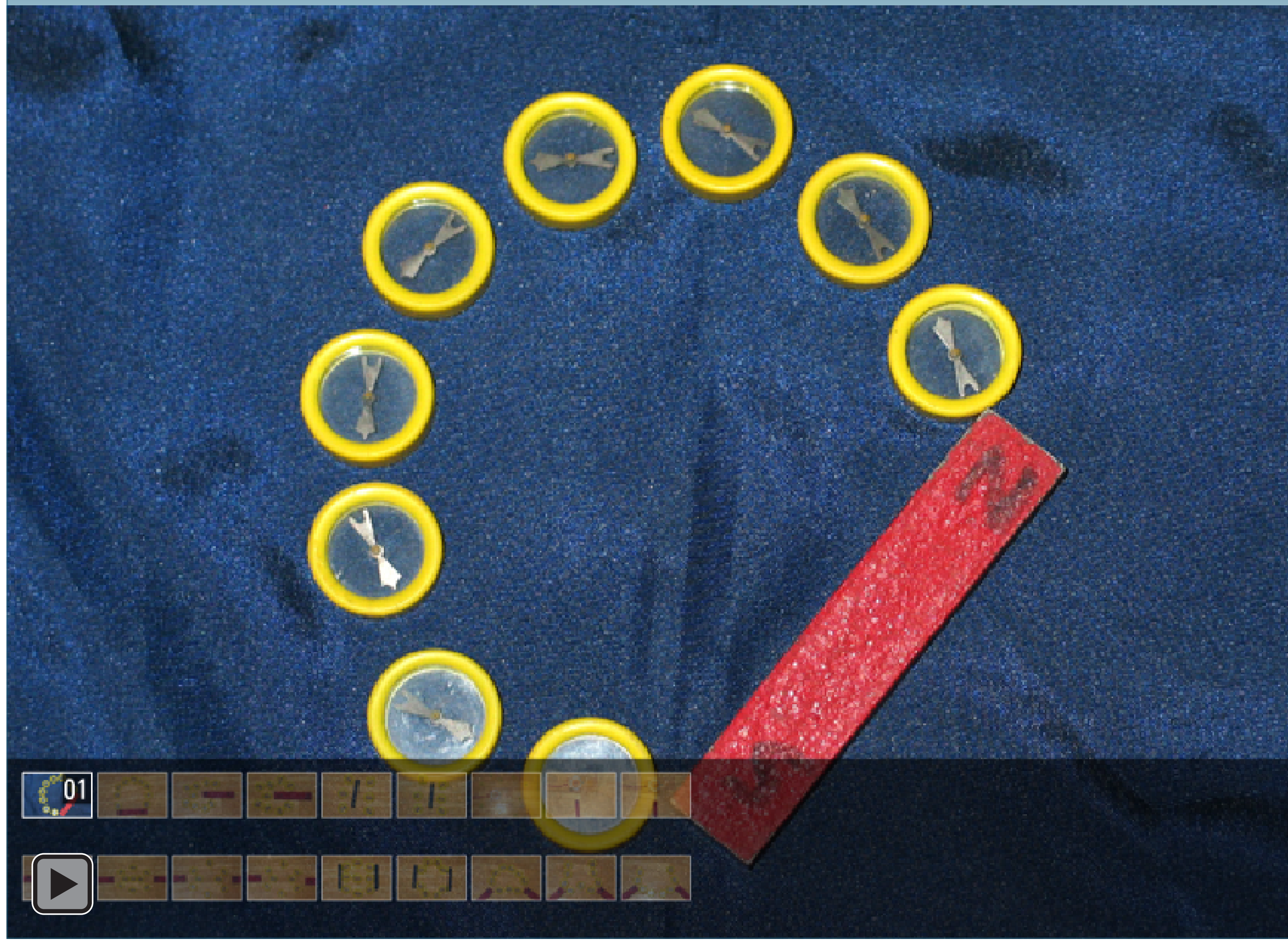
Representing magnetic fields: In practice

With plotting compasses

An alternative way to map a magnetic field is to use one or more plotting compasses. The plotting compass itself consists of a very small, suspended magnetic needle. If the plotting compass is placed in the magnetic field of a bar magnet, the needle will line up such that its north pole is attracted to the south pole of the magnet. By placing the plotting compass in adjacent positions in the field it is possible to map out some magnetic lines of force.

Using a plotting compass allows the direction of the field to be identified, with the needle of the compass pointing along the field lines from north to south. The plotting compass technique, however, gives less impression of the strength of the magnetic field than with iron filings technique, where the filings clearly clump around the poles.

Magnetic fields with compasses

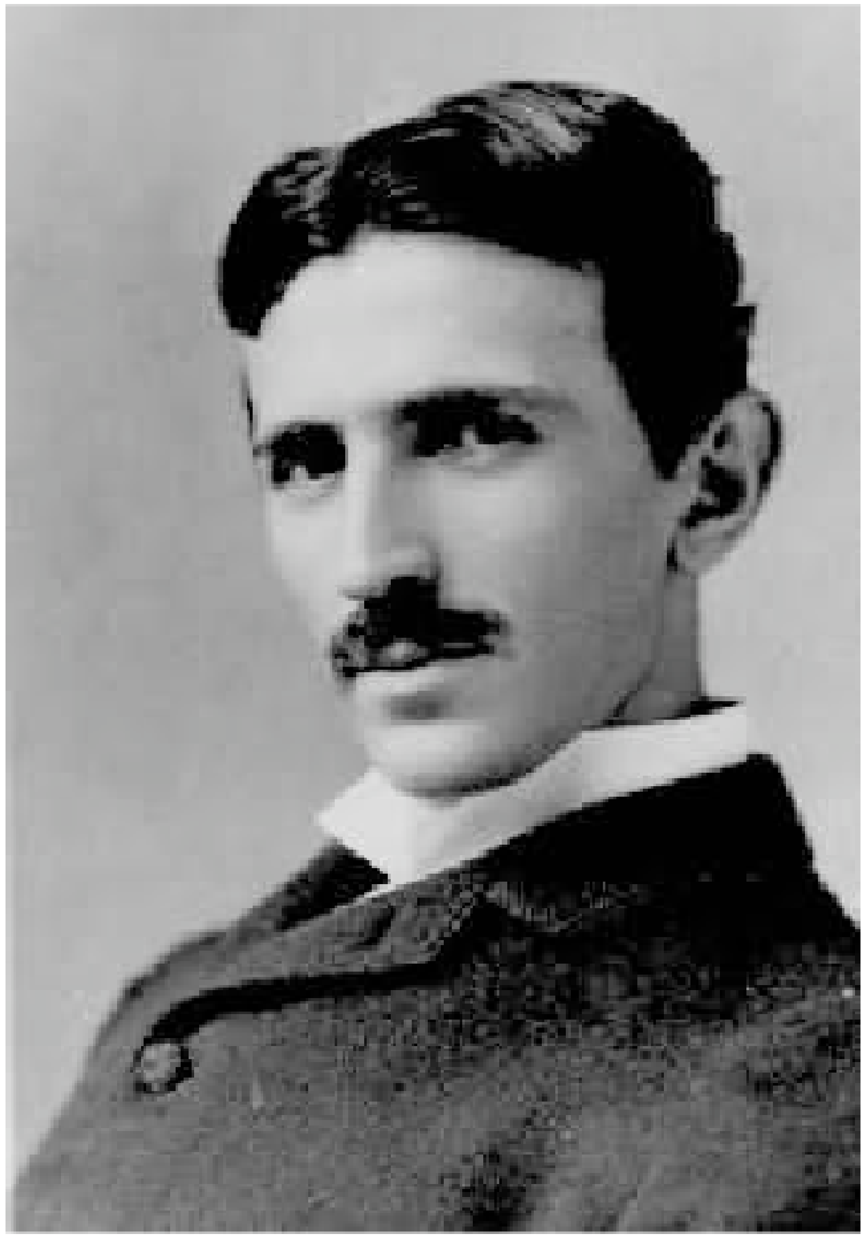


How is the strength of a magnetic field measured?

Here you can find out how to measure the strength of a magnetic field.

For quantitative work, the fact that a magnet will cause a force to act on a current-carrying wire is used to measure the strength of the magnetic field. If there is a direct current in a wire, a nearby magnet will cause a force to be exerted between the magnet and the wire. If the direction of the magnetic field is at a right angle to that of the current, and the length of the wire is 1 metre, carrying a current of 1 ampere, then a force of 1 newton will act on the wire when the magnetic field strength is equal to 1 tesla, 1 T. So the strength of a magnetic field is measured in units of tesla, (T). Nikola Tesla was a Yugoslav Serb physicist (1856-1943).

A magnetic field of 1 T is a strong field. The bar magnets found in schools create field strengths of the order of 10^{-4} T. The Earth's magnetic field near the UK has a strength of about one tenth of this, 10^{-5} T.



Niklas Tesla©www.classictesla.com

The Earth and its magnetism

As long ago as 600 BCE, the Greeks knew that a certain form of naturally occurring iron ore, known as lodestone, has the property of attracting small pieces of iron. Lodestone contains magnetite, an oxide of iron (Fe_3O_4) which is a magnetic material.

Historically, lodestone was important in providing one of the first clues towards establishing the connection between magnetic materials and the Earth. For example, in the Middle Ages, crude navigational compasses were made by attaching pieces of lodestone to wooden splints floating in bowls of water. These splints always lined up in a north/south direction on the Earth's surface and such early observations led to naming the ends of magnets "poles".

The magentic field of the Earth

Use the switches to explore the diagram.

The Earth and its magnetism

We now know much more about the shape and nature of the magnetic field due to the Earth. In its simplest form we might describe it as being rather like the magnetic field of a bar magnet with ends near the Earth's geographical north and south poles. However there is evidence that there are strong local variations in strength and direction of the field, and even that the field undergoes complete reversals in direction over long periods of time.

The locations of the geographical and magnetic poles are relatively close. However, arctic explorers seeking to reach the geographic North Pole would be hundreds of miles adrift if all they used was their compass. Their compass would direct them to the magnetic north.

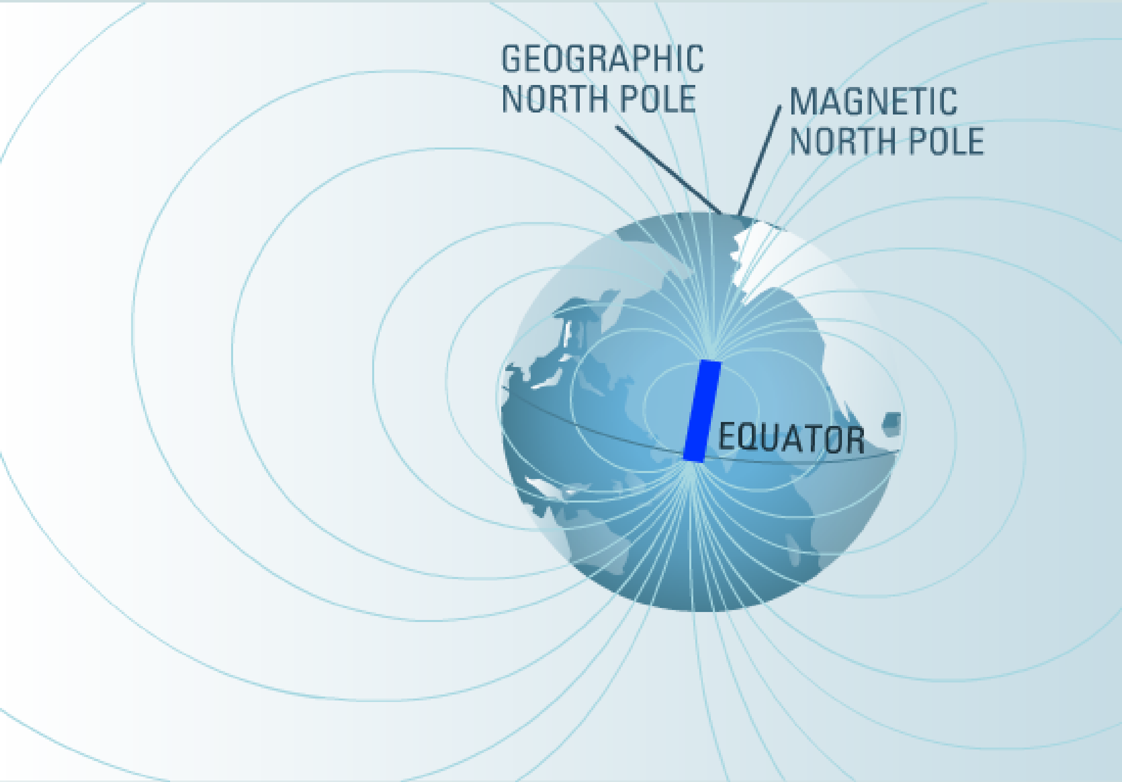
The Earth's magnetic field

Read more about the changes in the Earth's magnetic field over time.

Beneath the Earth's crust and mantle lies a complex internal structure believed to be a dynamic core of molten iron, perhaps mixed with nickel and sulphur. With a temperature maintained by nuclear processes, the molten iron moves slowly creating a system of circulating electric currents in the core. It is this motion which is believed to be responsible for the generation of the Earth's magnetic field.

The changing magentic field of the Earth

The pattern now:



At most places on the Earth's surface, the field dips or rises. The angle at which it does so is the inclination.

At most places on the Earth's surface, the field does not point towards the geographic pole. The angle at which it misses is called the declination.

STEP 1 of 4

The Earth's magnetic field

The resulting magnetic field evident on the surface of the Earth is far from static. There are variations in intensity and direction across the surface. These variations need to be taken into account whenever using a compass. Over a time scale of millions of years there appear to have been many major changes to the direction of the Earth's magnetic field, with up to 10 complete direction reversals in the last five million years. The last complete reversal occurred about 780 000 years ago.

Scientists make use of samples of igneous rock to help chart these magnetic changes. When molten volcanic rock emerges it rapidly cools. This cooling process traps within the rock evidence of the prevailing magnetic field direction of the Earth at the time of the eruption.

Magnetic poles in relation to the Earth's poles

Near to the Earth's geographic North Pole there is the magnetic pole which we can picture as being one end of a huge, imaginary bar magnet which passes up through a north/south axis of the Earth.

Suppose that you are using a compass and the needle settles down along a north/south line. The north pole (or north-seeking pole) of the compass points roughly (but not exactly) towards the geographic North Pole of the Earth. This makes sense.

However, if you stop to think for a moment, if we define the end of the compass needle which points north as the north pole of a magnet, then it must be attracted to a south pole. The inescapable conclusion is that the magnetic pole in the northern hemisphere of the Earth is, in fact, a south pole. On first meeting this concept, it seems very strange indeed, but it follows from the definition of the poles of a compass needle.

History, navigation and Gilbert

Read more about the development of compasses.

The magnet, as part of a compass, revolutionised the lives of sailors on perilous journeys across the world's oceans, allowing navigators to chart their course with much greater accuracy.

Pieces of loadstone were floated on wood and found to point towards the pole star. In later developments smaller iron needles were magnetised, which made the compasses more portable. The Chinese were using magnetic compasses around AD 1100, western Europeans around 1200, Arabs around 1250, and Scandinavians by 1300.

The first man to research the properties of the lodestone (magnetic iron ore) was William Gilbert, who, amongst other roles, was physician to Queen Elizabeth I. Gilbert published his findings in 1600 in a book called *De Magnete* (The Magnet) and caught the eye of such famous scientists as Johannes Kepler and Galileo. *De Magnete* was quickly accepted as the standard work on magnetism and electrical phenomena throughout Europe. In it, Gilbert distinguished between magnetism and static (known as the amber effect). He also compared the magnet's polarity to the polarity of the Earth.