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The Free High School Science Texts: Textbooks for High School Students Studying the Sciences
Physics
Grades 10 - 12

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Chapter 8

Magnetism - Grade 10

8.1 Introduction

Magnetism is the force that a magnetic object exerts, through its magnetic field, on another object. The two objects do not have to physically touch each other for the force to be exerted. Object 2 feels the magnetic force from Object 1 because of Object 1's surrounding magnetic field.

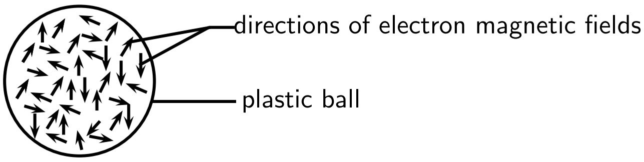
Humans have known about magnetism for many thousands of years. For example, *lodestone* is a magnetised form of the iron oxide mineral *magnetite*. It has the property of attracting iron objects. It is referred to in old European and Asian historical records; from around 800 BCE in Europe and around 2 600 BCE in Asia.

The root of the English word *magnet* is from the Greek word *magnes*, probably from Magnesia in Asia Minor, once an important source of lodestone.

8.2 Magnetic fields

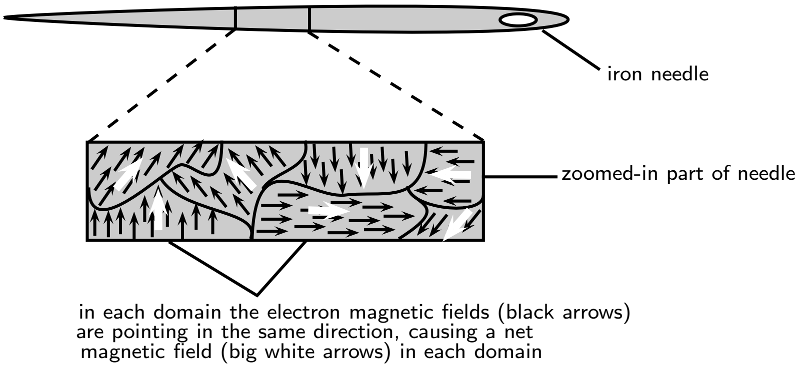
A magnetic field is a region in space where a magnet or object made of ferromagnetic material will experience a non-contact force.

Electrons moving inside any object have magnetic fields associated with them. In most materials these fields point in all directions, so the net magnetic field is zero. For example, in the plastic ball below, the directions of the magnetic fields of the electrons (shown by the arrows) are pointing in different directions and cancel each other out. Therefore the plastic ball is not magnetic and has no magnetic field.

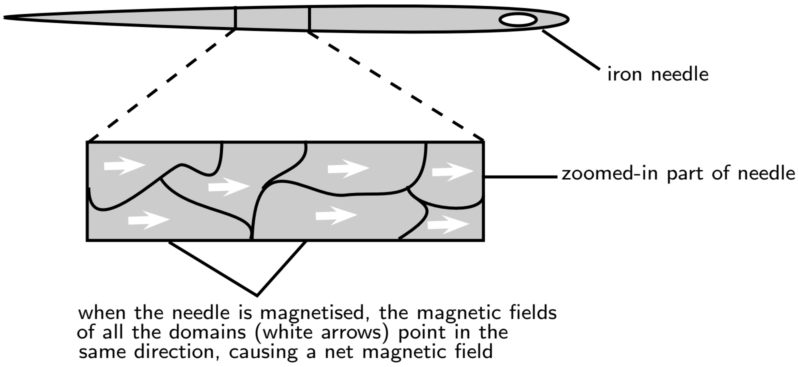


The electron magnetic fields point in all directions
and so there is no net magnetic field

In some materials (e.g. iron), called **ferromagnetic** materials, there are regions called *domains*, where these magnetic fields line up. All the atoms in each domain group together so that the magnetic fields from their electrons point the same way. The picture shows a piece of an iron needle zoomed in to show the domains with the electric fields lined up inside them.



In permanent magnets, many domains are lined up, resulting in a *net magnetic field*. Objects made from ferromagnetic materials can be magnetised, for example by rubbing a magnet along the object in one direction. This causes the magnetic fields of most, or all, of the domains to line up and cause the object to have a magnetic field and be *magnetic*. Once a ferromagnetic object has been magnetised, it can stay magnetic without another magnet being nearby (i.e. without being in another magnetic field). In the picture below, the needle has been magnetised because the magnetic fields in all the domains are pointing in the same direction.



Activity :: Investigation : Ferromagnetic materials and magnetisation

1. Find 2 paper clips. Put the paper clips close together and observe what happens.
   1.1 **What happens to the paper clips?**
   1.2 **Are the paper clips magnetic?**
2. Now take a permanent bar magnet and rub it once along 1 of the paper clips. Remove the magnet and put the paper clip which was touched by the magnet close to the other paper clip and observe what happens.
   2.1 **Does the untouched paper clip feel a force on it? If so, is the force attractive or repulsive?**
3. Rub the same paper clip a few more times with the bar magnet, in the same direction as before. Put the paper clip close to the other one and observe what happens.
   3.1 **Is there any difference to what happened in step 2?**

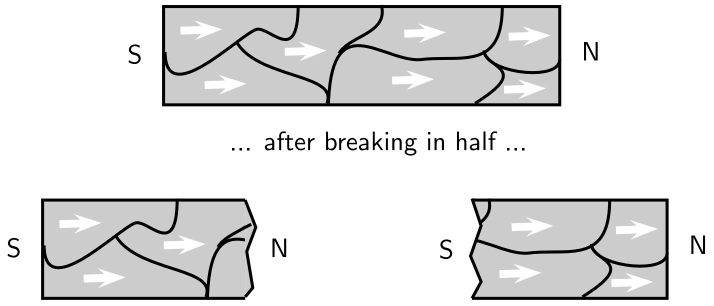
   3.2 **If there is a difference, what is the reason for it?**
   3.3 **Is the paper clip which was rubbed by the magnet now magnetised?**
   3.4 **What is the difference between the two paper clips at the level of their atoms and electrons?**

4. Now, find a *metal* knitting needle, or a plastic ruler, or other plastic object. Rub the bar magnet along the knitting needle a few times in the same direction. Now put the knitting needle close to the paper clips and observe what happens.
   4.1 **Does the knitting needle attract the paper clips?**
   4.2 **What does this tell you about the material of the knitting needle? Is it ferromagnetic?**
5. Repeat this experiment with objects made from other materials.
   5.1 **Which materials appear to be ferromagnetic and which are not? Put your answers in a table.**

8.3 Permanent magnets

8.3.1 The poles of permanent magnets

Because the domains in a permanent magnet all line up in a particular direction, the magnet has a pair of opposite poles, called **north** (usually shortened to **N**) and **south** (usually shortened to **S**). Even if the magnet is cut into tiny pieces, each piece will still have *both* a N and a S pole. These poles *always* occur in pairs. In nature we never find a north magnetic pole or south magnetic pole on its own.



Magnetic fields are *different* to gravitational and electric fields. In nature, positive and negative electric charges can be found on their own, but you *never* find just a north magnetic pole or south magnetic pole on its own. On the very small scale, zooming in to the size of atoms, magnetic fields are caused by moving charges (i.e. the negatively charged electrons).

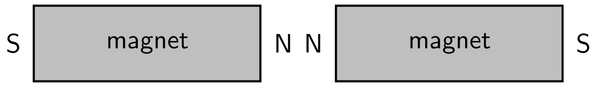
8.3.2 Magnetic attraction and repulsion

Like poles of magnets repel one another whilst unlike poles attract. This means that two N poles or two S poles will push away from each other while a N pole and a S pole will be drawn towards each other.

Definition: Attraction and Repulsion
Like poles of magnets *repel* each other whilst *unlike* poles *attract* each other.

Worked Example 39: Attraction and Repulsion

Question: Do you think the following magnets will repel or be attracted to each other?



Answer

Step 1 : Determine what is required

We are required to determine whether the two magnets will repel each other or be attracted to each other.

Step 2 : Determine what is given

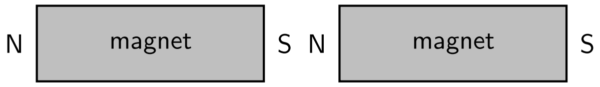
We are given two magnets with the N pole of one approaching the N pole of the other.

Step 3 : Determine the conclusion

Since both poles are the same, the magnets will repel each other.

Worked Example 40: Attraction and repulsion

Question: Do you think the following magnets will repel or be attracted to each other?



Answer

Step 1 : Determine what is required

We are required to determine whether the two magnets will repel each other or be attracted to each other.

Step 2 : Determine what is given

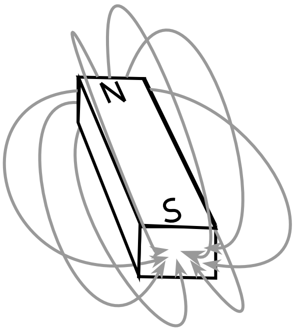
We are given two magnets with the N pole of one approaching the S pole of the other.

Step 3 : Determine the conclusion

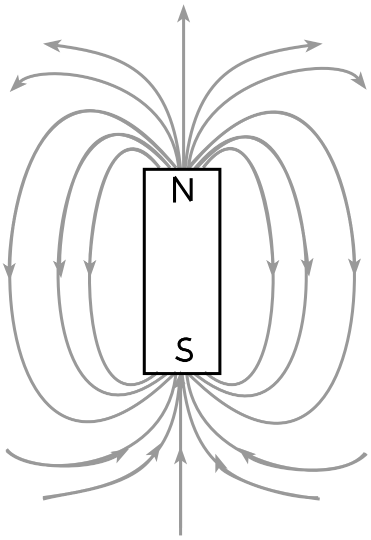
Since both poles are the different, the magnets will be attracted to each other.

8.3.3 Representing magnetic fields

Magnetic fields can be *represented* using **magnetic field lines**. Although the magnetic field of a permanent magnet is everywhere surrounding the magnet (in all 3 dimensions), we draw only some of the field lines to represent the field (usually only 2 dimensions are shown in drawings).



3-dimensional representation



2-dimensional representation

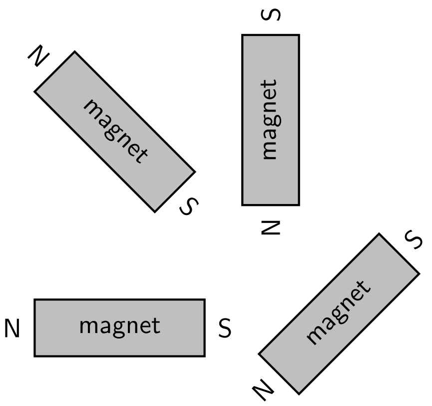
In areas where the magnetic field is strong, the field lines are closer together. Where the field is weaker, the field lines are drawn further apart. The strength of a magnetic field is referred to as the **magnetic flux**

Important:

1. Field lines *never* cross.
2. Arrows drawn on the field lines indicate the direction of the field.
3. A magnetic field points from the north to the south pole of a magnet.

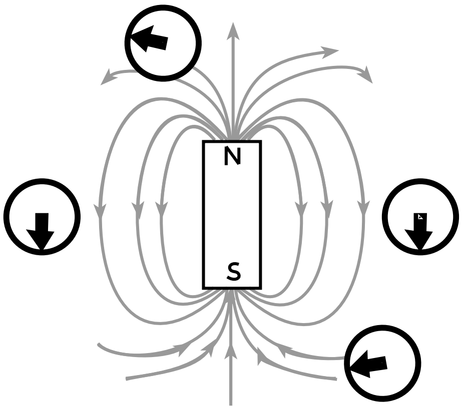
Activity :: Investigation : Field around a Bar Magnet

Take a bar magnet and place it on a flat surface. Place a sheet of white paper over the bar magnet and sprinkle some iron filings onto the paper. Give the paper a shake to evenly distribute the iron filings. In your workbook, draw the bar magnet and the pattern formed by the iron filings. Draw the pattern formed when you rotate the bar magnet as shown.



As the activity shows, one can map the magnetic field of a magnet by placing it underneath a piece of paper and sprinkling iron filings on top. The iron filings line themselves up parallel to the magnetic field.

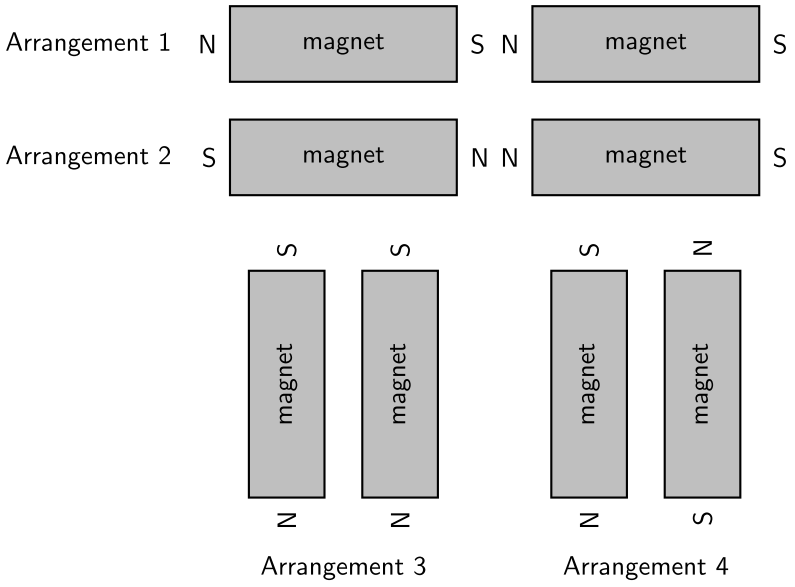
Another tool one can use to find the direction of a magnetic field is a *compass*. The compass arrow points in the direction of the field.



The direction of the compass arrow is the same as the direction of the magnetic field

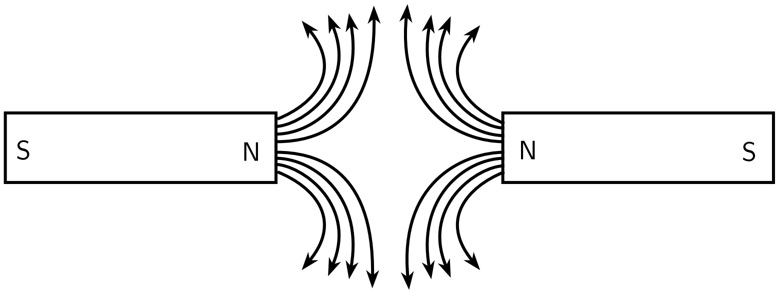
Activity :: Investigation : Field around a Pair of Bar Magnets

Take two bar magnets and place them a short distance apart such that they are repelling each other. Place a sheet of white paper over the bar magnets and sprinkle some iron filings onto the paper. Give the paper a shake to evenly distribute the iron filings. In your workbook, draw both the bar magnets and the pattern formed by the iron filings. Repeat the procedure for two bar magnets attracting each other and draw what the pattern looks like for this situation. Make a note of the shape of the lines formed by the iron filings, as well as their size and their direction for both arrangements of the bar magnet. What does the pattern look like when you place both bar magnets side by side?



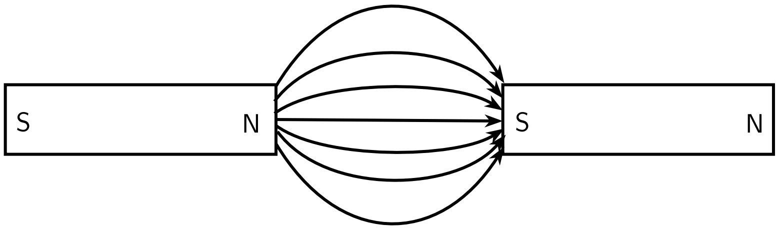
As already said, opposite poles of a magnet attract each other and bringing them together causes their magnetic field lines to *converge* (come together). Like poles of a magnet repel each other and bringing them together causes their magnetic field lines to *diverge* (bend out from each other).

Like poles repel each other



The field lines between 2 like poles diverge

Unlike poles attract each other



The magnetic field lines between 2 unlike poles converge

Extension: Ferromagnetism and Retentivity

Ferromagnetism is a phenomenon shown by materials like iron, nickel or cobalt. These materials can form permanent magnets. They always magnetise so as to be attracted to a magnet, no matter which magnetic pole is brought toward the unmagnetised iron/nickel/cobalt.

The ability of a ferromagnetic material to retain its magnetisation *after* an external field is removed is called its **retentivity**.

Paramagnetic materials are materials like aluminium or platinum, which become magnetised in an external magnetic field in a similar way to ferromagnetic materials. However, they lose their magnetism when the external magnetic field is removed.

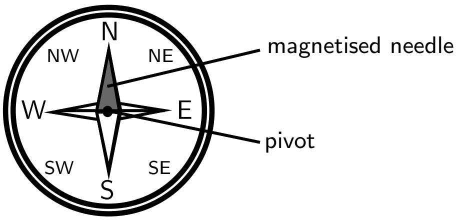
Diamagnetism is shown by materials like copper or bismuth, which become magnetised in a magnetic field with a polarity *opposite* to the external magnetic field. Unlike iron, they are slightly repelled by a magnet.

8.4 The compass and the earth's magnetic field

A **compass** is an instrument which is used to find the direction of a magnetic field. It can do this because a compass consists of a small metal needle which is magnetised itself and which is free to turn in any direction. Therefore, when in the presence of a magnetic field, the needle is able to line up in the same direction as the field.

Lodestone, a magnetised form of iron-oxide, was found to orientate itself in a north-south direction if left free to rotate by suspension on a string or on a float in water. Lodestone was therefore used as an early navigational compass.

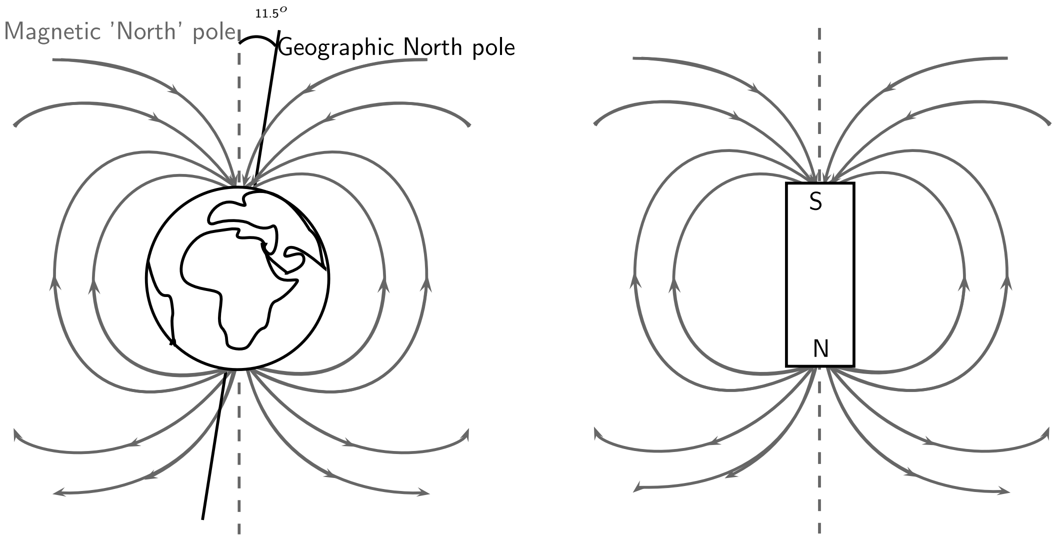
Compasses are mainly used in navigation to find direction on the earth. This works because the earth itself has a magnetic field which is similar to that of a bar magnet (see the picture below). The compass needle aligns with the magnetic field direction and points north (or south). Once you know where north is, you can figure out any other direction. A picture of a compass is shown below:



Some animals can detect magnetic fields, which helps them orientate themselves and find direction. Animals which can do this include pigeons, bees, Monarch butterflies, sea turtles and fish.

8.4.1 The earth's magnetic field

In the picture below, you can see a representation of the earth's magnetic field which is very similar to the magnetic field of a giant bar magnet like the one on the right of the picture. So the earth has two sets of north poles and south poles: **geographic poles** and **magnetic poles**.



The earth's magnetic field is thought to be caused by churning liquid metals in the core which causes electric currents and a magnetic field. From the picture you can see that the direction of magnetic north and true north are not identical. The **geographic north pole**, which is the point through which the earth's rotation axis goes, is about 11,5^o away from the direction of the **magnetic north pole** (which is where a compass will point). However, the magnetic poles shift slightly all the time.

Another interesting thing to note is that if we think of the earth as a big bar magnet, and we know that magnetic field lines always point *from north to south*, then the compass tells us that what we call the *magnetic north pole* is actually the *south pole* of the bar magnet!

The direction of the earth's magnetic field flips direction about once every 200 000 years! You can picture this as a bar magnet whose north and south pole periodically switch sides. The reason for this is still not fully understood.

The earth's magnetic field is very important for humans and other animals on earth because it stops charged particles emitted by the sun from hitting the earth and us. Charged particles can also damage and cause interference with telecommunications (such as cell phones). Charged particles (mainly protons and electrons) are emitted by the sun in what is called the solar wind, and travel towards the earth. These particles spiral in the earth's magnetic field towards the poles. If they collide with other particles in the earth's atmosphere they sometimes cause red or green lights or a glow in the sky which is called the aurora. This happens close to the north and south pole and so we cannot see the aurora from South Africa.

8.5 Summary

1. Magnets have two poles - North and South.

2. Some substances can be easily magnetised.
3. Like poles repel each other and unlike poles attract each other.
4. The Earth also has a magnetic field.
5. A compass can be used to find the magnetic north pole and help us find our direction.

8.6 End of chapter exercises

1. Describe what is meant by the term *magnetic field*.
2. Use words and pictures to explain why permanent magnets have a magnetic field around them. Refer to *domains* in your explanation.
3. What is a magnet?
4. What happens to the poles of a magnet if it is cut into pieces?
5. What happens when like magnetic poles are brought close together?
6. What happens when unlike magnetic poles are brought close together?
7. Draw the shape of the magnetic field around a bar magnet.
8. Explain how a compass indicates the direction of a magnetic field.
9. Compare the magnetic field of the Earth to the magnetic field of a bar magnet using words and diagrams.
10. Explain the difference between the geographical north pole and the magnetic north pole of the Earth.
11. Give examples of phenomena that are affected by Earth's magnetic field.
12. Draw a diagram showing the magnetic field around the Earth.

Appendix A

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