Physics Knowledge Organiser
P15 - Electromagnetism

Magnets

The __poles__ of a magnet are where the magnetic forces are strongest. This is because the magnetic field lines are *most concentrated* at the poles, as you can see on the diagram below.

Magnets exert forces on one another when they are brought together: a **non-contact** force. If like poles (N-N or S-S) are brought together, the force is of repulsion. If unlike poles are brought together (N-S), the force is of attraction.

Magnets can be classified as **permanent** or **induced** (temporary). Permanent magnets have their own magnetic field, and it doesn't go away. Induced magnets are made when a material is placed in a magnetic field. (In most cases, this needs to be a magnetic material. The __only__ magnetic materials are iron, steel, cobalt and nickel.) Induced magnets are always **attracted** to the magnet that turned them into a magnet – this is why you can pick up paper clips or nails with a bar magnet: the paper clip becomes an induced magnet with poles that are aligned so there is a force of attraction. See the poles labelled on the diagram. Induced magnetism is quickly lost when the material is removed from the magnetic field that induced it.

Magnetic fields

Magnetic fields are around all magnets (permanent or induced). The **__direction__** of the magnetic, as the diagram shows, is from **north** to **south**. The north pole of a magnet is properly defined as: *the pole that causes a force **away** from it, if a north pole is placed at that end.* This makes sense when you remember that like poles repel. So you can decide which end in north on an 'unknown magnet' by looking at the direction of the force that acts if a north pole (on another magnet) is brought to one end of your magnet. Repulsion (force away) means that end must be a north pole. Sometimes the north pole is called the **north seeking pole**, because it will point north on Earth if left freely suspended.

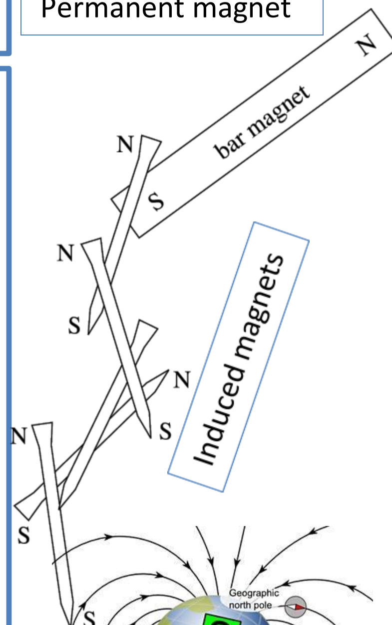
Magnetic fields are *strongest* at the poles and get weaker as the __distance__ from the magnet increases. Using a **magnetic compass** (sometimes called a plotting compass), we can find out the direction of a magnetic field – the diagram shows how to do this.

Earth has a **magnetic field**. Using a compass, you can tell that the magnetic field points towards the north pole (Santa's house), so this actually means that the geographic north pole of Earth is a south pole of a magnet! See diagram.

Furthermore, we know it is the **core** of the Earth that is magnetic (not the whole thing) because a compass at the north pole (in the Arctic circle) points down below your feet. It is worth realising, too, that the geographic north pole (the top of Earth's axis) is in a different location to 'magnetic north' – the latter is actually in northern Canada. So a magnetic compass actually wouldn't be much use if you were trying to get to Father Christmas's house.

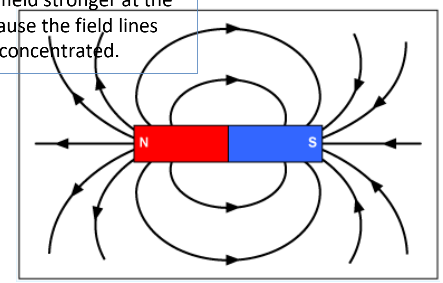
Key Terms	Definitions
Permanent magnet	A magnet that always has its own magnetic field. Attracts magnetic materials, and can attract or repel other magnets.
Induced magnet	A temporary magnet: make one by putting a suitable material in a magnetic field.
Poles	The ends of a magnet. Named north and south, based on which way on Earth they'd point if suspended freely. The other name is 'north seeking' or 'south seeking' as a result.
Magnetic field	The region around a magnet where a force acts on other magnets or on magnetic materials. (3D, unlike diagrams usually show)
Magnetic compass	A small bar magnet balanced on a pin so it can spin around. Points towards Earth's magnetic north due to Earth's magnetic field, but can also be used to find the direction of a magnetic field for another magnet.

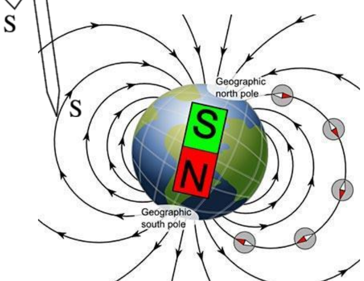
Permanent magnet



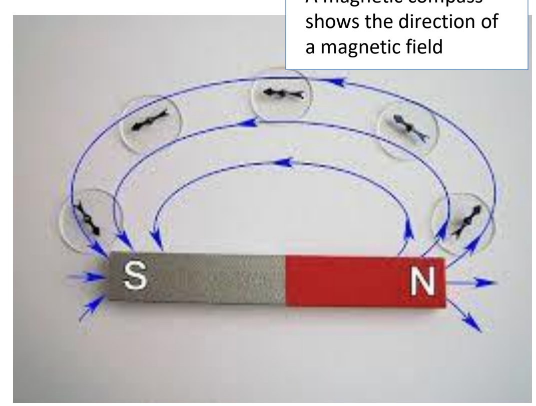
Induced magnets

Magnetic field stronger at the poles because the field lines are more concentrated.





A magnetic compass shows the direction of a magnetic field



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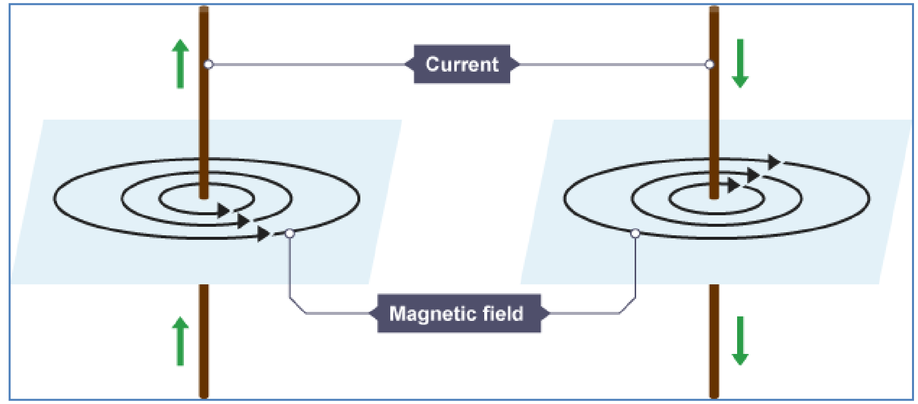
Key Terms	Definitions
Current	The rate of flow of charges in a circuit. If a current is flowing in a component, charges (e.g. electrons) are flowing through it.
Solenoid	A coil of wire.
Iron core	A piece of iron placed in the middle of a solenoid.
Electromagnet	A coil of wire with an iron core

Electromagnetism – current and magnetic fields

A wire that is carrying a current has a magnetic field around it. No current means no magnetic field, but switch it on and you get a magnetic field. As the diagram shows, switching the direction of the current switches the direction of the magnetic field. Also notice that the magnetic field gets stronger as you get closer to the wire carrying the current – this is shown by the field lines getting closer together (more concentrated).



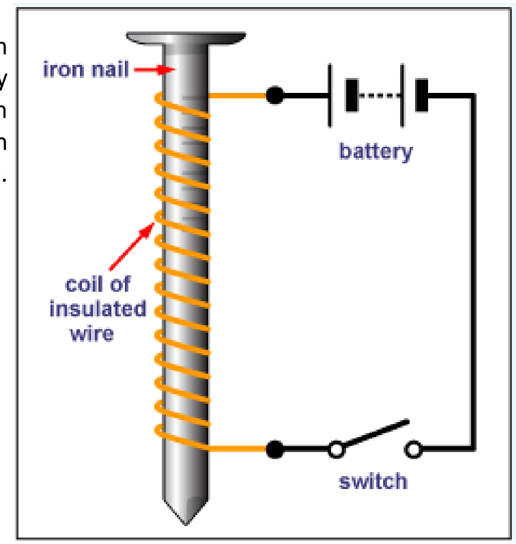
Not surprisingly, increasing the current increases the strength of the magnetic field. You can easily check the *direction* of the magnetic field with a magnetic compass, just like with bar magnets. We can dramatically increase the strength of the magnetic field by winding the current-carrying wire into a coil called a **solenoid**. Even with the same size current, the magnetic field is stronger in a solenoid. Once you've made a solenoid, notice that the magnetic field is very similar in shape to the magnetic field of a bar magnet – it has a north and south pole, and it strongest at the poles. The magnetic field is also strong *inside* the coil – as the concentrated field lines show.

We can increase the strength of the magnetic field even further by putting a magnetic (e.g. iron) **core** in the solenoid – literally a cylinder of iron. We call this an **electromagnet**. (see diagram)

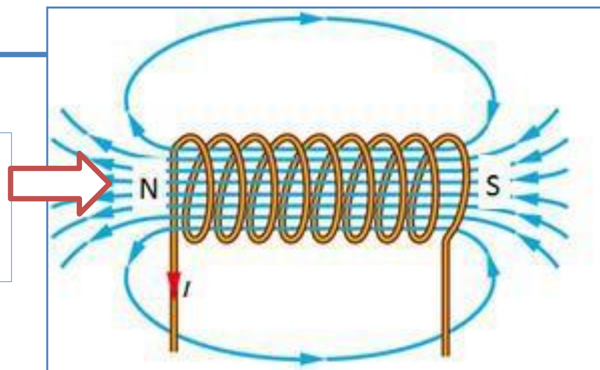
You can make an electromagnet **stronger** by:

- Increasing the **current** in the wire (probably by increasing the potential difference of the power supply)
- Increasing the **length** of wire in the solenoid – perhaps by adding more turns to the coil of wire.

In school, an iron nail is an easy choice for the iron core of an electromagnet.



A north pole, since another north pole brought to this end would be repelled.



Solenoid

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Fleming's left hand rule and the motor effect

If you have a current-carrying wire and a permanent magnet, each have their own magnetic fields. This means that if you put them near each other, there'll be a force acting on each other – just thanks to magnetic attraction or repulsion. This is called the **motor effect**. You can work out the direction that the force acts if you know the direction of the magnetic field and the direction of the current – we use **Fleming's left hand rule**. It has to be your left had to work. Hold it as shown, and you can work out the direction of whichever thing you don't know. You have to think in three dimensions here. You can twist your hand at the wrist to get it right – confirm using the example of the wire cutting through the magnetic field in the diagram – field from N to S with first finger, current with middle finger pointing downwards, meaning force must be out of the page towards you, like the diagram shows.

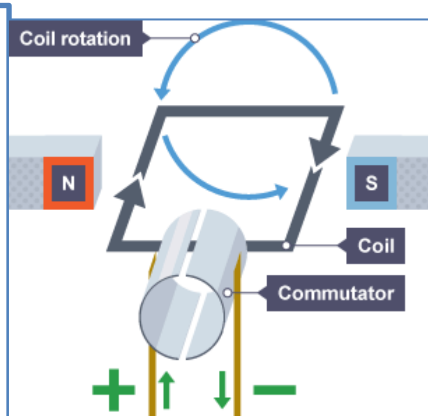
Now, the size (or *magnitude*) of the force on the conductor (the bit of wire) depends on three factors:

1. The **length** of the wire in the magnetic field, measured in metres
2. The **strength** of the magnetic field (formally, the **magnetic flux density**, in teslas, T)
3. The **size** of the **current** (A, as usual).

As the equation shows, increasing any or all of these factors will increase the size of the force on the conductor. [NB this equation only applies when the current and magnetic field are at right angles to each other]

Electric motors

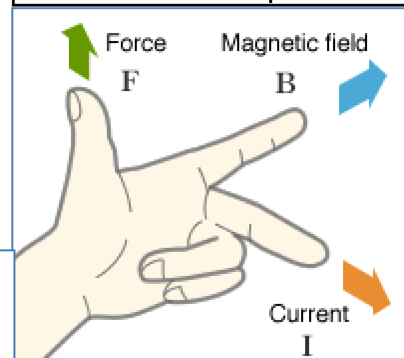
Electric motors make use of the motor effect. A coil of wire carrying a current is placed in a magnetic field; as you know, the magnetic fields interact to cause a force each other. If the coil is set up so it can spin, it most certainly will. In fact, it will spin round and round (**rotate**). This is thanks to the force acting **up** on one side of the coil, and **down** on the other – see the diagram and use Fleming's left hand rule to understand why…



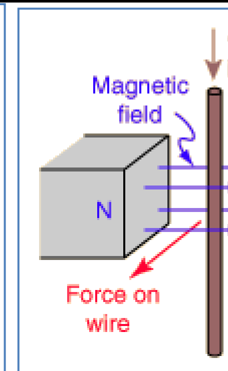
The magnetic field goes from N to S of course, and the arrows on the coil show the direction of the current. So, the left side of the coil has a force **downwards** exerted on it (use the left hand rule). The right side of the coil has a force **upwards** exerted on it, so it rotates as shown. (NB the commutator just allows the coil to spin without the wires getting tangled up!)

Key Terms	Definitions
Motor effect	The forces exerted on each other by a wire carrying a current and a magnetic field, thanks to the two magnetic fields interacting.
Magnetic flux density	A measure of the strength of a magnetic field – think of it as the number of magnetic field lines going through a set area – see diagram to help explain.
Electric motor	Device that causes rotation of a coil of wire carrying a current when it is placed in a magnetic field.

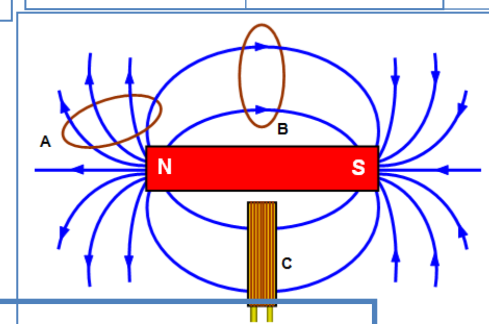
Equation	Meanings of terms in equation
$F = B\,I\,l$	*F = force (newtons, N)* *B = magnetic flux density (tesla, T)* *I = current (amps, A)* *l = length (m)*



Fleming's left hand rule. FBI – easy to remember!



The direction of each quantity fits with the left hand rule



Magnetic flux density is larger at A than B since more magnetic field lines cut through a given area (shown by the oval).

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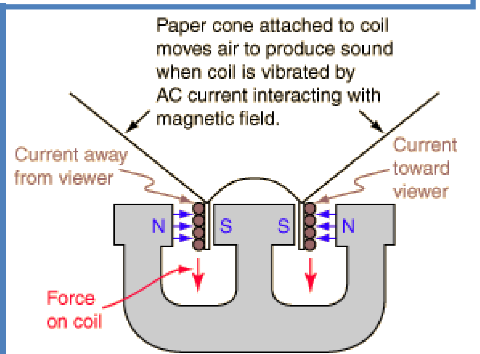
Loudspeakers and microphones

The motor effect is also put to good use in loudspeakers and headphones. They have a ‘moving coil’ which moves in a magnetic field according to the current running through the coil. This moving coil is connected to a cone that moves with it. The cone causes vibrations in the air around it – in other words, it causes sound waves. Microphones do the exact opposite: sound waves (pressure variations) cause the cone the move, which causes a changing current in the coil.

Study the diagram. Just like in a motor, a force is produced on the coil of wire by placing it in a magnetic field (that’s a permanent magnet at the bottom) and turning on the current. As the current alternates in direction (i.e. AC is used), and the size of the current is varied, the coil moves back and forth. As you can see, the coil is joined to a cone, which moves with it. The cone vibrates the air according to the current, then. The current transfers the information about the sound being played.



Key Terms	Definitions
Moving coil	Describes a loudspeaker that involves a coil of wire moving in a magnetic field, to vibrate a cone and produce sound waves.
Induce	To cause something to happen.
AC	Alternating potential difference – the direction of the current switches back and forth.
Cone	Literally a cone-shaped piece of material found in loudspeakers. They vibrate, causing pressure changes in the air – i.e. sound waves.
Induced potential	A potential difference caused by either: a) moving a coil in a magnetic field, or b) changing the magnetic field around a coil.
Generator effect	Using the interaction between a magnetic field and a conductor to generate electric current.

Induced potential and the generator effect

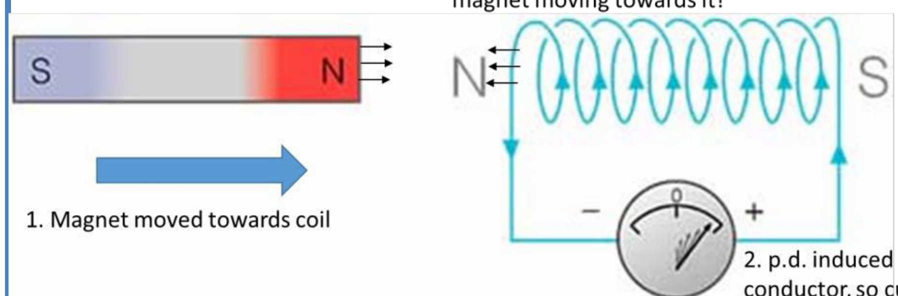
You can switch the motor effect around – instead of using interacting magnetic fields to produce movements, you can use movements to produce a current in a wire. Here’s how it works:

1. Place a conductor (e.g. coil of wire/solenoid) in a magnetic field and move it around (e.g. rotate the coil)
2. OR keep the coil still but change the magnetic field (e.g. flip N and S back and forth)
3. Either of these **induces** a potential difference across the ends of the conductor
4. Assuming your conductor is part of a complete circuit, a current starts to flow in the conductor thanks to this potential difference.

This is called the GENERATOR EFFECT, because the method is used to generate electricity. It is also known as electromagnetic induction.

Now, importantly, the current in the conductor produces a magnetic field, as always. But the direction of the magnetic field acts to oppose the change, the ‘change’ being the original 1 or 2 from the steps above. This is shown in the diagram right.

3. Current flows such that the magnetic field **opposes** the change – it repels the magnet moving towards it!



1. Magnet moved towards coil

2. p.d. induced across conductor, so current flows…

Factors affecting induced potentials

The size of the induced potential in the generator effect depends on:

- The size/strength of the magnetic field (larger magnetic field → larger induced potential)
- The number of turns on the solenoid (more turns → larger induced potential)
- The speed of movements/changes to magnetic fields (faster → larger induced potential)

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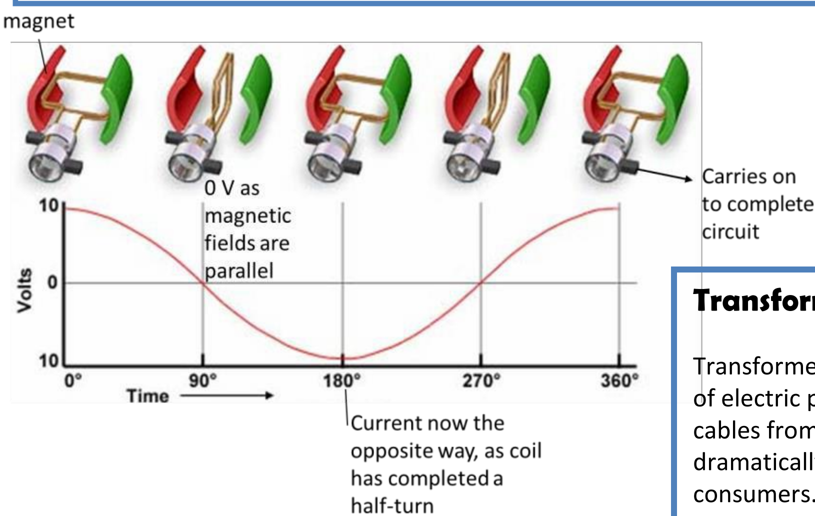
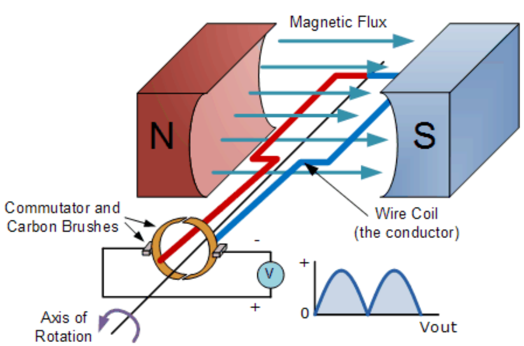
Using the generator effect

Depending on the set-up, you can use the generator effect to generate ac or dc.

- ac is generated in an alternator. In this set-up, each end of the coil of wire spin inside, and make contact with, a complete loop of conductor that's connected to the rest of the circuit. Since every 180° of turn of the coil the current flips direction (just like the left hand rule tells us), you get ac. This is shown on the diagram below, with a graph showing alternating potential difference.
- dc is generated in a dynamo. To prevent the current flipping direction every half-turn, a clever **commutator** is used. This ensures the current is restricted to one direction only in the coil – i.e. direct potential difference. See second diagram and graph.



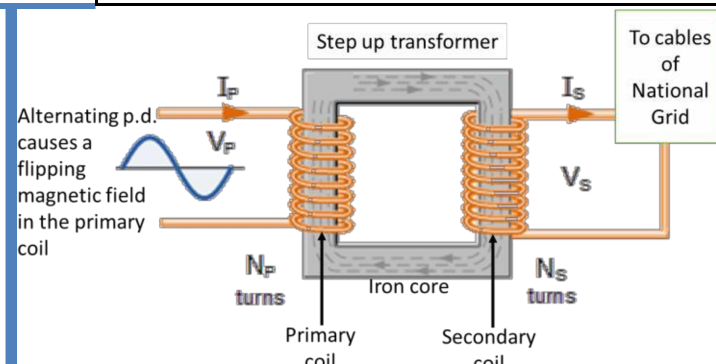


Key Terms	Definitions
National Grid	A system of cables and transformers linking power stations to consumers of electricity. The National Grid is used to transfer electrical power from the power stations to users.
Commutator	Device used in dynamo, made of two half-rings of conductor, not quite joined up to each other. Keeps the current flowing one way only.
Step-up transformer	Device that increases potential difference in an electric supply, using more turns on the secondary coil than the primary coil. Step-down transformers do the opposite.

Equation	Meanings of terms in equation
$\frac{V_P}{V_s} = \frac{N_P}{N_s}$	V_p = *potential difference across primary coil* (V) V_s = *potential difference across secondary coil* (V) N_p = *number of turns on primary coil* N_s = *number of turns on secondary coil*
$V_p \times I_p = V_s \times I_s$	V_p = *potential difference across primary coil* (V) V_s = *potential difference across secondary coil* (V) I_p = *current in primary coil* (A) I_s = *current in secondary coil* (A)

Transformers

Transformers exist to firstly, massively increase the p.d. of electric power to transmit it efficiently through cables from power stations, then, secondly, to dramatically decrease it again for safe use by consumers. They work using the second sort of generator effect – a changing magnetic field inducing a p.d. in a conductor nearby. Transformers are made of two coils of wire, wrapped around each end of a square-shaped iron core. Iron is used because it is easily magnetised. An alternating current in the primary coil causes a magnetic field in this coil, that constantly changes direction. This in turn induces a changing magnetic field in the iron core, which then induces a changing magnetic field (and therefore current) in the secondary coil.



Transformer equations

In transformers, the ratio of the potential differences across the coils is equal to the ratio of the number of turns on each coil. This is shown in the first equation.

Assuming transformers are 100% efficient, the power input is equal to the power output. This leads to the second equation (since $P = IV$).