Learning resource

Apply electromagnetic theory to a range of problems
(level 2, credits 5)

Trainee Name: ____________________

skills.

Contents

Part 1: Magnetism and Electromagnetism

It is believed that Asian shepherds discovered dark-coloured stones with mysterious properties around 5000 – 6000 years ago.

About 1200AD these mysterious stones were used for navigation because of their ability to align themselves to point in a North-South direction when suspended (one end always pointing north).

This navigation by crude compass gave rise to the name lodestone (=way stone). Lodestone is a naturally occurring mild magnet.

You may be forgiven for wondering why we are talking about magnets in an electrical resource. Aside from navigation, magnets have another extremely important property, incredibly, they can cause current to flow in a conductor.

By simply moving a magnetic field across a conductor causes an Electro Motive Force (EMF) to be induced into the conductor. If that conductor is connected in a circuit, the induced EMF will cause electrical current to flow. Magnetism is the key to the production of most of the world's electricity needs today.

Magnets and magnetism are used in very many ways in the electrical industry and they are critically important in the modern electrical age.

You will need to understand about magnets and magnetism and how you will put them to use.

The language of magnets

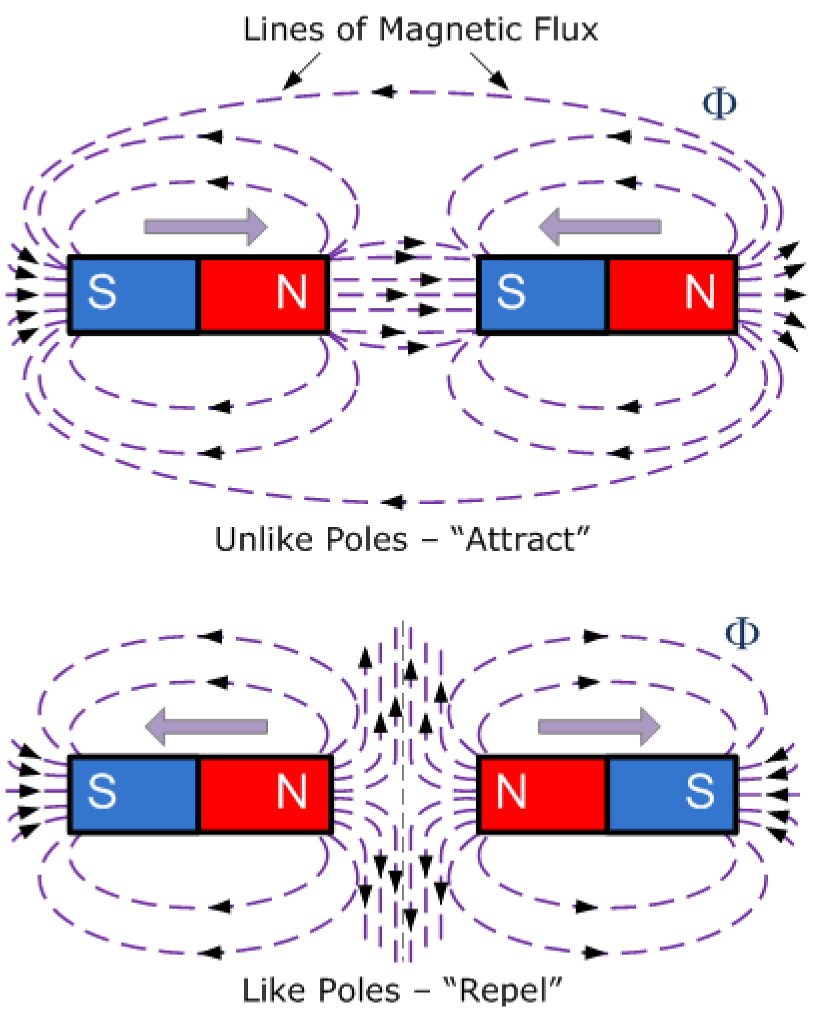
As with any technical subject, magnets and magnetism have terms and jargon you will need to understand.

Electromagnet

An electromagnet is a magnet that gets its magnetism from a coil of wire with an electrical current flowing through it. Generally, when the current is turned off, an electromagnet will lose its magnetism.

We will look at electromagnets in more detail later in this resource.

The following illustration below represents the magnetic field that exists around a bar magnet:



Magnetic field strength

The magnetic field strength is the overall strength of a magnet, how “powerful” the magnetic field is.

Magnetic field

A magnetic field is the area around a magnet where the magnet experiences a force, the field is made up of magnetic flux.

Magnetic flux

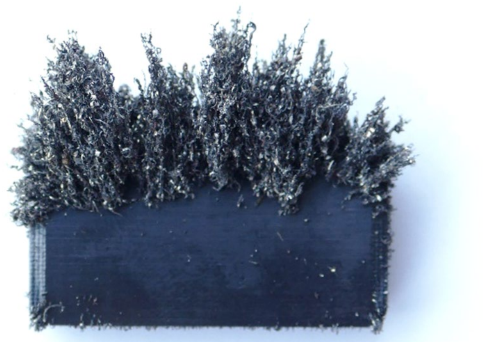
For lack of a better explanation, if you could see the magnetism around a magnet it would be like a glow around the magnet, glowing brightly close to the magnet and growing weaker the further away from the magnet you look. The magnetic flux makes up the magnetic field.

Magnetic flux is measured in Webers (Wb), and has the symbol Φ.

Lines of force

Sometimes referred to as lines of flux. The magnetic flux that surrounds a magnet is pretty difficult to draw, so we use “lines of force” to represent a magnetic field and its direction.

The lines of force have a “direction” and by convention are drawn leaving the north pole and entering the south pole.



Iron swarf lining up with magnetic flux

Properties of lines of force:

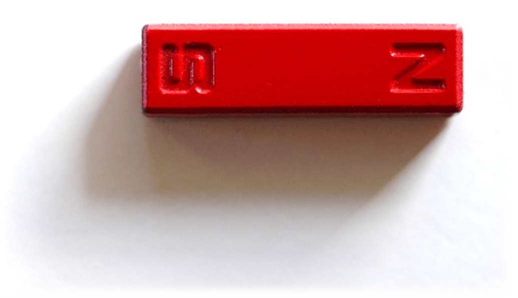
- They never cross;
- They always take the path of least reluctance;
- They always try to shorten; and
- They exit from the North Pole and re-enter through the South Pole.

Reluctance

Opposition to magnetic lines of flux.

Magnetic poles

The magnetic poles are the faces of the magnet where the lines of force leave and enter. There is a north and a south pole face.



- "Like" magnetic poles repel:

If you have ever played with two magnets, you will be aware that if you try and push the two north poles together the magnet will resist you more and more as the magnets get closer to each other. The same happens if you try to push two south poles together.

- Opposite magnetic poles attract:

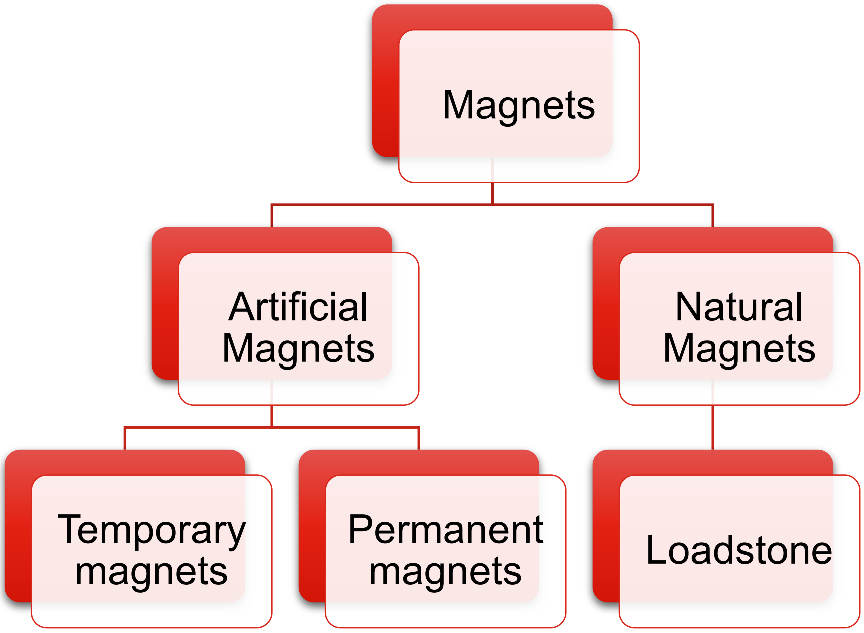
If you get those same magnets and put the north and south poles together, you will have trouble keeping them apart. They will snap together and if they are strong magnets like neodymium rare earth magnets you may be hurting if they caught your skin between them!

Flux density

Flux density is the amount of magnetic lines of force in a specific area of a magnetic field. The denser - the stronger the magnetic field.

For example, you might be designing a magnetic relay and need to work out if your electromagnet has enough "pull" to operate the armature from the distance between the two. You would be interested in the magnetic flux density of the magnet at the place where the armature is located.

Flux density (B) is measured in Webers per square metre (Wb/m2) or tesla (T).



Permanent Magnet

A permanent magnet is a magnet that stays magnetised after the magnetising force has been removed.

Permanent magnets require a great deal more energy to demagnetise them than their temporary counterparts. Permanent magnets are generally constructed from “magnetically hard” material.

Permanent magnets are used in: Compasses, motors, generators, tachometers, cupboard door latches, magnetic tools, separators, control devices, magnetic bearings, sheet floaters, speakers, moving-coil instruments, water treatment, magnetrons, televisions, metallurgy, lifting hot steel and probably quite a few other applications.

Temporary Magnets

Temporary magnets have a magnetic core manufactured out of “magnetically soft” materials such as soft iron, cast iron or Stalloy (a special soft iron alloy). They are easily magnetised but retain very little magnetism once the magnetising force is removed.

Useful temporary magnets are usually constructed as electromagnets, like a magnetic door locking mechanism for example - and the “temporary” bit is useful.

It would be a problem if you swipe your access card and the power to the magnetic door lock turns off, but the magnet stays magnetised! You would be late for work, lol.

A temporary magnet that loses its magnetism will allow the door to open when the magnetising power turns off.

Residual magnetism

Residual magnetism is the magnetism that remains when the magnetizing force is removed

Electromagnetism

We mentioned earlier that moving a magnetic field across a conductor causes an EMF in the conductor that will, in turn, cause current to flow in the conductor, that's pretty cool! We will look at that in more detail later.

Another cool thing (sort of the opposite side to above) is that current flowing in a conductor creates a magnetic field around the conductor!

- Magnetism moving across a conductor creates (EMF and then) current in the conductor.
- Current in the conductor creates a magnetic field.

The magnetic field around a current carrying conductor is shown as concentric circles of lines of force. The magnetic field has a direction and it is important to be able to work out that direction if you want to put the magnetism to use.

> The direction of the lines of force around a current carrying conductor depends on the direction of current flow in the conductor

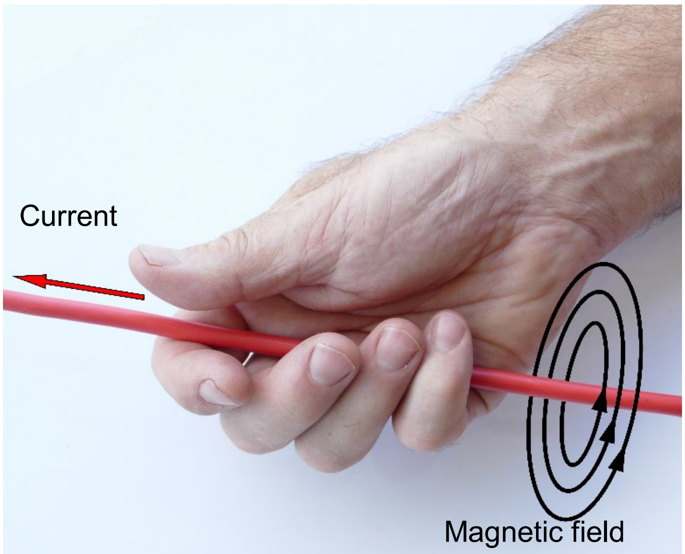
Right Hand Grasp Rule

When looking at the end of a conductor, if current flows away from view, the lines of force are in a clockwise direction, and if current is flowing towards your view, the lines of force are in an anticlockwise direction.

> The direction of the magnetic field can be found using the right hand grasp rule.

This rule can help you determine the direction of a magnetic field around a current carrying conductor.

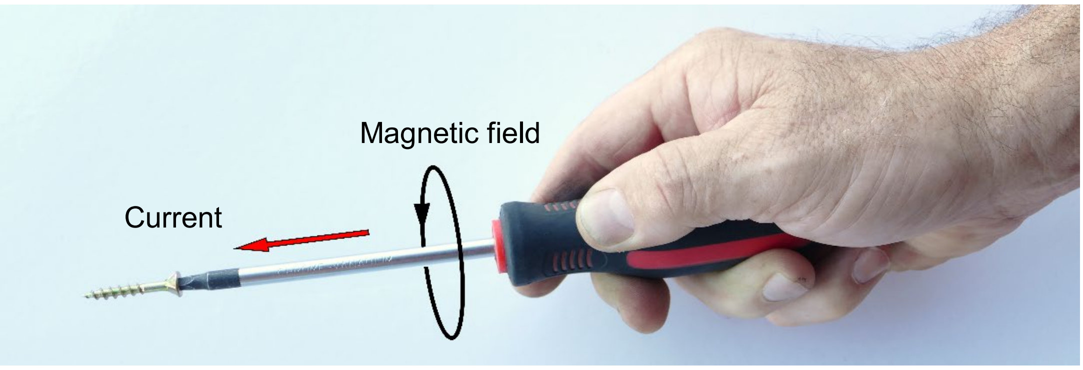
Simply hold the conductor in the right hand with your thumb pointing in the direction of conventional current flow. The direction that the fingers are pointing is the direction of the field produced.



The Right-Hand Screw Rule

Another way of working out the direction of a magnetic field around a current carrying conductor is, imagine a screwdriver being used to turn in a common right-hand screw.

The screwdriver is turned clockwise (in the direction of the fingers), this represents the direction of the magnetic field and the screw will move away from the user representing the direction of current.



If the direction the screw moves represents the direction of current flow in a conductor then the direction which the screwdriver is rotated represents the direction of the magnetic field around the conductor.

Electromagnets

Electromagnets are used extensively in the electrical industry and in the world in general.

A very strong magnet can be created by wrapping a coil of fine insulated wire around a “soft magnetic” metallic core such as iron.

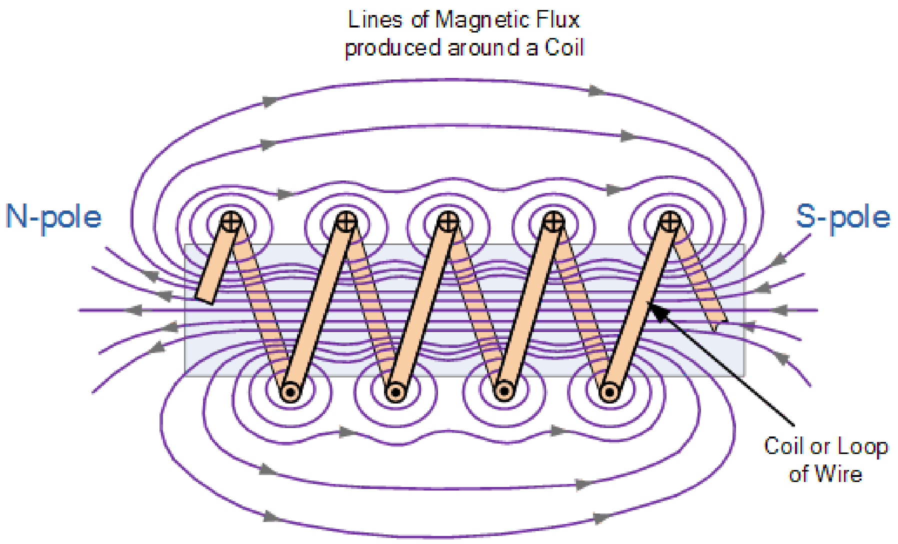
A magnetic core is used because it greatly increases the power of the electromagnet by “focussing” the magnetic flux through the iron rather than spreading out in the air around the coil. An iron core also has 1000 times less reluctance than the air so it is like a super highway for the magnetism.

Current flowing in the wire creates magnetism which in turn magnetises the iron core.

When the wire is formed into a coil, it is like a magnifier for magnetism. The same circuit current goes round and round the core multiple times, each time producing another “ring” of magnetism.

Also, when two conductors are adjacent to each other and carry current in the same direction, their magnetic fields combine to form a stronger magnetic field.

If an electromagnet is viewed in cross section as in the picture below, it can be seen that the magnetic fields around individual conductors combine to form a very strong magnetic field.



The strength of this field depends on the number of turns in the electromagnet and the amount of current flowing in it.

The magnetising force in an electromagnet is measured in Ampere-turns and this is the product of the current times the number of turns.

The beauty of an electromagnet is that it can very simply be turned on and off and they are used in lots of equipment like solenoids, relays and contactors, lifting magnets for scrap iron, speakers, school bells, or any application which requires a magnet which can be switched on and off.

Solenoid

A solenoid has an insulated winding around a core, an armature or plunger depending on the application, and a spring (sometimes gravity is used instead of a spring).

When electric current flows through the winding, a magnetic field is created in the core. The core then attracts the armature/plunger against spring tension or gravity.

When the current flow is removed, the core loses its magnetism and the spring/ gravity, pulls the armature back. A solenoid produces linear movement which can be used to operate fluid valves, door locks, etc.

Relay / contactor

A relay has an electromagnet that, when an EMF is applied to the relay coil, it attracts a lever or electrical contact.

When the lever moves, the contact switches from one state to the other (such as normally open to normally closed).

When the coil is de-energised again, the sprung contact returns back to its original position and so, the contact changes position and state whenever the EMF is applied or removed from the coil.

Relays and contactors are used to switch high current and or high voltage circuits using low current / voltage controls.

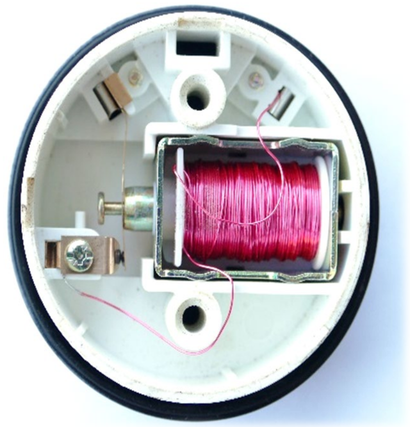
Electric bell

An electric bell, like a school bell, uses an electromagnet to pull the "hammer" of the bell towards the bell creating the first ring sound.

As this happens, a contact in the circuit supplying the electromagnet is broken, the electromagnet demagnetises, and a spring pulls the hammer back to its resting place.

When this happens, the contact re-closes, the supply circuit is complete again and so the electromagnet pulls the hammer to hit the bell again. As it does, the contact opens again.

This rapidly repeating cycle will continue as long as EMF is supplied to the circuit, and the bell will continue to ring rapidly over and over until the supply to the bell is switched off.

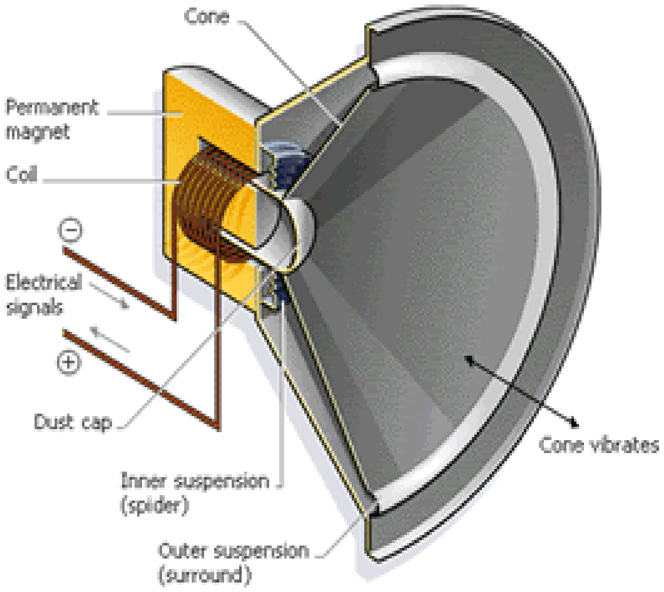


Loudspeaker

A speaker operates by having a coil of wire wrapped around a tubular core that is attached to the speaker cone. This coil sits inside a circular permanent magnet.

When a changing EMF (audio signal) is applied to the coil the generated magnetic field created around the coil repels and attracts itself to the permanent magnet in time with the varying audio signal.

This causes the speaker cone to move, pumping backwards and forwards in time with the audio signal creating soundwaves that travel through the air and into our ears which we receive as audible sounds.



Magnet pulled off a speaker showing the circular slot in the magnet

Lifting magnet

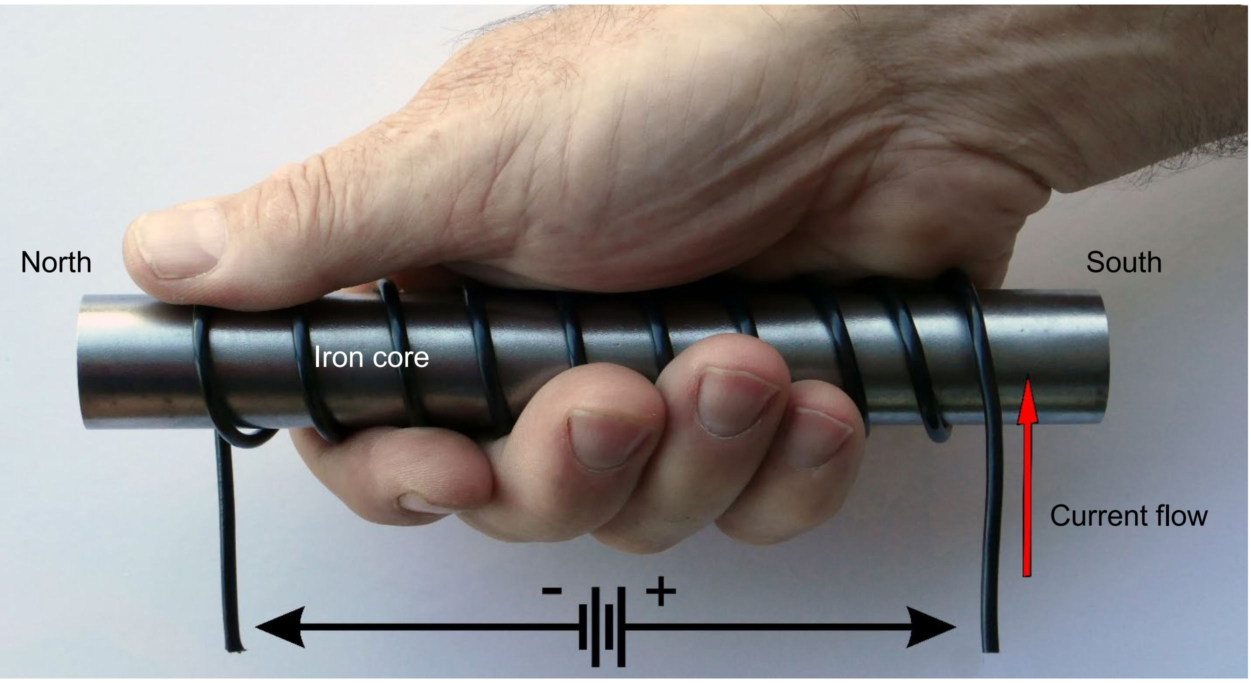
Lifting magnets are giant electromagnets, constructed with very large coils wrapped around an iron core. These magnets are usually suspended from heavy machines which move metal around.

The magnet is supplied with large currents that flow through the coils and create a large magnetic field enabling lifting of heavy items such as cars / scrap metal etc. The magnet can be switched on and off the pick up metal and then drop it again.

The Right-Hand Grasp/Grip Rule

In your studies you will need to be able to identify the “polarity” (the way round the poles are) of an electromagnet, i.e. which end is north and which end is south. It would be a pity if your electromagnet repelled when it should attract!

To work out which end of an electromagnet is north, either imagine or actually grasp the coil with your right hand, holding it so that your fingers twist in the direction of the current flow around the coil. Your thumb will be pointing to the north pole end of the electromagnet, amazing!



Transformers and transformer action

Transformers are amazing! We will cover them in more depth in another resource, but for the moment you need to have an idea of how they work – they use the two principles we pointed out earlier:

- Current in a conductor creates a magnetic field around the conductor.
- Magnetism moving across a conductor creates (EMF and then) current in the conductor.

If we told you transformers send electricity across the air and space, from one conductor to a completely separate one that is not connected to it at all, would you believe it? You should, they do!

Does your phone charge wirelessly? Well there you go you see! Transformers, induction cook tops and induction kilns use versions of the same transformer principles which we will discuss briefly here.

There are three conditions needed for magnetic induction:

1. A magnetic field.
2. A conductor.
3. Relative motion between the two.

Firstly, to understand a transformer you need to know that a simple transformer has at least two coils of conductor close together, but not electrically connected. They are wrapped around a soft iron magnetic core which passes the magnetic flux between the coils.

Next you need to remember that the magnetism around a conductor is proportional to the current. And that AC current “pulses” up and down so the magnetism around a conductor carrying AC also “pulses” up and down.

The first (primary) coil is supplied with AC and as a result, has a pulsating magnetic field around it. This pulsating magnetic field cuts across the magnetic core and induces a pulsating magnetic flux into the core.

As the pulsating magnetism in the core passes through the second (secondary) coil it induces an EMF into the secondary coil without being connected to it! Wow! That principle is called mutual induction.

As the AC supply current changes direction every cycle, so the magnetic flux also changes direction with every cycle of the AC supply. The result is that the EMF induced into the secondary coil follows the same pattern and is also AC.

Mutual induction

Mutual induction is when the magnetic field around a current carrying conductor cuts through a second separate conductor and induces an emf into the second conductor.

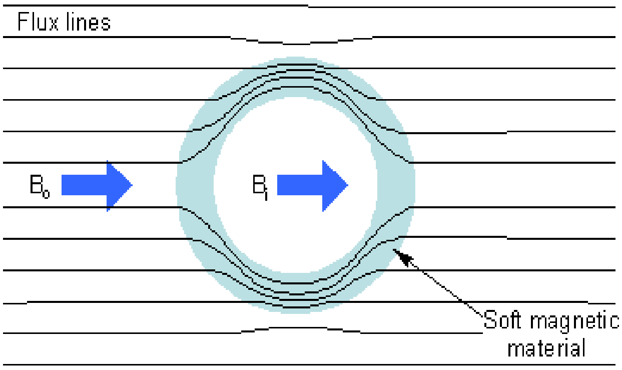
Protection of sensitive meters and circuits

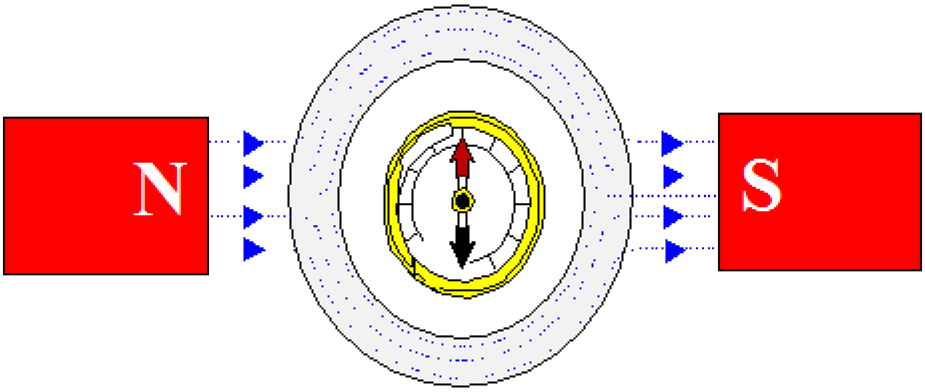
Electrical measuring instruments and sensitive electronic devices can be affected by the magnetic fields set up by electrical equipment such as, transformers and motors and also even by the earth’s magnetic field. In some cases, they need to be shielded from these.

Magnetic Screening

Magnetic screening is a way of achieving protection of sensitive equipment from magnetic fields.

This is done by placing sensitive equipment inside a soft iron ring. The ring forms a magnetic screen around the equipment because it has low reluctance i.e. it is a much easier path for magnetic lines of force than the surrounding air. The ring diverts the magnetic lines of force around the equipment so that it is not affected by the magnetic field.





Screening can also be achieved by placing a steel box around the object that needs to be protected against magnetic interference. The magnetic flux will concentrate in the box rather than travel through the air inside.

Alternatively, if it suits the situation, the source of the magnetism can be placed in a steel box to prevent magnetic flux from escaping in the first place.

If a cable is run through one of the ferrite sleeves (left), the sleeve will absorb the electromagnetic energy emitted by a cable and reduce the magnetic interference the cable causes to electrical/electronic equipment in the immediate area.

Electromagnetic shielding for cables.

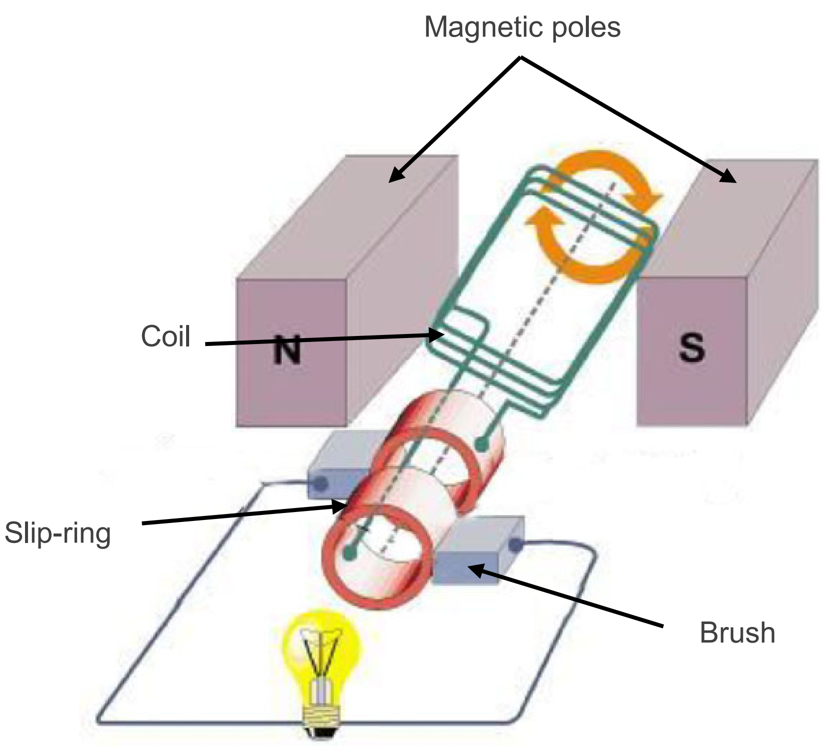
Part 2: AC generation

Generators that produce alternating current are called alternators and are found in many different forms. From the alternators used in most cars, to the large water driven turbines in NZ power stations.

In this assignment we will take a look a simplified alternator which consists of a single loop coil that rotates in a magnetic field produced by a set of permanent magnets.

The Simple Alternator

The figure below shows the construction of a simple alternator.



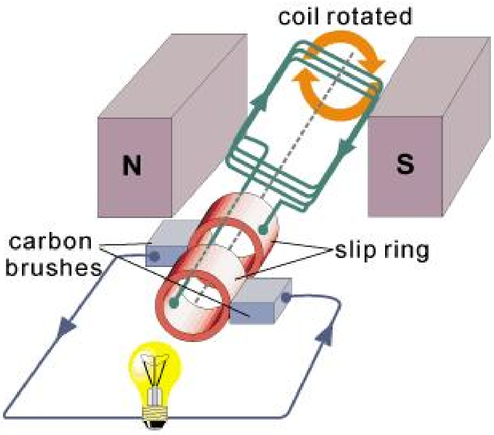
Voltage production

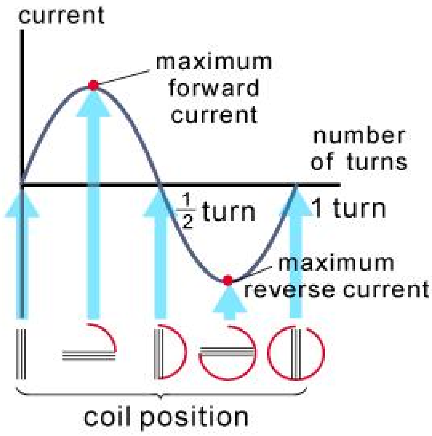
If you remember earlier in this resource, we mentioned that there are three conditions necessary to induce a voltage into a conductor.

1. A magnetic field.
2. A conductor.
3. Relative motion between the two.

Operation of a Simple Alternator

- As long as the loop is stationary, the magnetic field has no effect (because there is no relative motion between the magnetic field and the coil).
- When a rotating force is applied to the coil of an AC generator, it forces the coil through the magnetic field created by the permanent magnets.
- As this is a conductor moving through a magnetic field, this causes an EMF to be mutually induced into the coil.
- The coil connects to the slip rings and, carbon brushes make sliding contact with the slip-rings to provide an electrical connection to the supply leads. This allows the induced EMF to be exported to an external circuit.
- An alternating EMF output is produced in the coil as it rotates in the magnetic field. If you follow just the left-hand side of the coil as it rotates, first it moves upwards through the magnetic field and then it moves downward. The direction the coil travels through the field determines the polarity of the EMF produced which will reverse polarity every half revolution.
- The direction of the emf produced when a conductor cuts across magnetic lines of force can be found by using Fleming's Right Hand Rule.
- The slip rings allow the polarity of the output to the external circuit to alternate during rotation.
- The greatest emf (measured in volts), is induced in the coil as it moves at right angles to the magnetic flux as the conductor is cutting the most magnetic lines of force.
- No emf is induced when it moves parallel to the magnetic flux because the coil is not cutting any magnetic lines of force.
- A single-loop coil rotating in the uniform magnetic field will produce an emf that when graphed, has the shape of a sine wave.

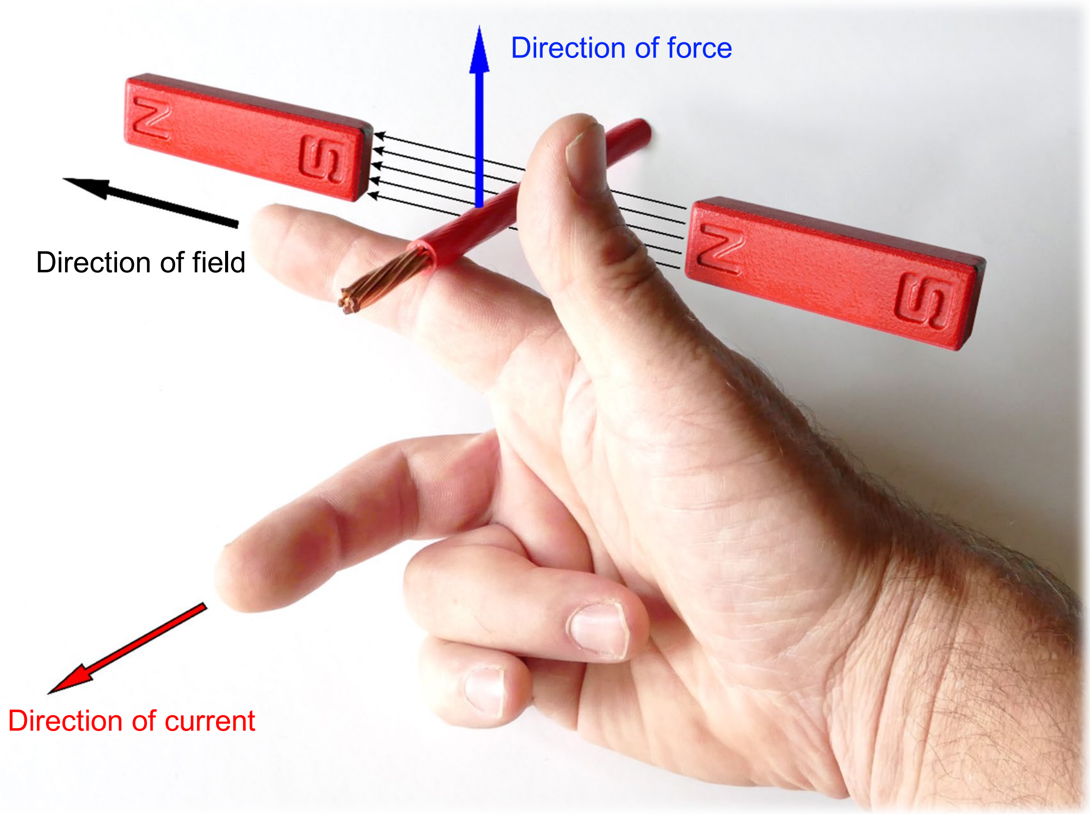




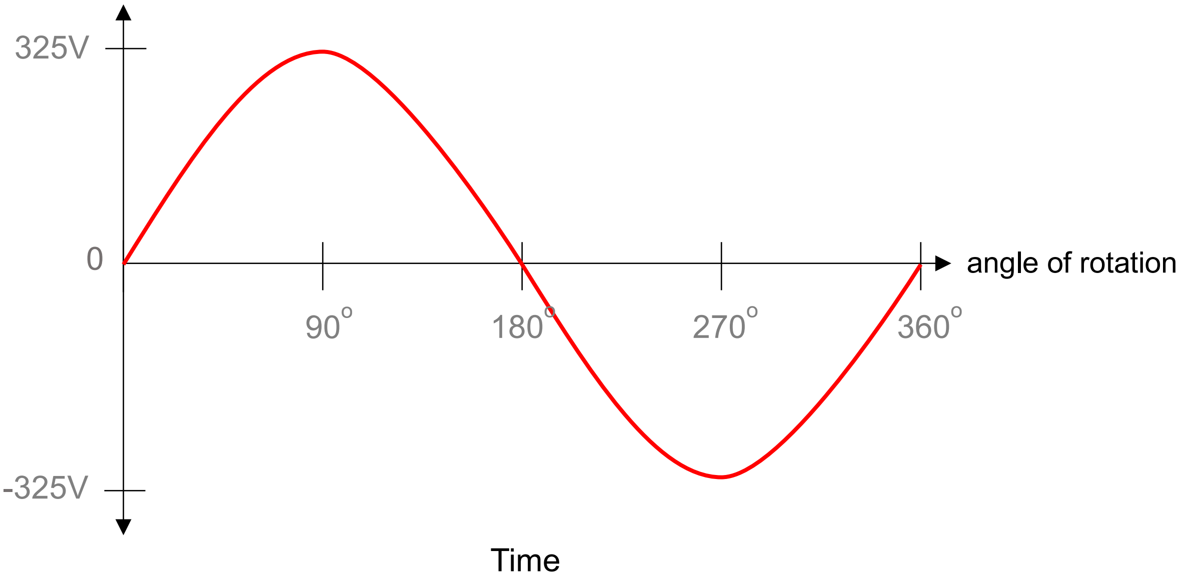
Fleming's Right Hand Rule (for generators) states:

If the first finger, second finger, and thumb of the right hand are held at right angles (90 degrees) to each other, with the **F**irst finger pointing in the direction of the magnetic **F**ield, and the thu**M**b pointing in the direction which the conductor is **M**oving across the magnetic field, then the se**C**ond finger will show the direction of the **C**urrent induced into the conductor.

Note how the highlighted letters **F**, **C** & **M** will help you to remember this rule.



Summary of the output of an AC Generator



Angle of rotation	Description
0°	At the start of the cycle the conductors of the coil are moving with the magnetic field and so, as they are not cutting through the field, there is no voltage induced.
90°	At this point the conductors of the coil are cutting through the magnetic field at 90^0 and so maximum positive voltage is induced into the coil.
180°	The coil continues to rotate towards the halfway point. The induced voltage decreases as the conductors cut through the magnetic field at a smaller angle until at this point, they are moving with the field and so no voltage is induced.
270°	The coil continues to rotate and the conductors cut through the magnetic field at a greater angle until at this point it is cutting through at 90^0 and producing maximum negative voltage.
360°	The coil completes one full revolution with the conductors once again moving with the magnetic field and inducing zero voltage. The cycle is now ready to start again

AC terms

There are some terms and jargon that accompany AC voltage and current sine waves that you will have to understand.

AC Terms	Definition/Description
Average Value	The average of all the instantaneous values of an alternating voltage or current over one-half cycle. It is calculated by 0.637 x peak (max) value. It is important when AC is converted to DC in rectifier circuits.
Cycle	One complete sinewave to the point it is about to repeat.
Frequency	The number of cycles per second. The unit of frequency is Hertz (Hz) and one Hz is one cycle per second. The NZ electricity supply system has a frequency of 50 Hz.
Instantaneous Value	The value produced at any given point of a sine wave, it is calculated by Sin Ø x peak.
Peak Value	The maximum value attained by an alternating quantity during one cycle. There is one "positive" peak and one "negative" peak per cycle.
Period	The time taken to complete one cycle. In the NZ electricity supply system, the period is 1/50 second (= 20 milliseconds).
RMS Value	The root mean square value of the sinewave. It can also be calculated by 0.707 x peak (max) value.

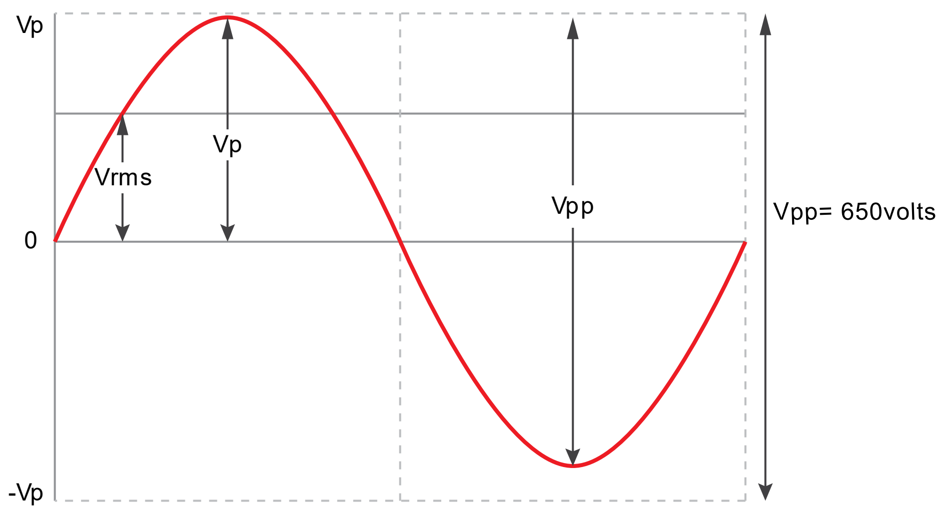


Fig 1

AC formulas

The formulas for working with AC sine waves are as follows.

$f(x)$

Formula

RMS value:

$$RMS = peak \times 0.707$$

Average value:

$$Average = peak \times 0.637$$

Frequency *(Hz) (cycles per second:)*

$$Frequency = \frac{1}{period}$$

Period *(T) (seconds:)*

$$Period = \frac{1}{frequency}$$

Instantaneous value:

$$Instantaneous\ value = \sin \emptyset \times peak$$

When AC voltmeters and ammeters are connected to AC circuits, they indicate a constant value. But these voltages and currents are not constant, they are alternating in the form of a sine wave.

AC instruments are designed so that they automatically calculate and display "Root Mean Square" or "RMS" values of voltage and current.

The RMS value (also called the "effective value") of an AC voltage or current is defined as:

> *The RMS value of a given AC waveform, is the equivalent DC value that would produce the same quantity of heat if both were connected to the same value of resistance for the same period of time.*

When we describe the AC voltage value of New Zealand's domestic supply circuits as 230volts, we actually mean that this voltage has an RMS value of 230volts.

> The RMS value of a sine wave voltage or current is 0.707 times the maximum (or peak) value.

So, it should be noted that if our normal AC supply voltage is 230 volts, then this voltage has a peak value which is higher than 230 volts. In fact, the peak value of a 230 volt RMS supply voltage is.

Example 1.1

Vpeak = Vrms x $\sqrt{2}$

Or

Vrms = $\frac{\mathbf{Vpeak}}{\mathbf{0.707}}$

Vpeak = $\mathbf{230 \times \sqrt{2}}$

Vpeak = 325.3V

Peak = $\frac{\mathbf{RMS}}{\mathbf{0.707}} = \frac{\mathbf{230}}{\mathbf{0.707}}$ *= 325.3V*

This means that AC circuits and equipment which are supplied at 230V RMS are actually subjected to 325 volts when the waveform reaches its peak value each half cycle.

This places more electrical stress on the insulation in the circuit than 230V DC would, and also causes a greater electric shock danger than 230v DC would if a fault occurs.

Example 1.2

A circuit is supplied with an AC voltage which has a peak value of 325volts at a frequency of 50 Hz.

What is the RMS value of this voltage?

V_{RMS} = 0.707 x V_{peak}

= 0.707 x 325 = 230volts

Example 1.3

What is the average value of this voltage?

V_{AV} = 0.637 x V_{peak}

= 0.637 x 325 = 207volts

Example 1.4

What is the time period for one cycle of this voltage?

50Hz = 50 cycles per second

So, period = 1/50 second = 20 milliseconds (time for one cycle)

Example 1.5

What is the frequency of an AC voltage which completes one cycle in 40 milliseconds?

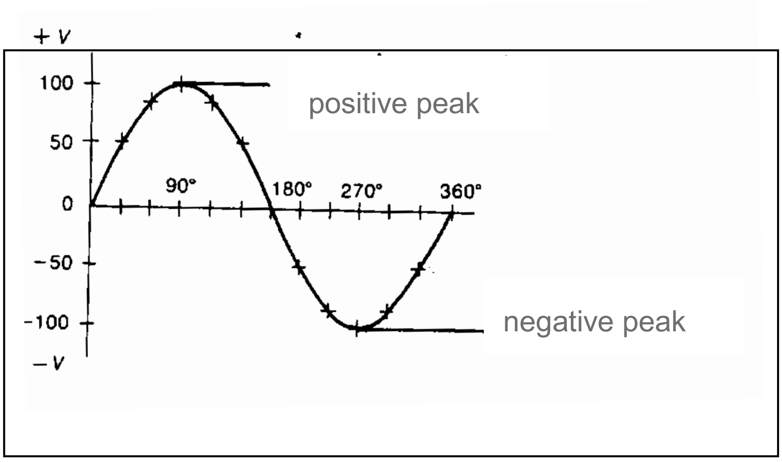
Period = $\frac{1}{frequency}$

F = $\frac{1}{time\ x\ 10^{-3}}$

= 25 Hz

Example 1.6

If an AC voltage waveform has its zero values at 0°, 180°, and 360°, at what angles does it produce its positive and negative peak values?



Values of a sine wave voltage or current

Positive peak value at 90°

Negative peak value at 270°

Example 1.7

A circuit is supplied with AC voltage which has a peak value of 400V at a frequency of 60Hz

What is the RMS value of this voltage?

RMS = 0.707 x Peak

= 0.707 x 400

= 282.8V

Example 1.8

What is the time period for one cycle of this voltage?

60 Hz = 60 cycles per second

So…

Period = $\frac{1}{frequency}$

= $\frac{1}{60}$ seconds

= 0.0166 seconds (time for one cycle)

Example 1.9

What is the frequency of an a.c voltage that completes one cycle in 0.02 seconds?

Period = $\frac{1}{frequency}$

Frequency = $\frac{1}{period}$

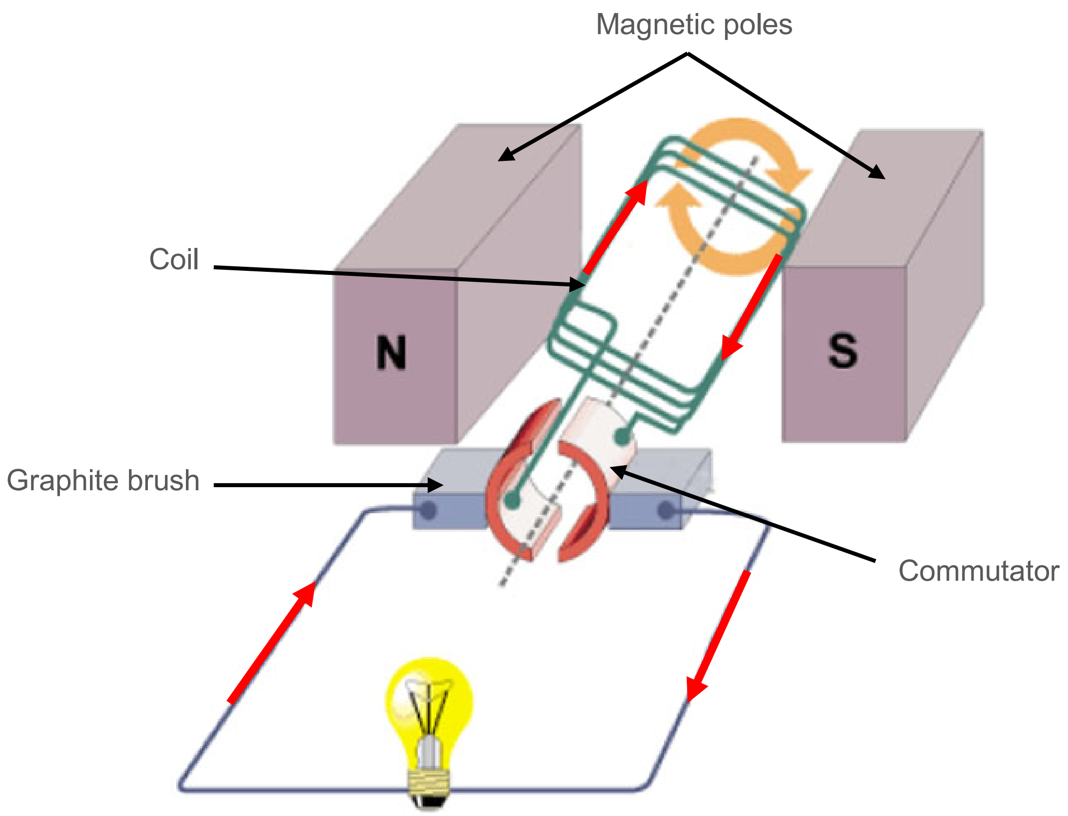
= $\frac{1}{0.02}$

= 50Hz

Part 3: DC generation

The Simple DC Generator

The figure below shows the construction of a simple DC generator.



Commutator

This DC generator operates in exactly the same way as the simple AC alternator above, except for one small alteration, it has a commutator on the output rather than a pair of slip rings.

The same explanation can be used for the production of EMF in the armature coil until, we get to the slip rings on an alternator as the DC generator has a commutator instead.

If you have a look at the design of the commutator in the diagram, instead of the continuous connection of the alternator slip rings, the commutator swaps the connection to the external circuit every 180˚ turn of the armature coil.

If you look at the coil and the commutator in the diagram, you will see that the side of the coil moving down through the magnetism is always the one that connects to the right-hand side of the external circuit. That is the job of the commutator.

The commutator is cleverly designed to keep the polarity of the EMF to the external circuit the same (in the diagram, positive on the right and negative on the left), the polarity no longer swaps every 180˚ like the output of the alternator.

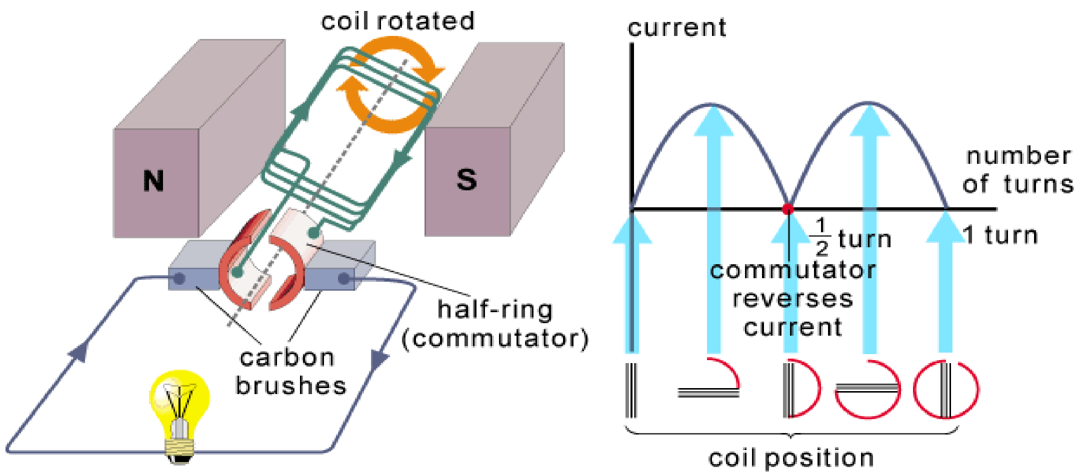
This simplistic DC generator does not give a steady DC voltage as you would expect from a battery. The EMF will still go up and down in voltage level, but it will always be the same polarity.

In a more practical DC generator the loop is formed of many coils connected to a commutator with many segments. This will result in a much smoother DC output.

Theory of Operation

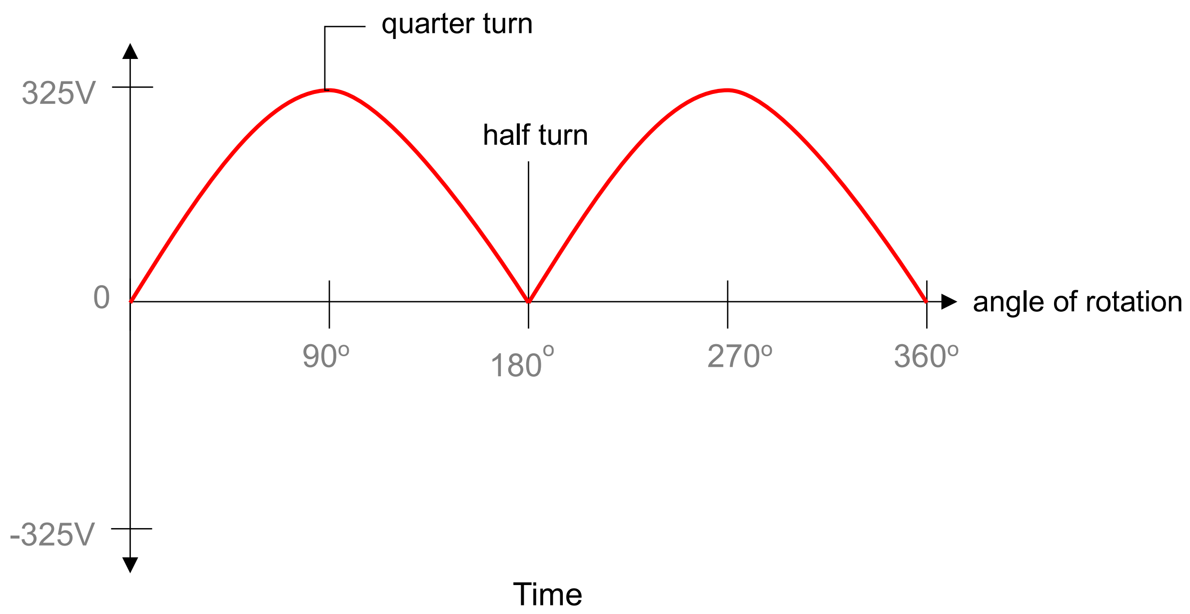
- When a rotating force is applied to the coil, this forces the coil through the magnetic field of the permanent magnets.
- This induces an EMF into the coil which connects to the commutator, brushes and supply leads.
- The commutator is used to keep the polarity of the EMF constant at the output terminals as the coil rotates.

This generator gives us a (ripple) DC voltage and current output.



Looking at the diagram again, you can see the point clearly where the commutator reverses the direction of the current.

Summary of the output of an DC Generator



Angle of rotation	Description
0^0	At the start of the cycle the conductors of the coil are moving with the magnetic field and so, as they are not cutting through the field, there is no voltage induced.
90^0	At this point the conductors of the coil are cutting through the magnetic field at 90^0 and so the first maximum positive voltage is induced into the coil.
180^0	The coil continues to rotate towards the halfway point. The induced voltage decreases as the conductors cut through the magnetic field at a smaller angle until at this point, they are moving with the field and so no voltage is induced.
270^0	At this point the conductors of the coil are cutting through the magnetic field at 90^0 and so the maximum voltage is induced into the coil. The commutator ensures that this second maximum current is also seen by the load as a positive voltage.
360^0	The coil completes one full revolution with the conductors once again moving with the magnetic field and inducing zero voltage. The cycle is now ready to start again.

Part 4: DC motor

We will now have a look at a simple DC motor, but first to help you understand, let's have a look at how current carrying conductors react in a magnetic field.

Current carrying conductor in a magnetic field

As you already know, a conductor that has current flowing in it has a magnetic field around it. It is an electromagnet.

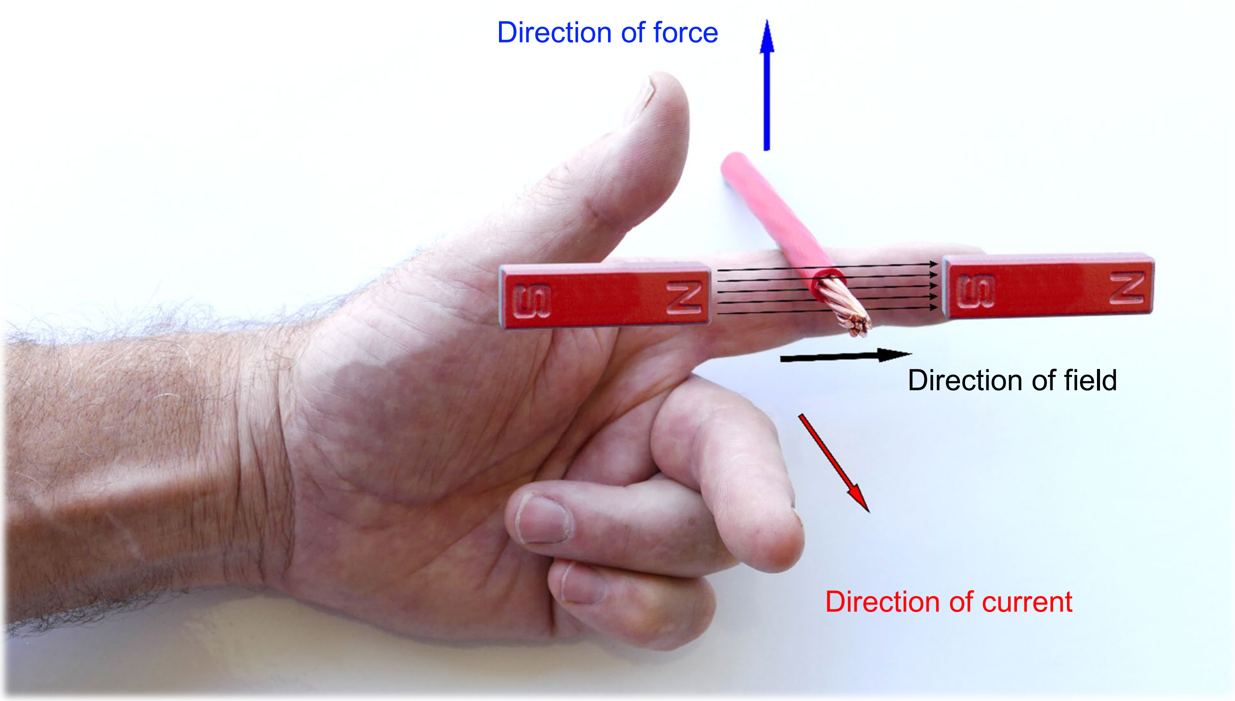
Because the conductor has a circular magnetic field with a direction, it behaves in a slightly different way to a bar magnet.

When the current carrying conductor (electromagnet) is placed into another magnetic field, you now have two magnets that interact with each other (one being circular).

A force is produced between the two magnetic fields and if the second magnetic field is fixed in place, the conductor will be forced to move. The direction it will move can be predicted by using Fleming's Left Hand Rule (for motors).

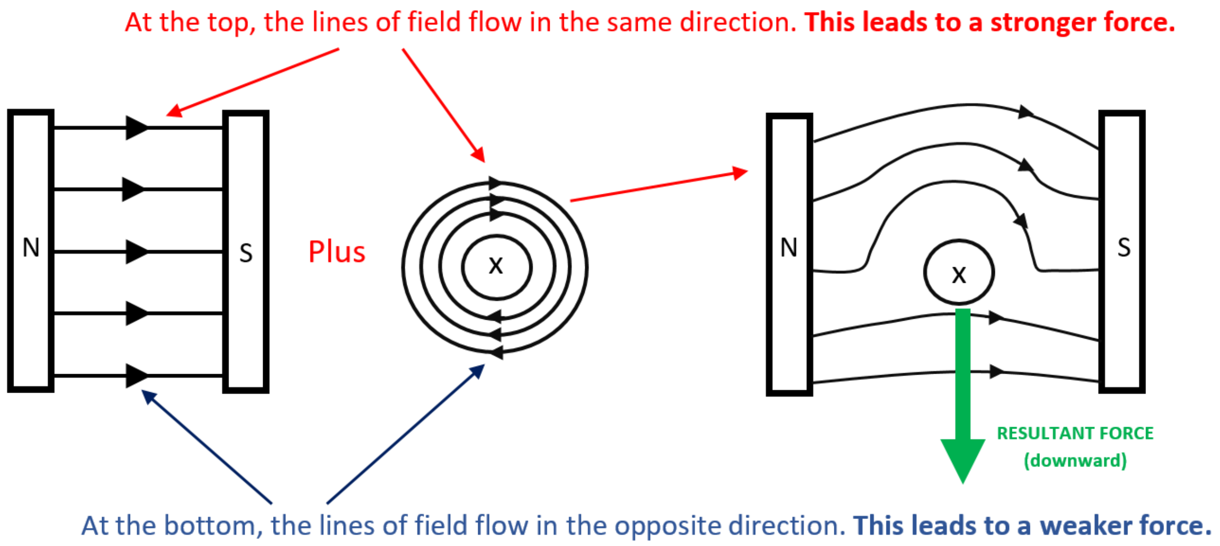
If the first finger, second finger, and thumb of the left hand are held at right angles to each other, with the **F**irst finger pointing in the direction of the magnetic **F**ield, and the se**C**ond finger pointing in the direction of the **C**urrent in the conductor, then the thu**M**b will show the direction in which the conductor will be forced to **M**ove.

Note how the highlighted letters **F**, **C** & **M** will help you to remember this rule.



This is a very useful magnetic principle by which moving coil meters and electric motors operate, and it is so simple!

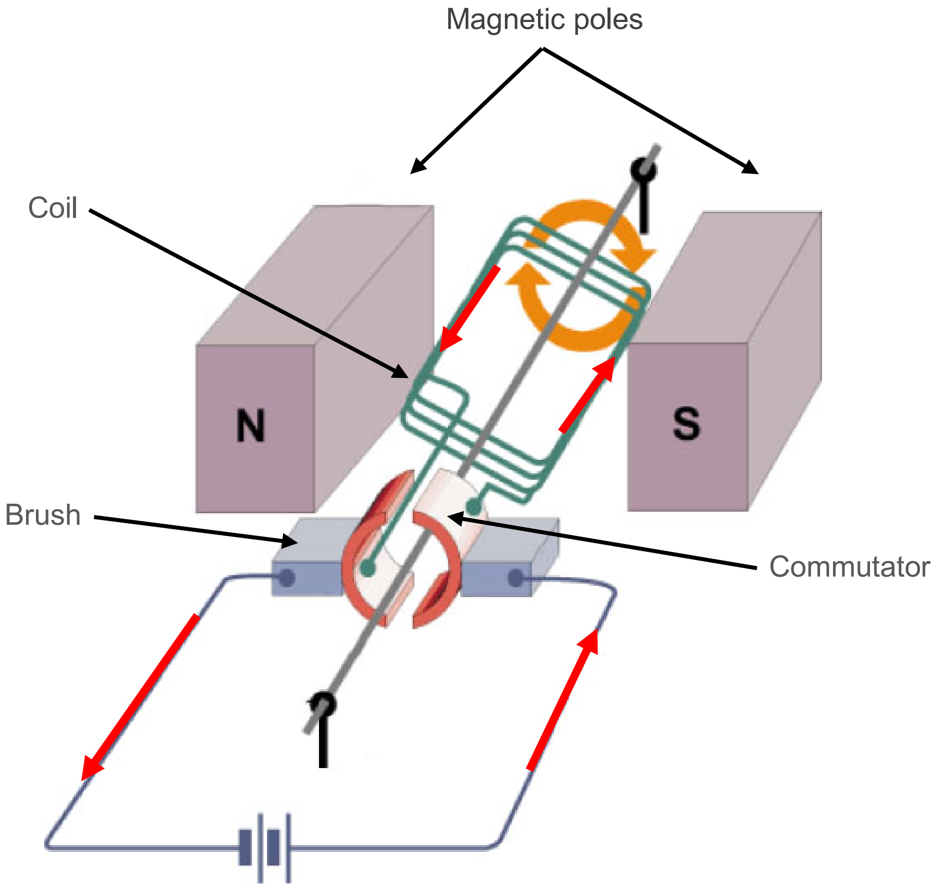
The diagram below indicates how the two magnetic fields interact. The movement of the conductor is caused by a combination of repulsion and attraction.



The diagram shows an adding of magnetism at the top of the conductor and a cancelling of some at the bottom. This combined with the repulsion of magnetic lines of flux of the two magnetic fields when they are in the same direction, and attraction when they are in the opposite directions, as well as the tendency of magnetic lines of flux to want to be as short as possible - all produces the force to move the conductor.

The Simple DC Motor

A simple DC motor as shown in the diagram below looks very similar to the DC generator seen previously.



The difference being, instead of forcing the coil to turn in the magnetic field to produce EMF and current, we are going to feed current into the loop to make it an electromagnet.

The magnetism of the loop will interact with the magnetism of the permanent magnets and causes the coil to turn on its bearings.

Note: pay careful attention to the difference between an DC generator and a DC motor as students often get confused with the difference - the construction is basically the same but the operation is basically the opposite!

A generator is turned - when it is turned produces EMF and current.

A motor is supplied with EMF and current and when it is, it turns.

Theory of Operation

When voltage is applied to the supply leads of a simple DC motor, current flows through the brushes, commutator and into the coil.

As current flows through the coil it creates its own magnetic field which interacts with the field from the permanent magnets. This creates a turning force (or torque) which causes rotation.

The commutator ensures that the current flow reverses every half cycle so that the coil continues to rotate in the same direction.

Commutator

The commutator in this simple DC motor works the same way as in the DC generator, except it is for current in the opposite direction and for the opposite reason.

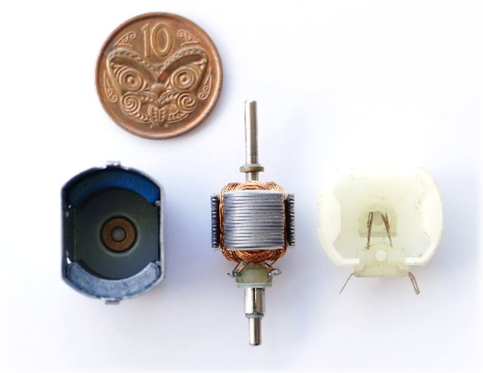
The commutator always feeds current into the armature coil the correct way around to keep the coil turning the right way. That is the job of the commutator in a DC motor.

If you look at the coil and the commutator in the diagram, using Flemings left hand rule you can see that the current needs to be flowing from near you to away from you on the right-hand side of the armature coil to cause the motor to rotate clockwise.

The simple DC motor shown on the previous page would not be very practical as its rotation would be very jerky.

In a more practical DC motor the loop is formed of many coils connected to a commutator with many segments. This will result in a much smoother and more powerful DC motor.

DC motors are used in battery tools, radio-controlled cars and toys.



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