Magnetism

Underpinning Knowledge

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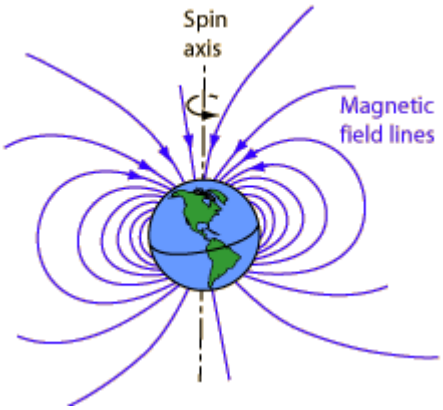
Introduction

Magnetism was recognized as a naturally occurring phenomenon by Greek philosophers as long ago as 600BC. For centuries, magnetic compasses have been used for navigation.

Today, magnetism is used of in every form of modern technology.

Magnetic Field of the Earth

The Earth's magnetic field is similar to that of a bar magnet tilted an angle of 11^0 the spin axis of the Earth.

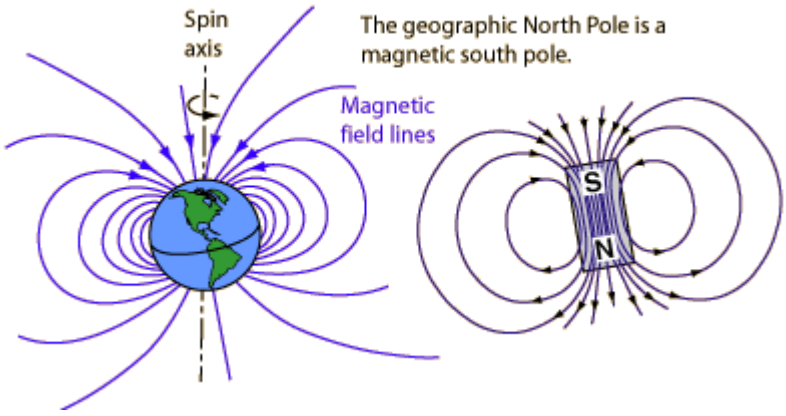


Magnetic fields surround electric currents, so we surmise that circulating electric currents in the Earth's molten metalic core are the origin of the magnetic field. A current loop gives a field similar to that of the earth.

The Earth's magnetic field is attributed to a dynamo effect of circulating electric current, but it is not constant in direction. Rock specimens of different age in similar locations have different directions of permanent magnetization

Although the details of the dynamo effect are not known in detail, the rotation of the Earth plays a part in generating the currents which are presumed to be the source of the magnetic field.

Interaction of the terrestrial magnetic field with particles from the solar wind sets up the conditions for the aurora phenomena near the poles.



The north pole of a compass needle is a magnetic north pole. It is attracted to the geographic North Pole, which is a magnetic south pole (opposite magnetic poles attract).

The Earth acts as a giant magnet.

Magnets

The ends of a magnet are called poles. The end of the magnet that points toward the north of the Earth is called the north-seeking pole. The other end is the south-seeking pole. If a bar magnet is free to move, one end will always point toward the north of the Earth. You can try this out by suspending a bar magnet on a piece of string to see which way it points In practice, the word “seeking” is often omitted, and the poles of the magnet are simply referred to as the north pole and the south pole. A compass needle is a magnet and will align with the Earth's magnetic field. One end turns toward the north, the other end turns toward the south.

Magnet Attraction and Repulsion

You can use two bar magnets to investigate the force between the poles of a magnet.

For two magnets, the following rules apply

- Unlike poles brought close together attract each other

- Like poles brought close together repel each other.

Magnetic Materials

Some materials will interact with a magnet and some will not. You can use a bar magnet to investigate a range of different materials to see which are affected by a magnet. Good materials to investigate include iron, steel, copper, and aluminum. You could also try a range of coins.

Ferromagnetic Materials

The magnetic field of a magnet can bring about (induce) magnetism in certain materials. This induced magnetism causes the material to become attracted to the magnet. These materials are known as magnetic or ferromagnetic materials.

Common ferromagnetic materials are:

- elements such as iron, cobalt, and nickel
- alloys of these elements, such as steel or alnico (an alloy of aluminum, nickel, and cobalt)

Ferromagnetic materials fall into two categories

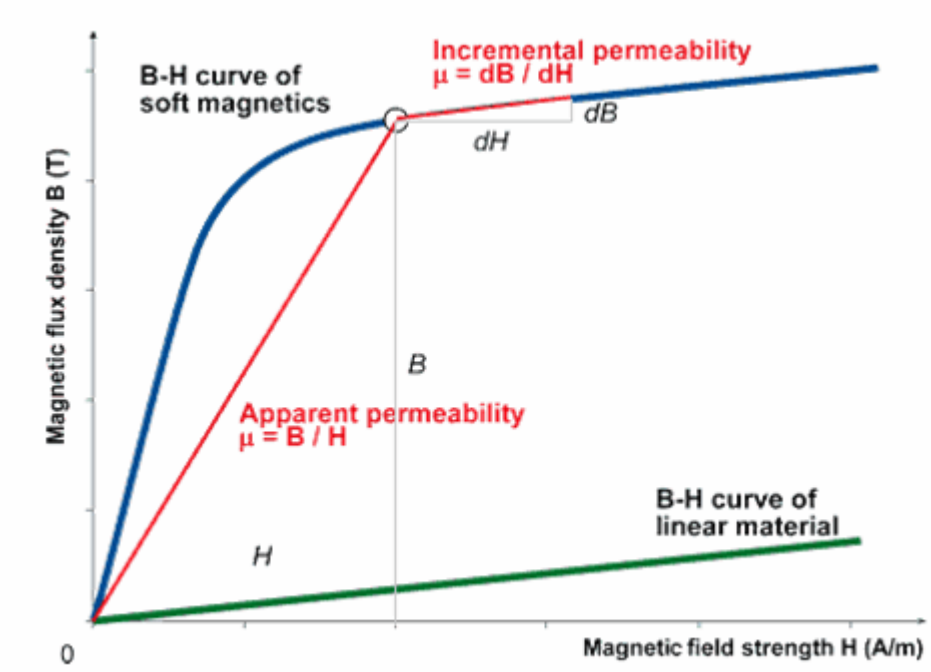
- hard magnetic materials
- soft magnetic materials

Hard magnetic material, such as steel cannot be easily magnetized. However, they retain their induced magnetism when the magnetizing field is removed. Hard magnetic are used to make materials permanent magnets.

Soft magnetic materials, such as iron, can be magnetized easily. However, they lose this induced magnetism when the magnetizing field is removed Soft magnetic materials are used to make temporary magnets. These materials are often used in the cores of electromagnets.

Permeability

In electromagnetism, permeability is the measure of the ability of a material to support the formation of a magnetic field within itself. Hence, it is the degree of magnetization that a material obtains in response to an applied magnetic field



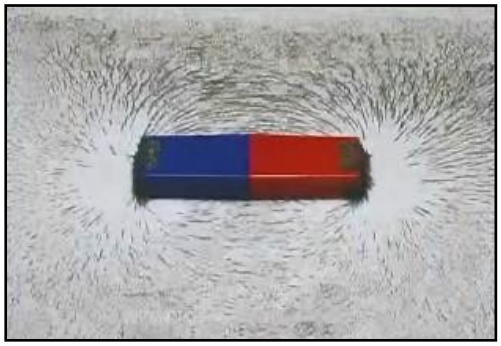
See Hysterisis loops

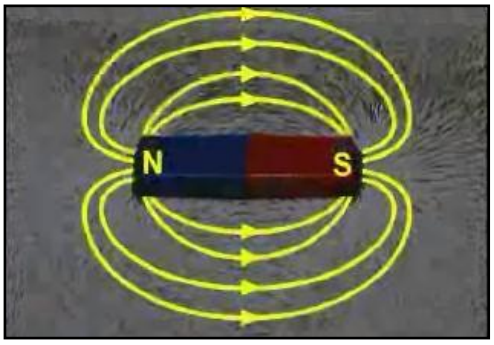
Reluctance

Magnetic reluctance, or magnetic resistance, is a concept used in the analysis of magnetic circuits. It is analogous to resistance in an electrical circuit, but rather than dissipating electric energy it stores magnetic energy.

Magnetic Field Around a Bar Magnet

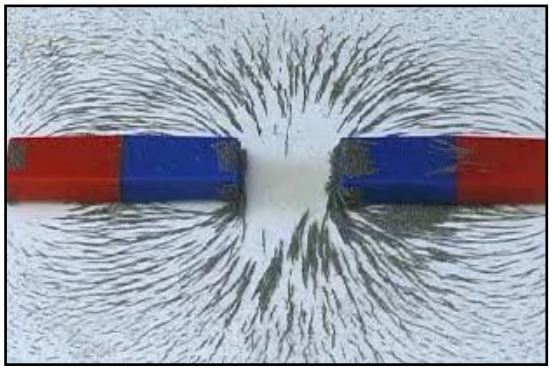
The magnetic field around a bar magnet can be revealed by using iron filings. The field is strongest at the poles of a magnet and it flows from the north pole to the south pole. The lines of force never overlap.



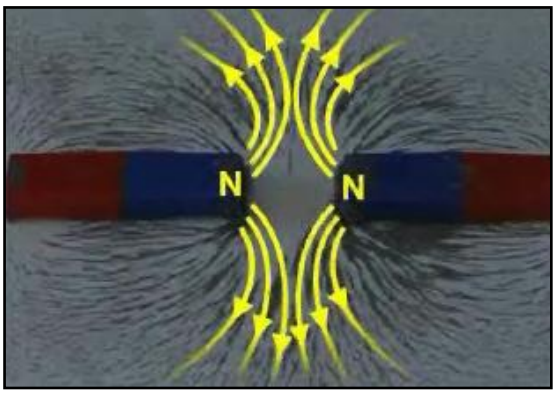


Magnetic Field Between Like Poles

- a magnetic field between like poles of two magnets causes the magnets to repel



- the force of a magnetic field is stronger if the magnets are closer

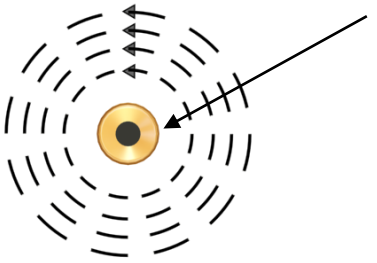


- a magnetic field between the unlike poles of two magnets causes the magnets to attract
- the force of a magnetic field is stronger if the magnets are closer

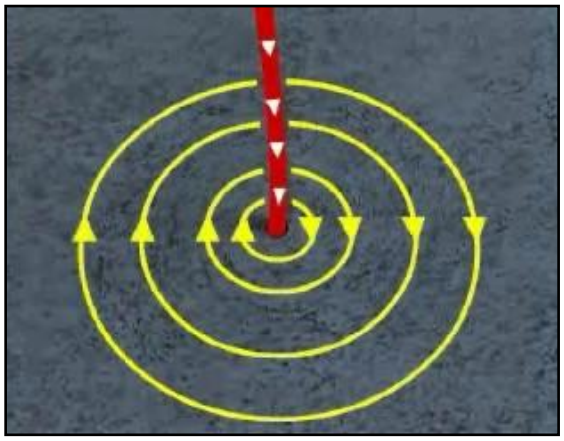
Copper wire and a magnetic field

A magnetic field exists around a copper wire when current flows through it. Copper wire is used because copper is a good conductor of electricity. If a current is passed through a wire (conductor), then a magnetic field forms around the wire.

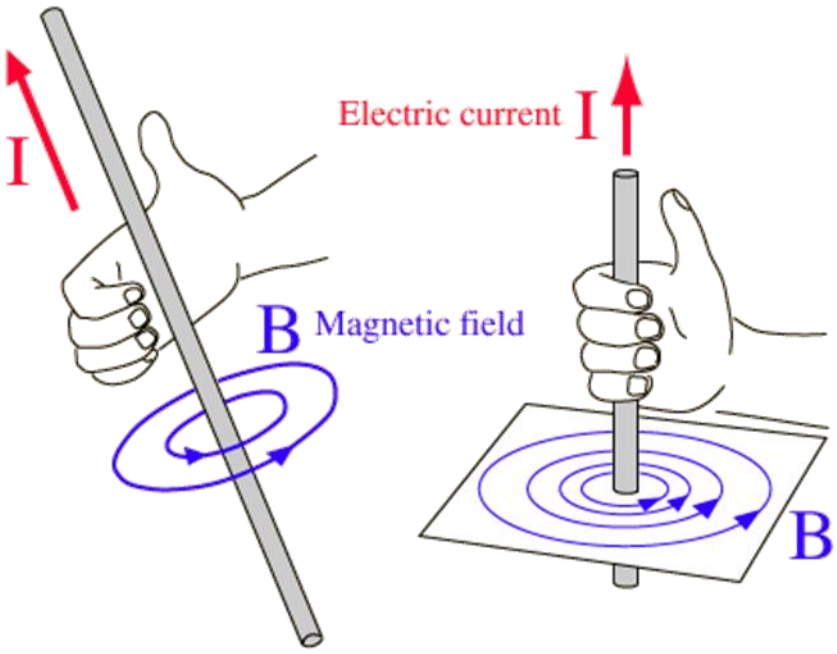
The magnetic field direction is dependent upon current direction.
The strength of the magnetic field is proportional to the size of the current.



The magnetic field around a wire can be seen using by iron filings. Circles of magnetic field can be seen when a current flows through the wire.

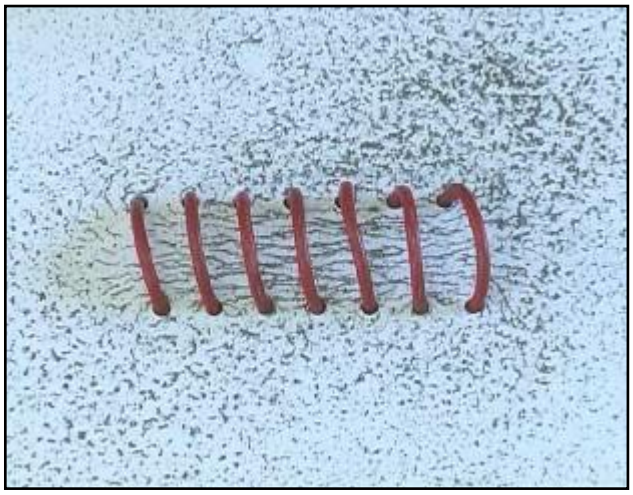


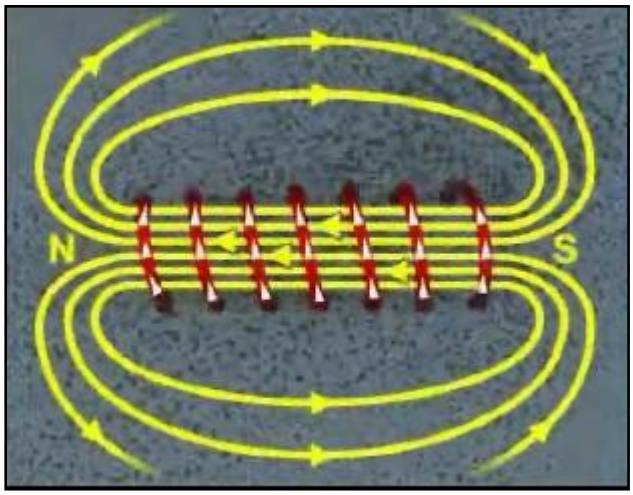
The direction of the magnetic field is perpendicular to the wire and is in the direction the fingers of your right hand would curl if you wrapped them around the wire with your thumb in the direction of the current.


I
Electric current I
B Magnetic field
B

Magnetic Field Around a Coil

If the copper wire is arranged as a coil, the magnetic field is stronger

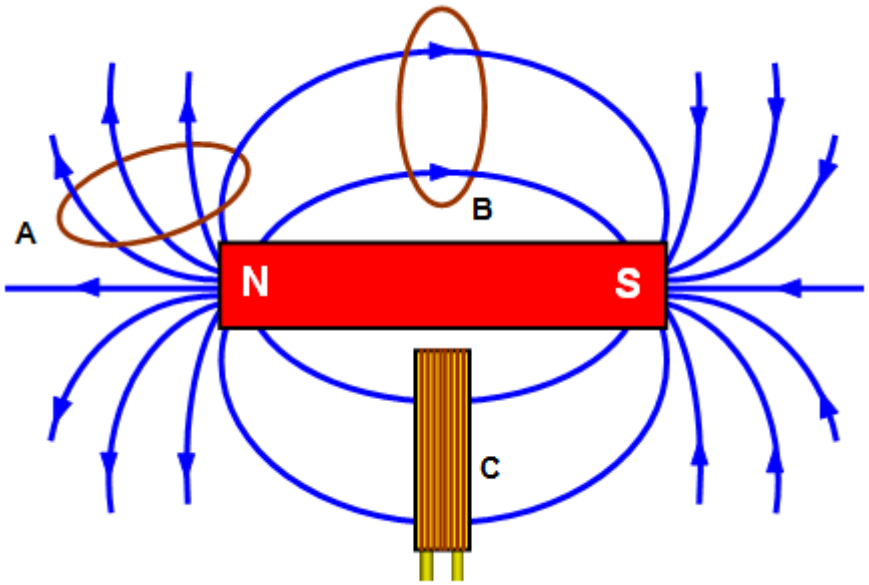




Magnetic Flux and Flux Density

To understand the meaning of magnetic flux (Φ) and magnetic flux density (B) think first about an ordinary bar magnet.

Around the magnet there is a magnetic field and this gives a 'flow of magnetic energy' around the magnet. It is this flow of energy that we call magnetic flux (Φ). We think of magnetic flux as flowing from the north pole of a magnet round to its south pole as shown by the arrows on the lines in the diagram. Looking at the diagram you should see that there is as much flux flowing 'from the north pole' as there is 'flowing into the south pole'.



Magnetic flux is given the symbol Φ and is measured in units called Webers (Wb).

However the amount of magnetic flux flowing through a given area will change from one point to another around the magnet and you can understand this by thinking about a loop of wire placed in the field at two different points (A and B). You can see that in position B there are a smaller number of magnetic field lines passing through the loop than there is when it is in position A.

We call the amount of flux passing through a unit area at right angles to the magnetic field lines the flux density (B) at that point.

Flux density is measured in Tesla (T) where 1 T = 1 Wbm^{-2}

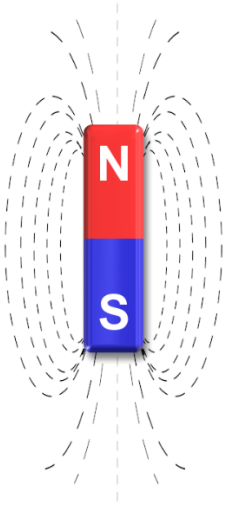
So:

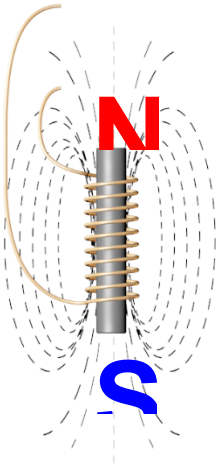
Flux (Φ) = Flux density (B) x area through which flux passes (A) $\Phi = BA$

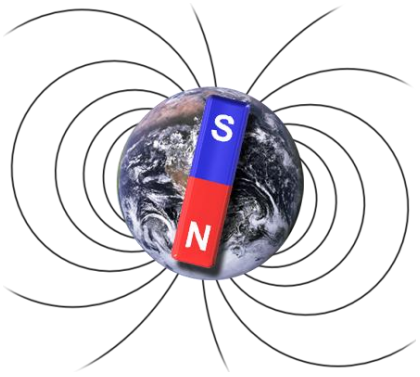
If we now use more than one loop of wire, in others words a coil of N turns as shown in position C the flux flowing through the N turns is simply N times that flowing through the single loop. The quantity NΦ is called the flux linkage for the coil at that point.

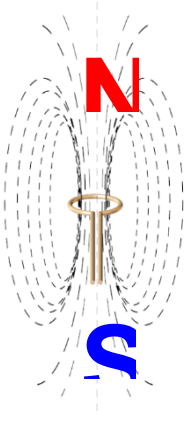
Therefore:

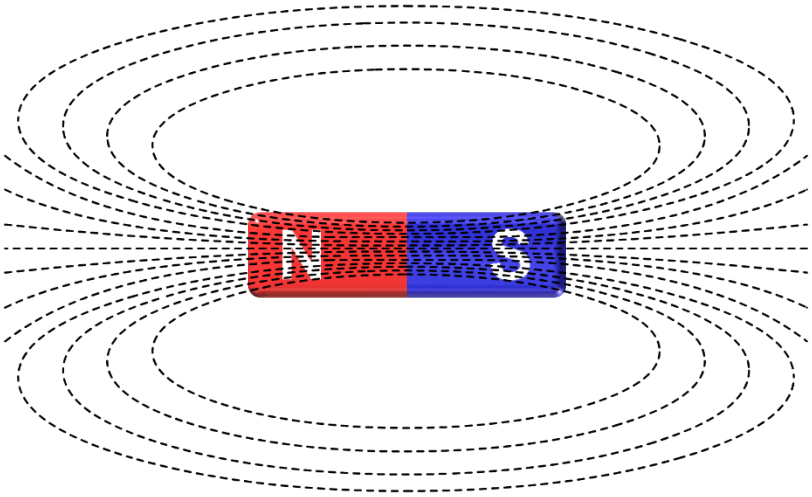
Flux linkage = NΦ = NBA



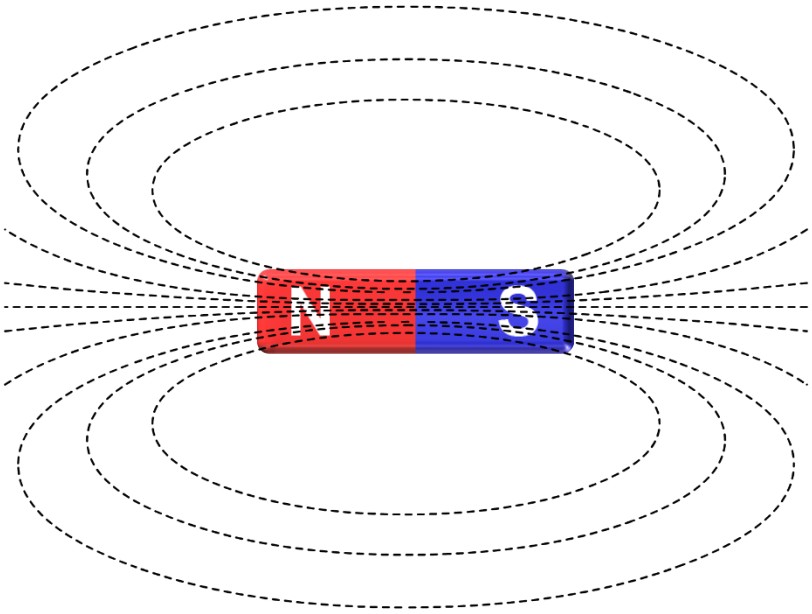








Strong magnetic field



Weak magnetic field

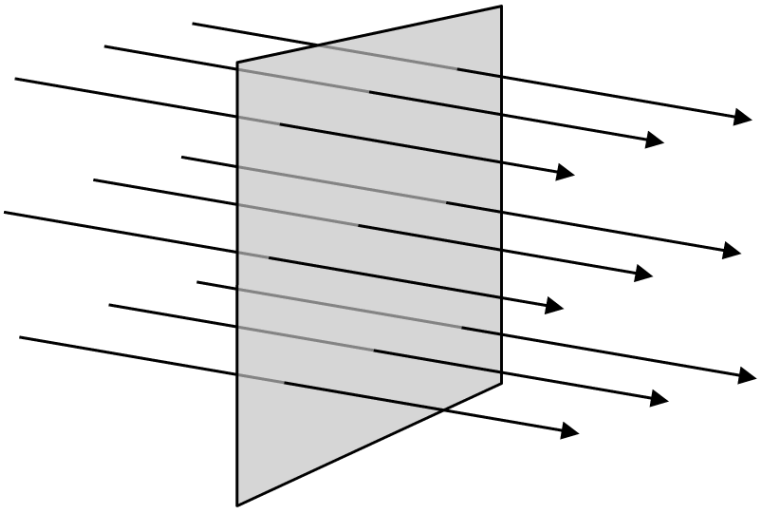
A high density of nearby field lines indicates a strong magnetic field.

Magnetic Flux Density

The magnetic flux density describes the concentration of the magnetic field within a specific area.

Magnetic flux density has the symbol *B*.

The SI unit of magnetic flux density is the tesla, T.



Magnetic field lines

Magnetic flux density can be described in terms of magnetic flux.

Magnetic flux density is the magnetic flux per unit area.

A magnetic flux density of 1 T is equal to a magnetic flux of 1 Wb per m^2

A magnetic field has a flux of 0.2 Wb through an area of 500 mm by 500 mm. Here is an example calculation to find its magnetic flux density:

$$B = \frac{\phi}{A}$$

$$B = \frac{0.2\ \text{Wb}}{0.5\ \text{m} \times 0.5\ \text{m}}$$

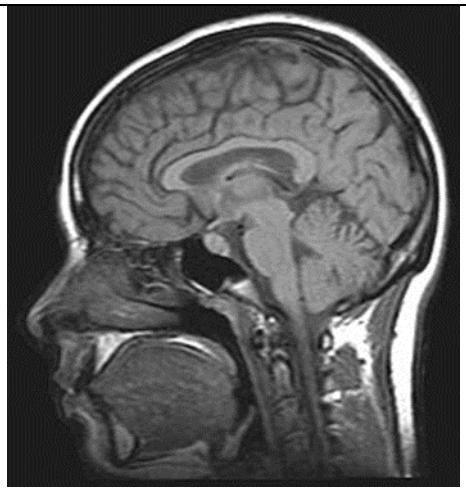
$$B = \frac{0.2\ \text{Wb}}{0.25\ \text{m}}$$

$B = 0.8\ \text{Wb/m}^2$

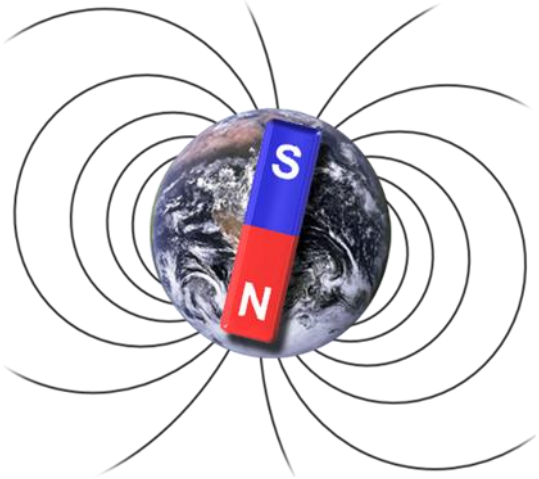
$B = 0.8\ \text{T}$

Magnetic field around a neutron star: 10^{6} T

Fridge magnet: 5×10^{-3} T



MRI Machine: 3 T



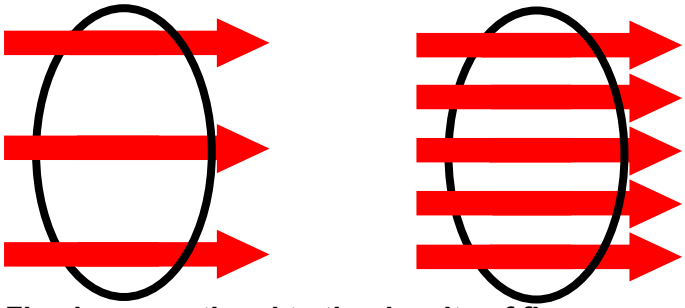
Earth's magnetic field at the equator: 10^{-6} T

Magnetic Flux

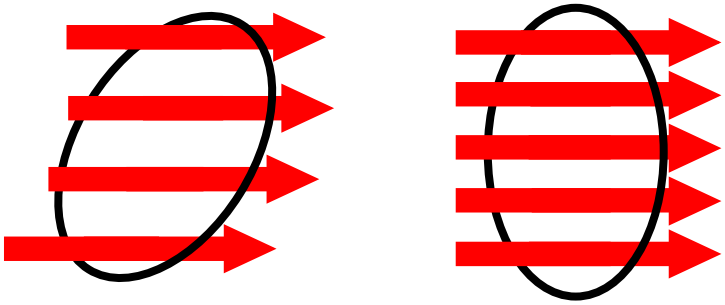
Magnetic flux is a measure of the strength of the magnetic field through a specific area.

Magnetic flux has the symbol Φ (phi).

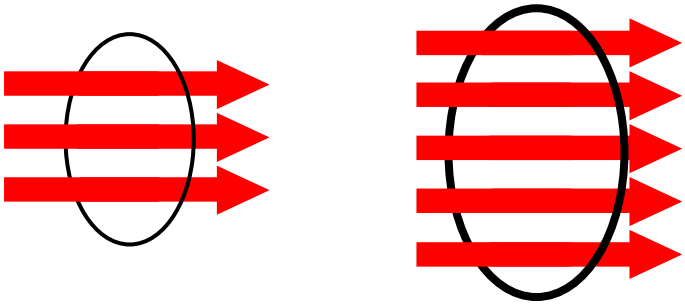
The SI unit of magnetic flux is weber, Wb.



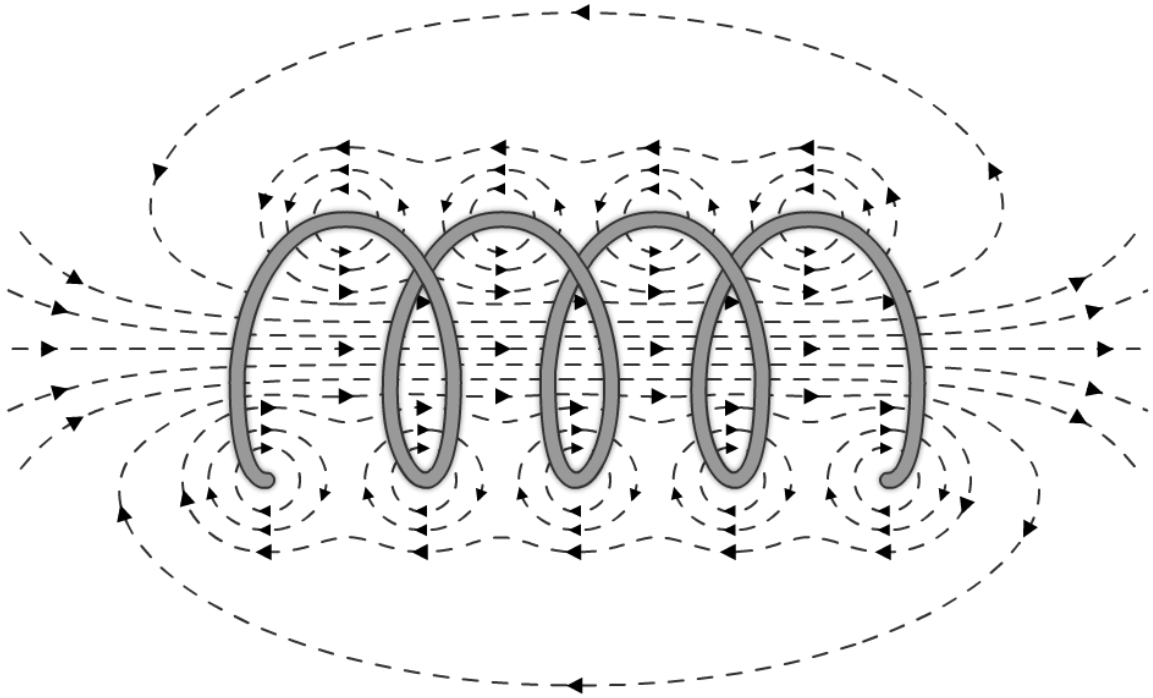
Flux is proportional to the density of flux



lux varies by how the boundary faces the direction of flux



Flux is proportional to the area within the boundary



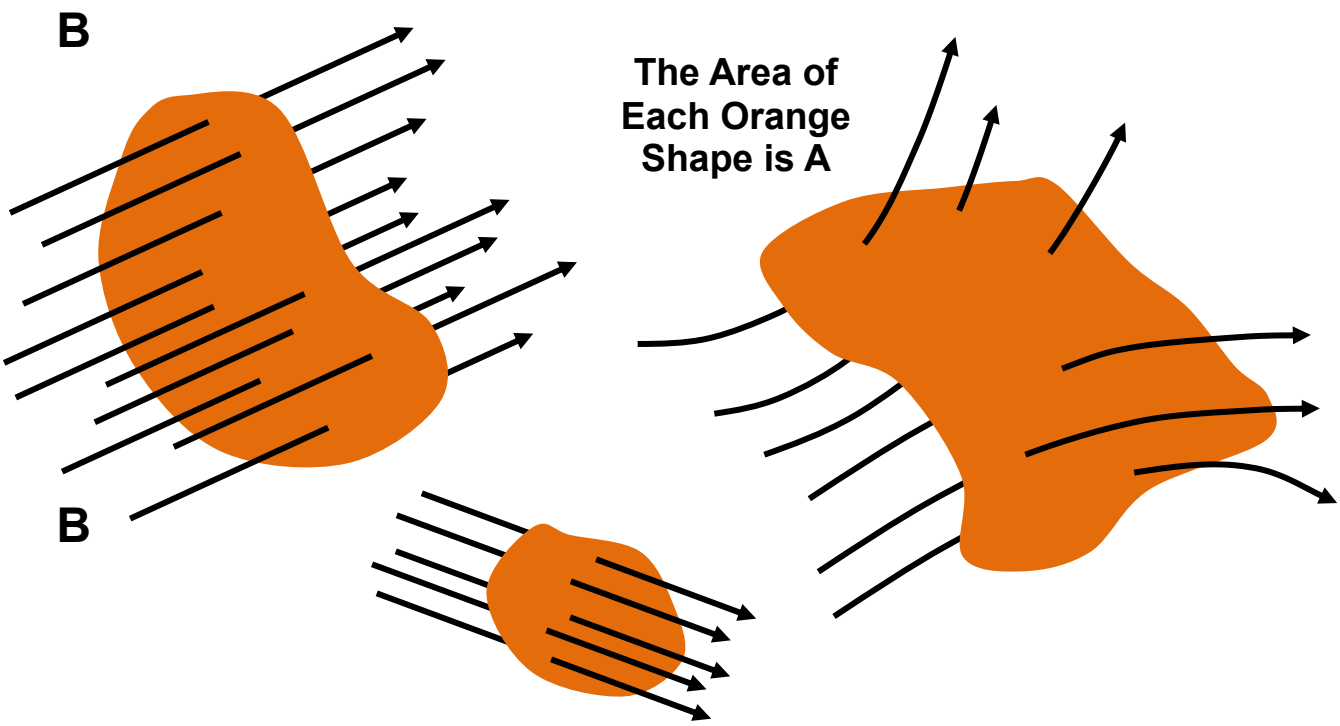
Magnetic flux can be described in terms of induced voltage as follows:

1 weber is the magnetic flux which, when cut at a uniform rate by a conductor in 1 second, induces an emf of 1 volt.

$\Phi = V\,t$

1 weber = 1 volt second

Magnetic Flux and Density Relationship



Magnetic flux and magnetic flux density are related:

$$\text{Magnetic flux density in T} = \frac{\text{Magnetic flux in Wb}}{\text{Area in m}^2}$$

$$B = \frac{\phi}{A} \quad \text{or} \quad \phi = B\,A$$

Hysteresis loop is a four-quadrant B-H graph from where the hysteresis loss, coercive force and retentively of a magnetic material

Hysteresis loop

Hysteresis loop is a four-quadrant B-H graph from where the hysteresis loss, coercive force and retentively of a magnetic material are shown.

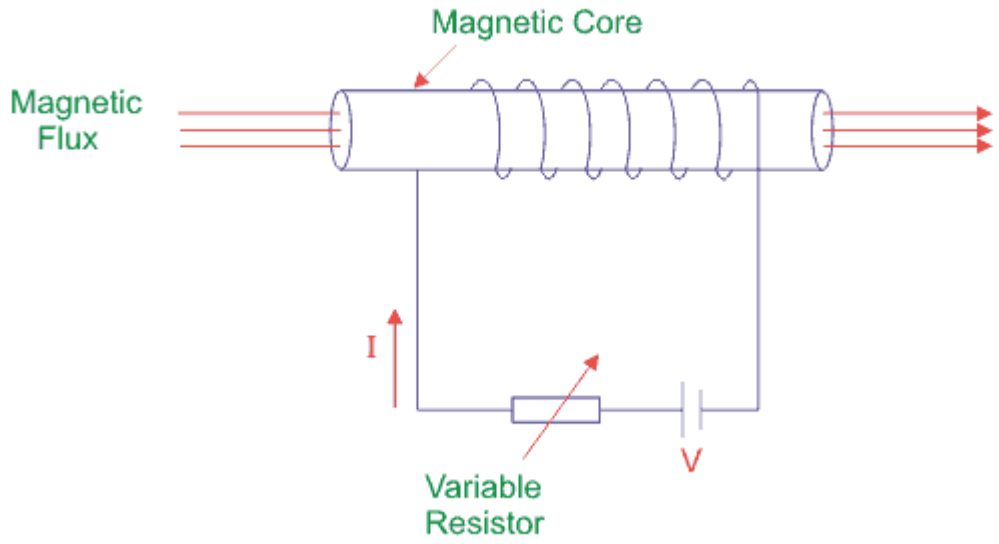
If we built the circuit below and had a magnetic material as a core around which we wound some insulated wire and connected it to a DC supply via a variable resistor so to vary the current I.

The current I is directly proportional to the value of magnetizing force (H) as $H = \frac{NI}{l}$

Where, N = no. of turn of coil

l is the effective length of the coil.

The magnetic flux density of this core is B, which is directly proportional to magnetizing force H.



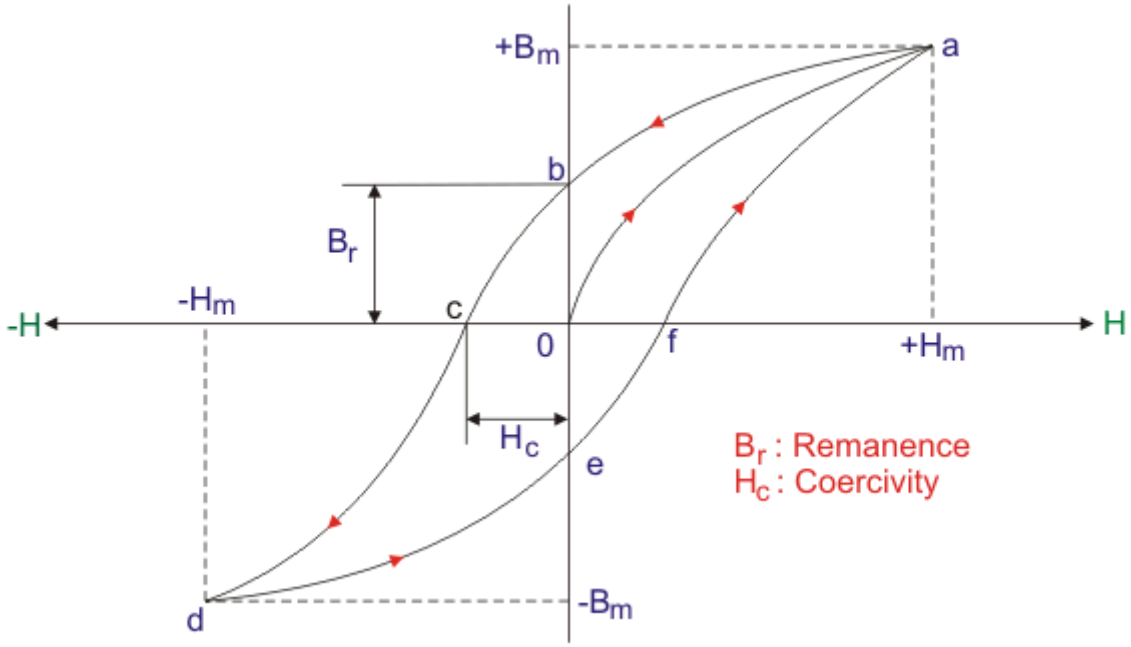
Hysteresis of a magnetic material is a property by virtue of which the flux density (B) of this material lags behind the magnetizing force (H).

Coercive force is defined as the negative value of magnetizing force (-H) that reduces residual flux density of a material to zero.

Residual flux density is the certain value of magnetic flux per unit area that remains in the magnetic material without presence of magnetizing force (i.e. H = 0).

Retentivity is defined as the degree to which a magnetic material gains its magnetism after magnetizing force (H) is reduced to zero.

If we consider the following diagram.



1. When supply current I = 0, so no existence of flux density (B) and magnetizing force (H). The corresponding point is 'O' in the graph above.

2. When current is increased from zero value to a certain value, magnetizing force (H) and flux density (B) both are set up and increased following the path o – a.

3. For a certain value of current, flux density (B) becomes maximum (B_{max}). The point indicates the magnetic saturation or maximum flux density of this core material. All element of core material get aligned perfectly. Hence H_{max} is marked on H axis. So no change of value of B with further increment of H occurs beyond point 'a'.

4. When the value of current is decreased from its value of magnetic flux saturation, H is decreased along with decrement of B not following the previous path rather following the curve a – b.

5. The point 'b' indicates H = 0 for I = 0 with a certain value of B. This lagging of B behind H is called hysteresis. The point 'b' explains that after removing of magnetizing force (H), magnetism property with little value remains in this magnetic material and it is known as residual magnetism (B_r). Here o – b is the value of residual flux density due to retentivity of the material.

6. If the direction of the current I is reversed, the direction of H also gets reversed. The increment of H in reverse direction following path b – c decreases the value of residual magnetism (B_r) that gets zero at point 'c' with certain negative value of H. This negative value of H is called coercive force (H_c)

7. H is increased more in negative direction further; B gets reverses following path c – d. At point 'd', again magnetic saturation takes place but in opposite direction with respect to previous case. At point'd', B and H get maximum values in reverse direction, i.e. ($-B_m$ and $-H_m$).

8. If we decrease the value of H in this direction, again B decreases following the path de. At point 'e', H gets zero valued but B is with finite value. The point 'e' stands for residual

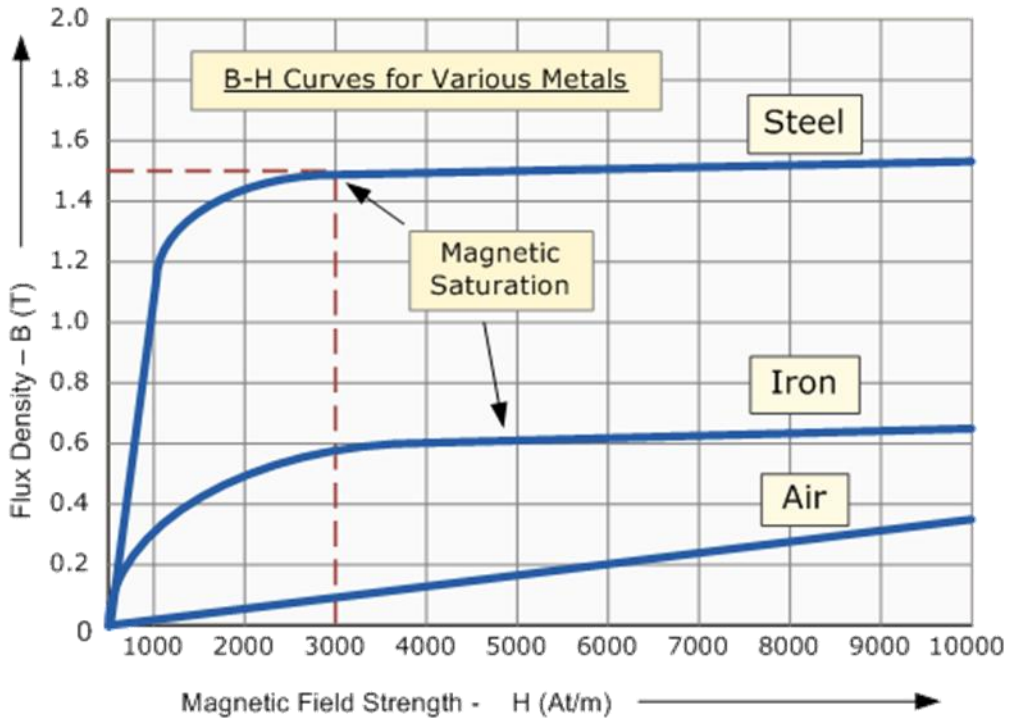
magnetism ($-B_r$) of the magnetic core material in opposite direction with respect to previous case.

9. If the direction of H again reversed by reversing the current I, then residual magnetism or residual flux density ($-B_r$) again decreases and gets zero at point 'f' following the path e – f. Again further increment of H, the value of B increases from zero to its maximum value or saturation level at point a following path f – a.

The path a – b – c – d – e – f – a forms hysteresis loop

The main advantages of **hysteresis loop** are given below.

1. Smaller hysteresis loop area symbolizes less hysteresis loss.
2. Hysteresis loop provides the value of retentivity and coercivity of a material. Thus the way to choose perfect material to make permanent magnet, core of machines becomes easier.
3. From B-H graph, residual magnetism can be determined and thus choosing of material for electromagnets is easy.

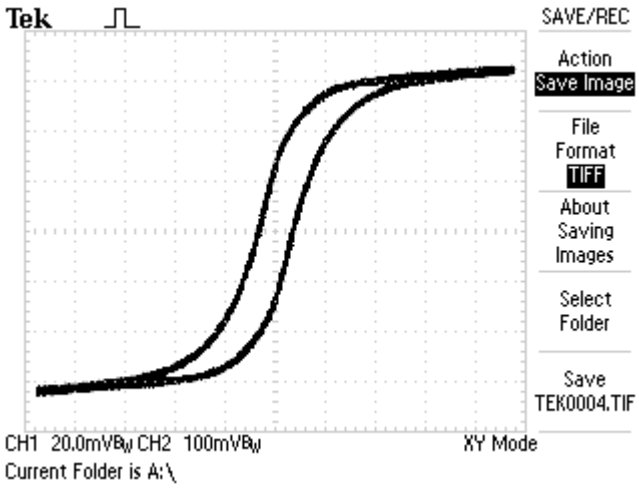


The set of magnetisation curves, M above represents an example of the relationship between B and H for soft-iron and steel cores but every type of core material will have its own set of magnetic hysteresis curves. You may notice that the flux density increases in proportion to the field strength until it reaches a certain value were it cannot increase any more becoming almost level and constant as the field strength continues to increase.

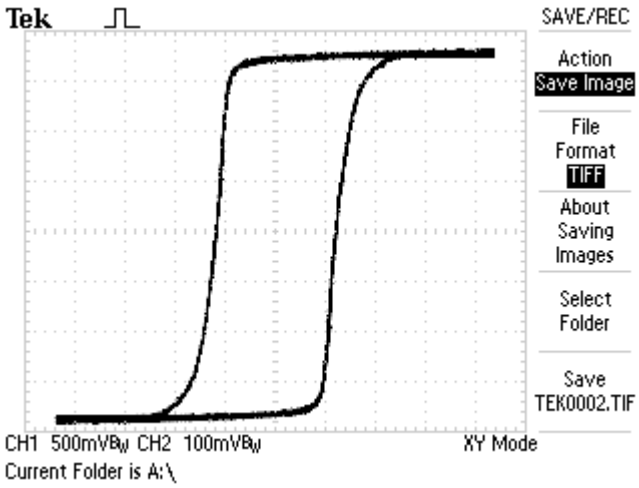
This is because there is a limit to the amount of flux density that can be generated by the core as all the domains in the iron are perfectly aligned. Any further increase will have no effect on the value of M, and the point on the graph where the flux density reaches its limit is called **Magnetic Saturation** also known as **Saturation of the Core** and in our simple example above the saturation point of the steel curve begins at about 3000 ampere-turns per metre.

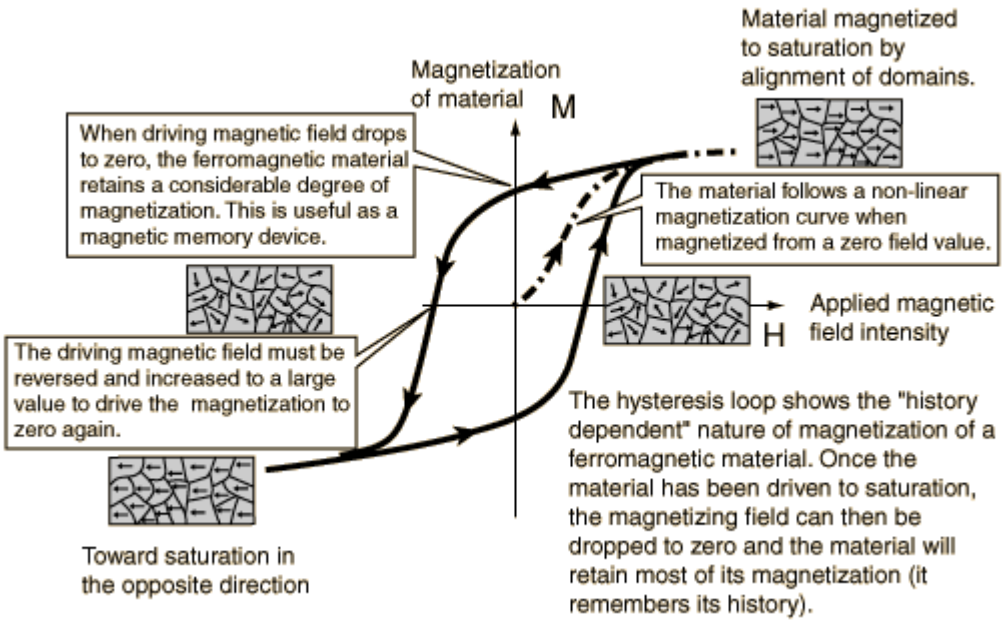
Saturation occurs when the molecular magnets become more and more aligned until they reach perfect alignment producing maximum flux density and any increase in the magnetic field strength due to an increase in the electrical current flowing through the coil will have little or no effect.

Silicon steel



Nickel Iron





It is customary to plot the magnetization M of the sample as a function of the magnetic field strength H, since H is a measure of the externally applied field which drives the magnetisation.

Magnetic Hysteresis

The lag or delay of a magnetic material known commonly as **Magnetic Hysteresis**, relates to the magnetisation properties of a material by which it firstly becomes magnetised and then de-magnetised. We know that the magnetic flux generated by an electromagnetic coil is the amount of magnetic field or lines of force produced within a given area and that it is more commonly called "Flux Density". Given the symbol B with the unit of flux density being the Tesla, T.

The magnetic strength of an electromagnet depends upon the number of turns of the coil, the current flowing through the coil or the type of core material being used, and if we increase either the current or the number of turns we can increase the magnetic field strength, symbol H.

Previously, the relative permeability, symbol μ_r was defined as the product of the absolute permeability μ and the permeability of free space μ_o (a vacuum) and this was given as a constant. However, the relationship between the flux density, B and the magnetic field strength, H can be defined by the fact that the relative permeability, μ_r is not a constant but a function of the magnetic field intensity thereby giving magnetic flux density as: $B = \mu H$. Then

the magnetic flux density in the material will be increased by a larger factor as a result of its relative permeability for the material compared to the magnetic flux density in vacuum, $\mu_o H$ and for an air-cored coil this relationship is given as:

$$B = \frac{\Phi}{A} \quad \text{and} \quad \frac{B}{H} = \mu_o$$

So for ferromagnetic materials the ratio of flux density to field strength (B/H) is not constant but varies with flux density. However, for air cored coils or any non-magnetic medium core such as woods or plastics, this ratio can be considered as a constant and this constant is known as μ_o, the permeability of free space, ($\mu_o = 4.\pi.10^{-7}$ H/m).

By plotting values of flux density, (B) against the field strength, (H) we can produce a set of curves called Magnetisation Curves**,**Magnetic Hysteresis Curves or more commonly B-H Curves for each type of core material used as shown below.

When a ferromagnetic material is magnetized in one direction, it will not relax back to zero magnetization when the imposed magnetizing field is removed. It must be driven back to zero by a field in the opposite direction. If an alternating magnetic field is applied to the material, its magnetization will trace out a loop called a hysteresis loop. The lack of retraceability of the magnetization curve is the property called hysteresis and it is related to the existence of magnetic domains in the material. Once the magnetic domains are reoriented, it takes some energy to turn them back again. This property of ferrromagnetic materials is useful as a magnetic "memory". Some compositions of ferromagnetic materials will retain an imposed magnetization indefinitely and are useful as "permanent magnets".

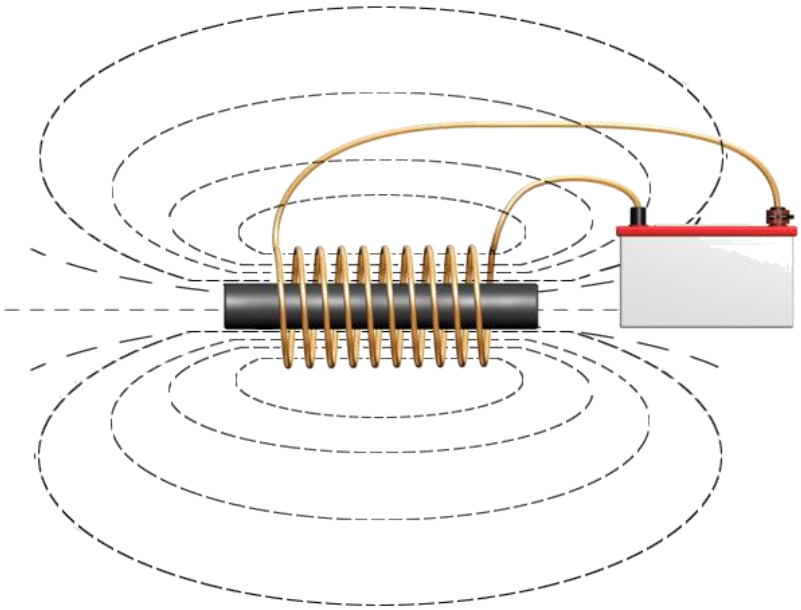
Electromagnets

Imagine a copper wire is shaped into a loop and connected to a voltage source. A current will flow to form a magnetic field.

If more loops are made, the magnetic field will become stronger.

This is like putting magnets next to each other.

The strength of the magnetic field is directly proportional to the number of turns.



In a coil, the individual circular fields combine to cover the entire length of the coil. The field pattern produced by this is similar to that of a permanent magnet. The field lines inside the coil are parallel, showing the field strength is constant within the coil. Using a soft-iron core makes the field stronger. Together, the coil and the core form an electromagnet.

Magnetomotive force (mmf)

The force of a magnetic field, is referred to as magnetomotive force (mmf). The Magnetomotive force is the work that carries a measurable unit of strength through a magnetic circuit. This unit of strength is measured in ampere-turns (AT).

Magnetism in a circuit flows from the north to the south pole. Following a specific path, the force of the magnetism is similar to the force in an electrical circuit. While electricity follows a certain path from a point of origin to a receiving point and back, magnetism always flows from one pole to the other. As magnetism flows through the circuit, it produces lines of force, or flux lines, and generates a magnetic field.

In simplest terms, anything that produces magnetism can be described as exerting a magnetomotive force. Understanding the basic meaning of the word itself makes it easy to understand its application. Magnetomotive force translates, quite literally, to "magnetic motion causing." The motion that magnetomotive force generates is always exerted perpendicular to the magnetic circuit's resistance.

Although magnetism exerts a force all its own, it does exhibit a reluctance to travel across large spans of air. This reluctance is similar to the resistance of an electrical circuit. Magnetism travels much more successfully through iron. A magnetic circuit composed exclusively of iron will have much lower reluctance than a magnetic circuit crosses an air gap.

Either permanent magnets or coiled wire conducting electricity may produce a magnetomotive force. When a coil of wire produces a magnetomotive force, the number of turns of the wire is directly related to the value of the force generated. For instance, the magnetomotive force of a coil with 50 turns would be 25 times greater than the magnetomotive force of a coil with only two turns. The magnetic flux of a magnetic circuit is, then, equal to the magnetomotive force divided by the circuit's reluctance. This relationship may be better understood if one takes time to consider that magnetic flux represents the journey of a substance's magnetism through a magnetic circuit. Each turn in a coil concentrates the force of the magnetic. Overcoming the reluctance of the circuit to travel through each of the coils, the natural strength of the magnet is demonstrated as sheer force.

Bar magnet with iron filings to illustrate the magnetic field.

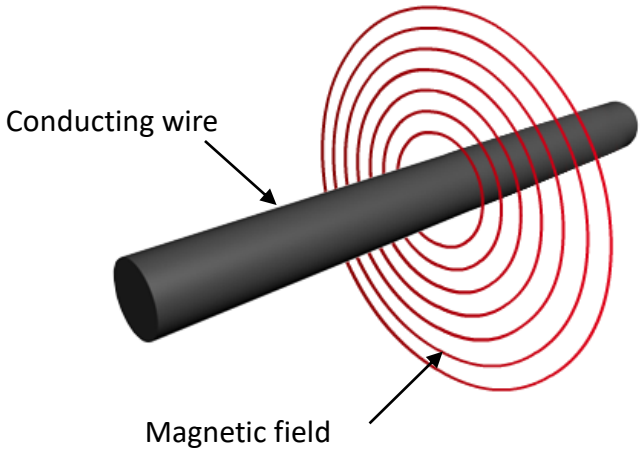
Magnetic Effect of an Electric Current

Moving electric charges produce a magnetic field.

If a wire, through which a current is flowing, is placed between the poles of a magnet, the interacting magnetic fields will force the conductor to move.

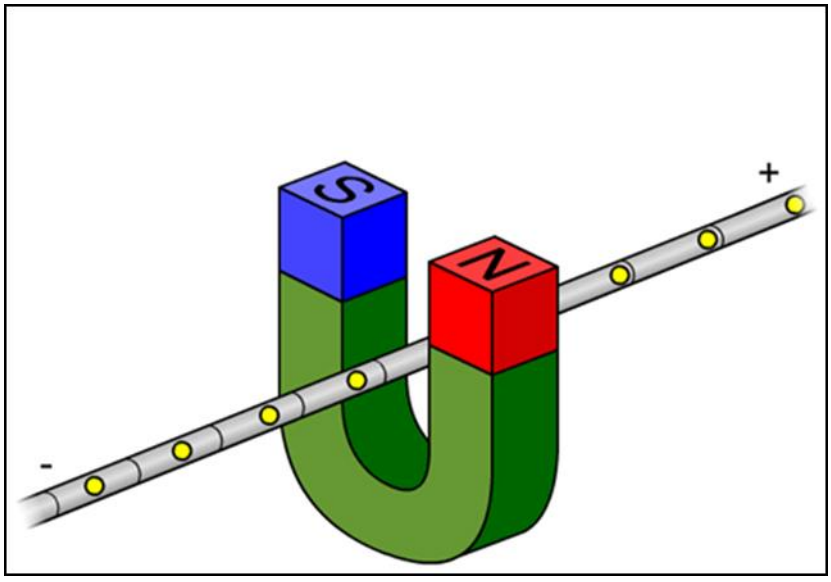
If the conductor is free to move, it will be forced out of the magnetic field.

This is the phenomenon of electromagnetism.



Bar Magnet

The lines of magnetic field from a bar magnet form closed lines. By convention, the field direction is taken to be outward from the North pole and in to the South pole of the magnet. Permanent magnets can be made from ferromagnetic materials


S
N
+
-

Magnetic screening

Electromagnetic shielding is the practice of reducing the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic materials.

Shielding is typically applied to enclosures to isolate electrical devices from the 'outside world', and to cables to isolate wires from the environment through which the cable runs.

Electromagnetic induction

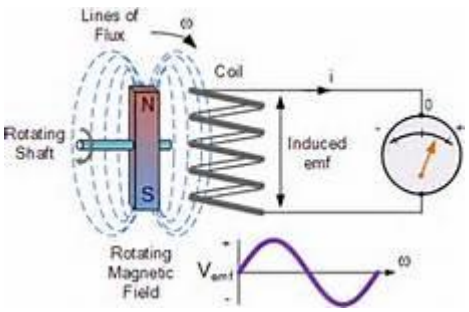
As the name "electromagnetism" suggests, electricity and magnetism are very closely linked. This relationship allows them to affect each other without contact, as in the maglev train example, or through electromagnetic induction. **Electromagnetic induction** occurs when a circuit with an alternating current flowing through it generates current in another circuit simply by being placed nearby. An alternating current is the kind of electricity flowing through power lines and home wiring, as opposed to a direct current, which we get from batteries.

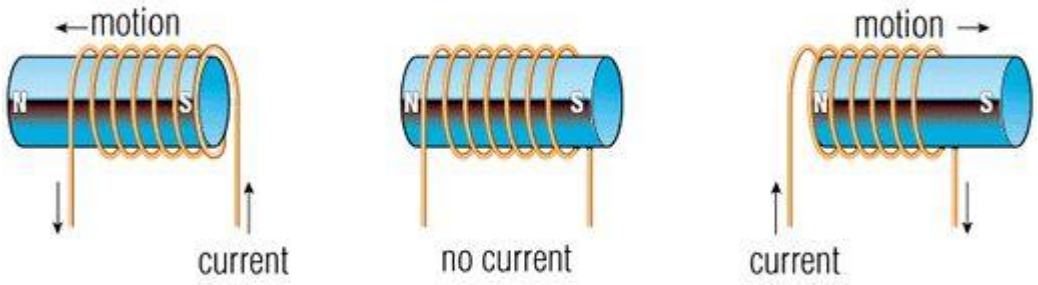
How does one circuit cause a current in another without touching it, and what does any of this have to do with magnetism? Before we get into that, we need to look at a few principles linking magnetism and electricity:

1. Every electric current has a magnetic field surrounding it.
2. Alternating currents have fluctuating magnetic fields.
3. Fluctuating magnetic fields cause currents to flow in conductors placed within them, which is also known as Faraday's Law.

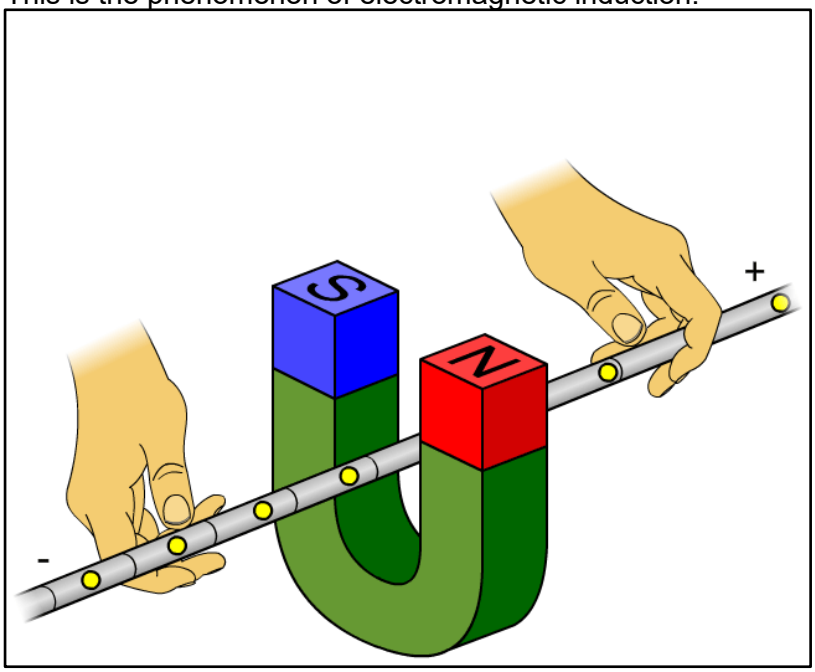
Adding these three properties together means that a changing electric current is surrounded by an associated changing magnetic field, which in turn generates a changing electrical current in a conductor placed within it, which has its own magnetic field…and so on. Thus, in the case of electromagnetic induction, placing a conductor in the magnetic field surrounding the first current generates the second current.

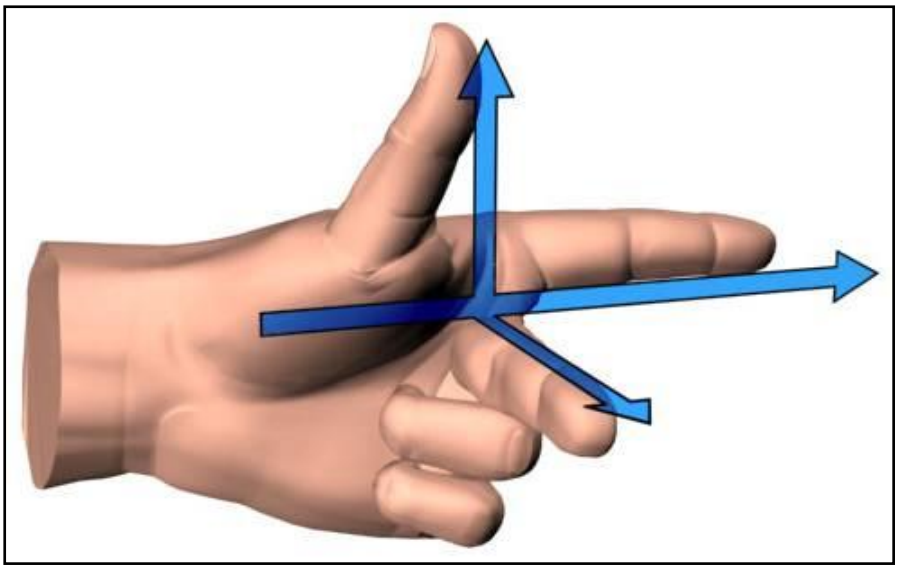
Induction is the principle that makes electric motors, generators and transformers possible, as well as items closer to home such as rechargeable electric toothbrushes and wireless communication devices.





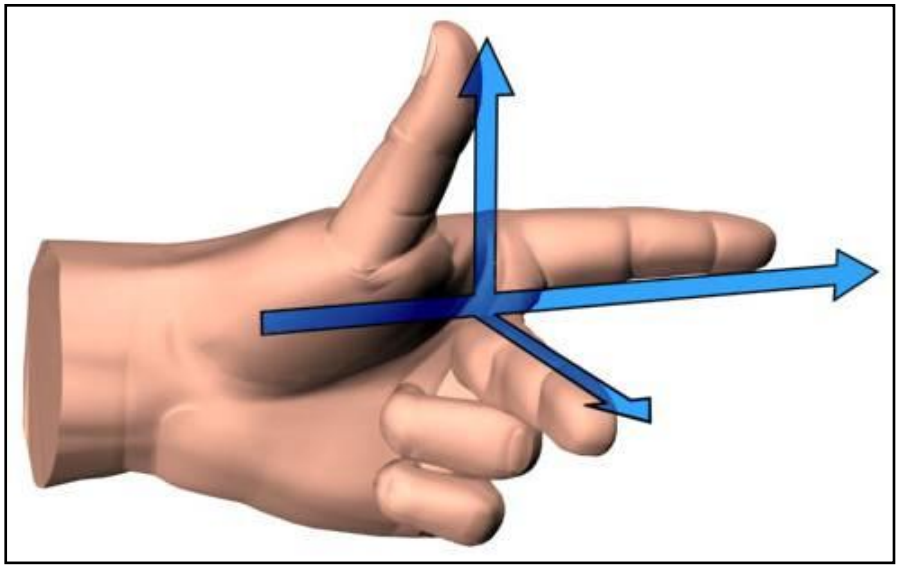
If moving charge produces a magnetic force, does moving a magnet produce a flow of electric charge?
If a wire is moved inside a magnetic field, an electric current is generated.
This is the phenomenon of electromagnetic induction.





The direction of the force on a current in a magnetic field is given by Fleming's Left-Hand Rule.

Place the thumb, first and second fingers of the left hand at right-angles to each other.



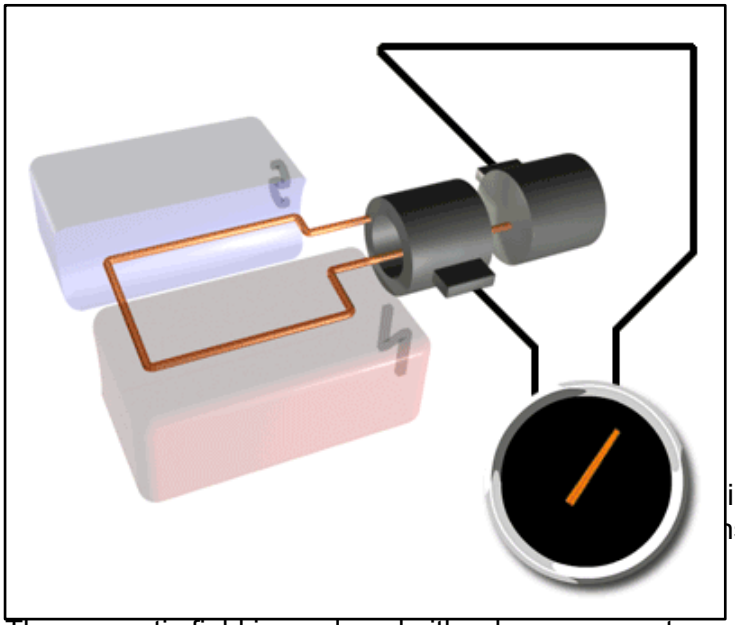
The first finger points in the direction of the magnetic field (N to S).
The second finger points in the direction of the electric current.
The thumb then shows the direction of the force (and motion if it is free to move).

If we hold the magnet in the coil, no electricity is generated.

If we drop a magnet through a coil, electricity is generated in the coil.
The size of the voltage generated is related to:

- the speed of the magnet
- the number of turns in the coil
- the strength of the magnet

Generator

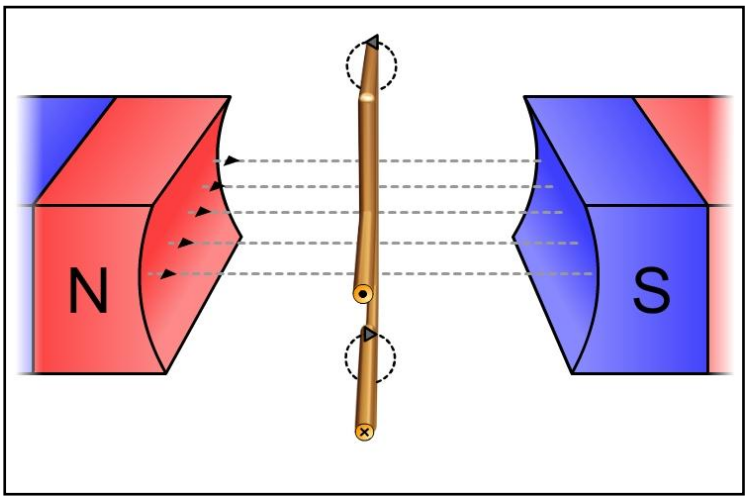


induction to generate electricity.
nside a magnetic field.

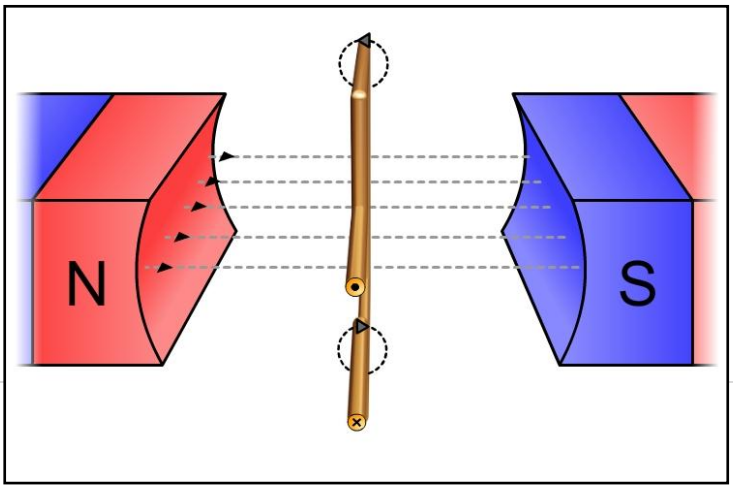
The magnetic field is produced either by permanent magnets or electromagnets.
Almost all of the electricity we use is produced this way in power plants

Motor

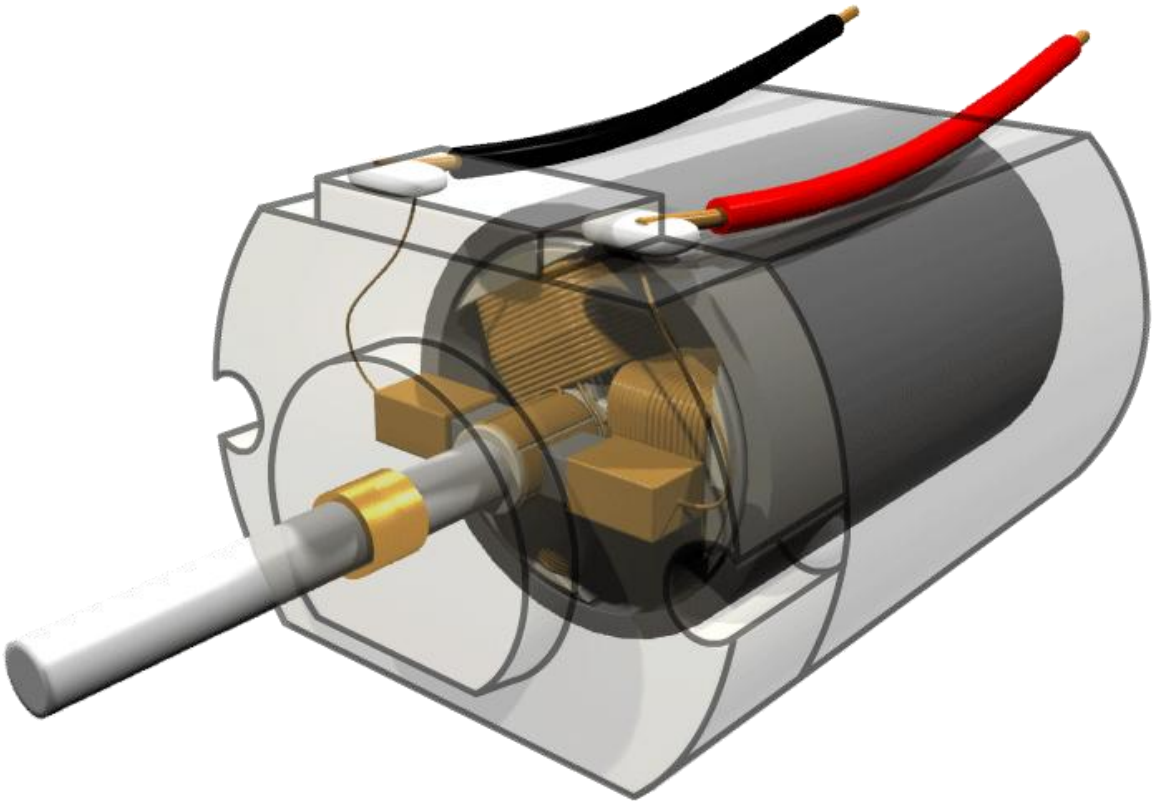
Electric motors are used in a wide range of machines
Micro motors are used in many consumer devices including DVD players, smart phones, and medical equipment.
Larger motors are used in many industrial processes; running conveyor systems, pumps, and even powering ships.
Some large motors can be the size of a building.



The electric motor uses this force to produce motion.
When current passes through the coil, the side of the coil near the magnetic north pole is pushed up, and the side near the south pole is pushed down.
This creates the turning effect.
A device called a commutator, switches the direction of the current every half revolution so the turning force is always in the same direction.

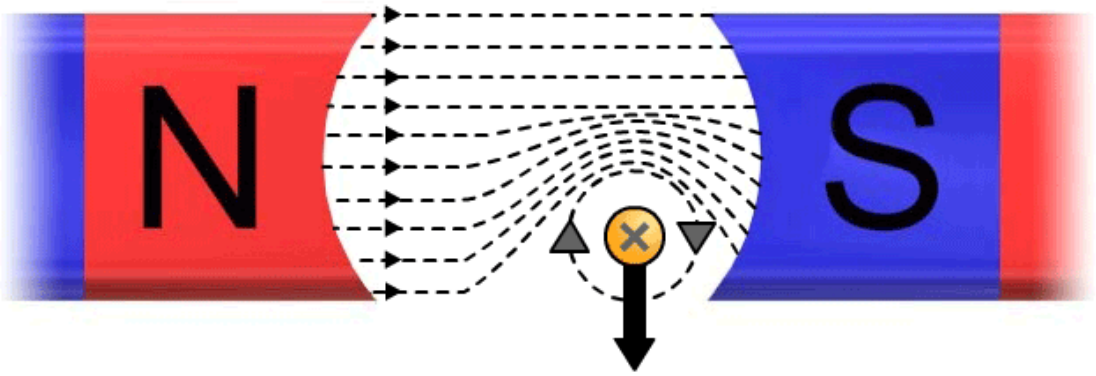


DC Motor



Electric motors are found in many machines, both in industry and in the home
Electric motors consume around 50% of all electricity generated.

All electric motors are based on the interaction between magnetic and electric fields.

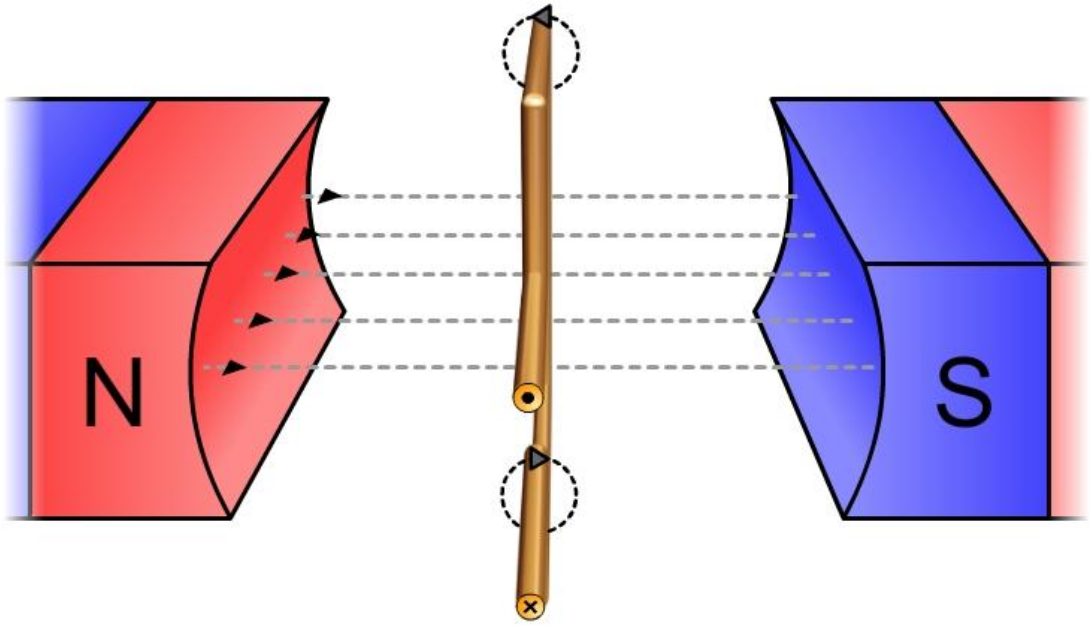


= current flowing into the picture

A current carrying conductor will experience a force when in a magnetic field.
The direction of the force depends on these factors:

- magnetic field direction
- current direction

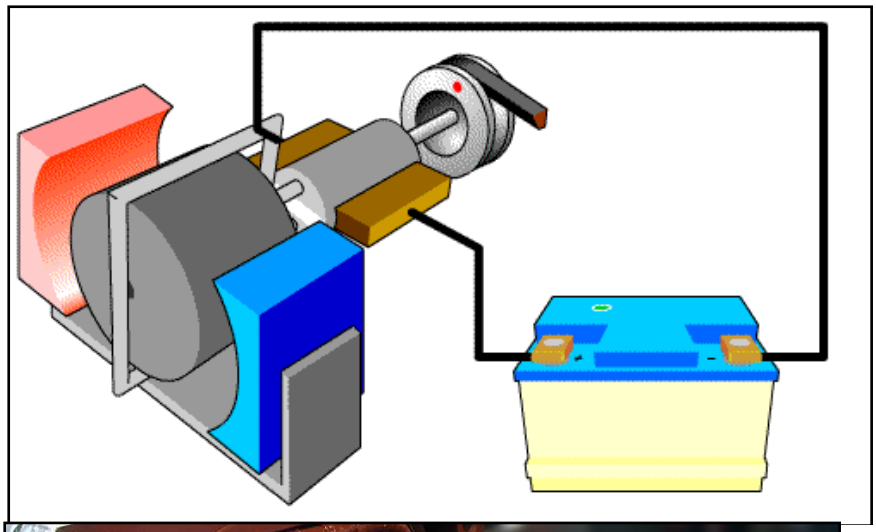
The Motor Effect

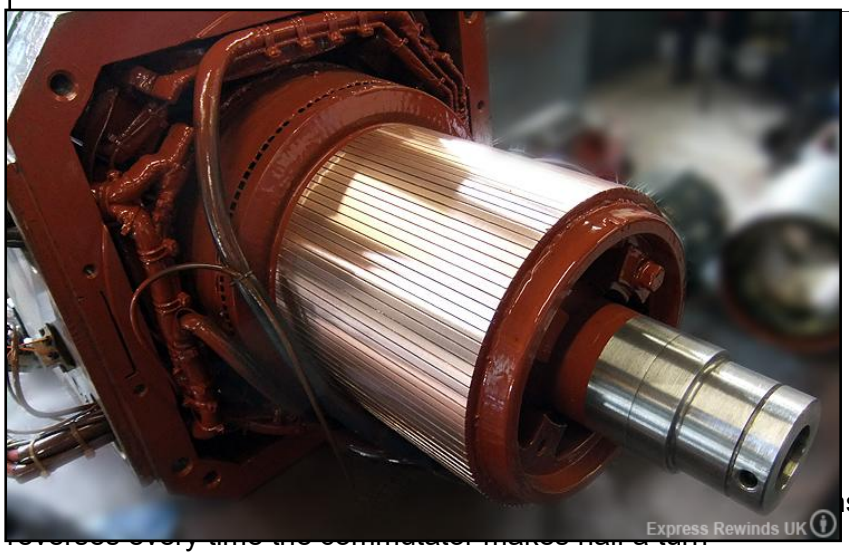


A coil is suspended in a magnetic field and is free to rotate.
A current flows through the coil.
The forces on each side of the coil will act in opposite directions and produce a turning effect on the coil.

Once the coil is at right angles to the field, it will stop rotating
The coil can be kept turning by reversing the direction of the current when the coil is at right angles to the magnetic field.

This is achieved by using a commutator.





s, the current in the winding

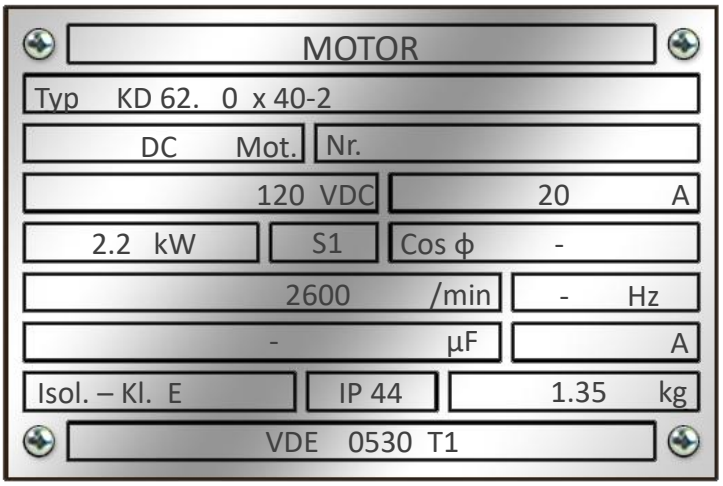
It compensates for the winding that has also rotated half a turn relative to the magnetic field.

Real motors with more coils use commutators that have many more segments.
This enables the current to be reversed more times during one revolution.
Carbon brushes conduct current between the power supply and the rotating coil.

One of the characteristics of a motor is the speed
at which the motor
shaft rotates.

Motor speed is quoted as revolutions per minute (rpm).

One of the main benefits of DC motors is the ease by which motor speed can be controlled.



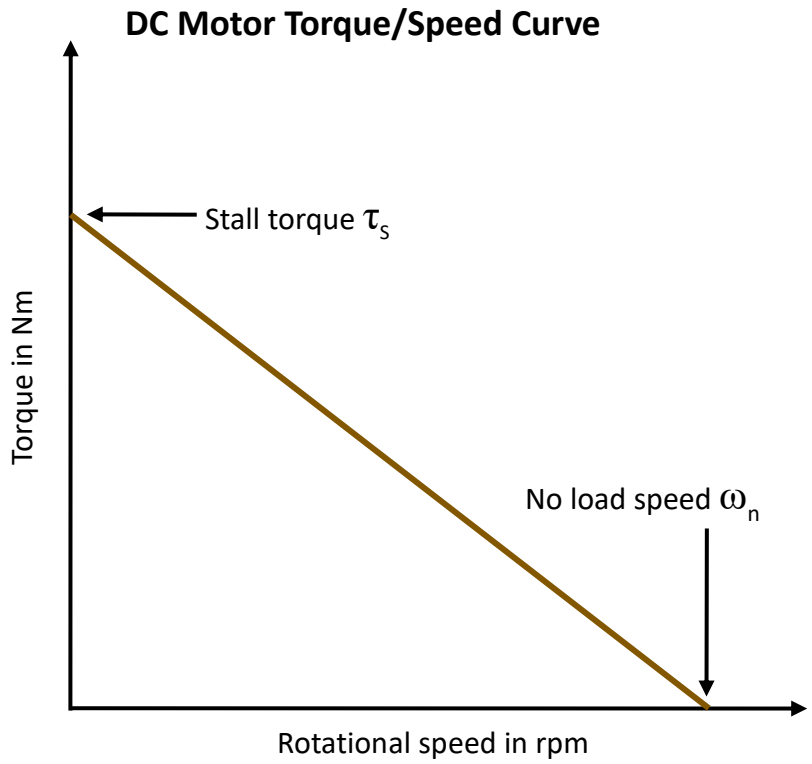
Motor Torque

Motors are rated in terms of torque. Torque is the turning force produced by a motor.

The unit of torque is the newton metre (Nm).

A torque curve shows the characteristics
of a motor at
different speeds.

Stall torque is the torque produced when the rotational speed is zero.



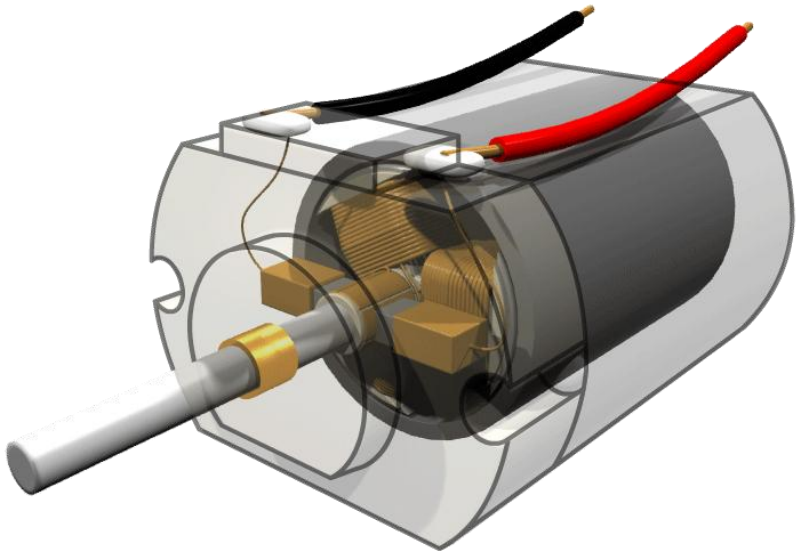
Permanent Magnet Motors

The simplest DC motor design is the permanent magnet motor.

The stator consists of permanent magnets.

**These motors can
be small and cost
a few pence**

Permanent magnet motors are used in a huge range of devices

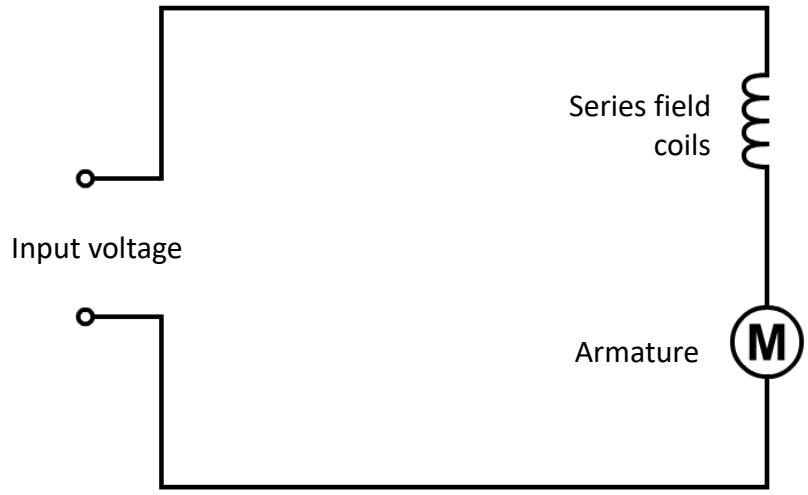


Series Wound DC Motors

Larger DC motors usually have their magnetic field produced by field windings in the stator.

Series wound motors have the field coils connected in series with the armature.

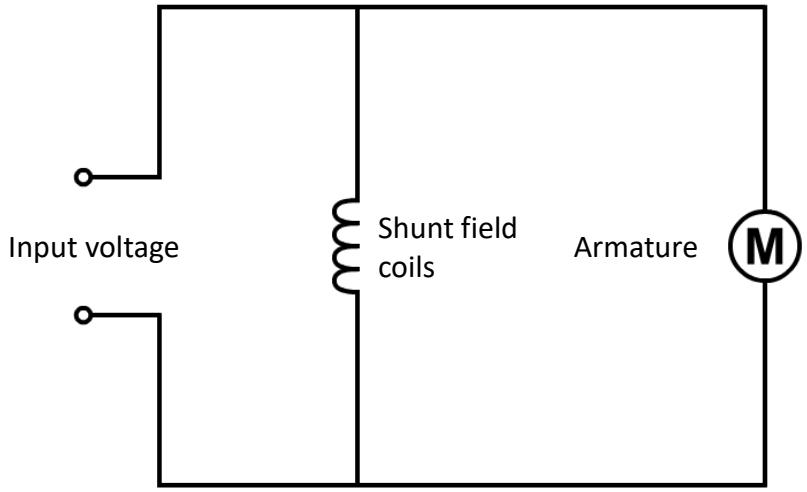
These motors have a high starting torque and the speed varies with the mechanical load on the output shaft.



Shunt Wound DC Motors

Shunt wound motors have the field coils connected in parallel with the armature.

These motors have a speed that remains constant, even under varying load conditions



Brushless DC Motor

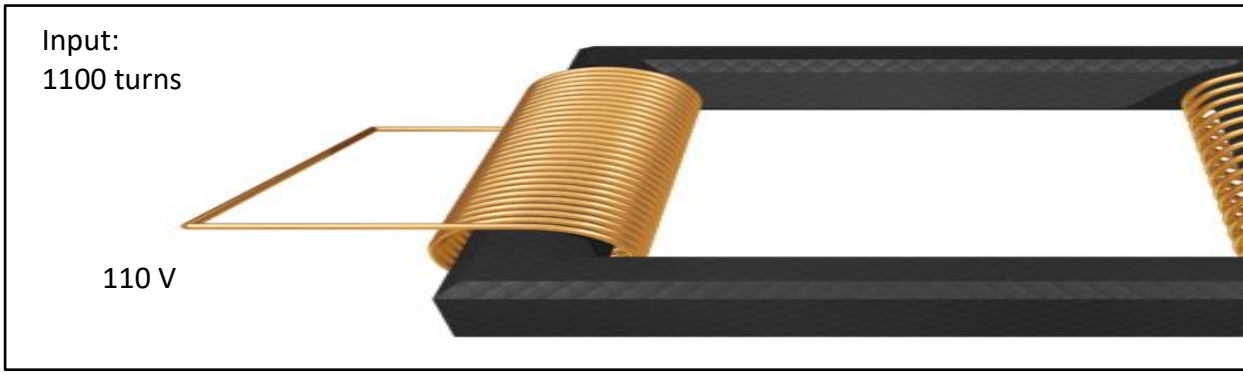
These motors have no commutator or brushes.
The rotor has permanent magnets and no electrical connection.
The stator field coils are electronically switched to produce a rotating magnetic field.
These motors are popular in small sizes and are ideal for models and toys.

induced electromotive force (emf),
eddy currents
self and mutual inductance
Applications (electric motor/generator eg series and shunt motor/generator;
transformer egprimary and secondary current and voltage ratios);
application of Faraday's and Lenz's laws
Faraday's and Lenz's laws

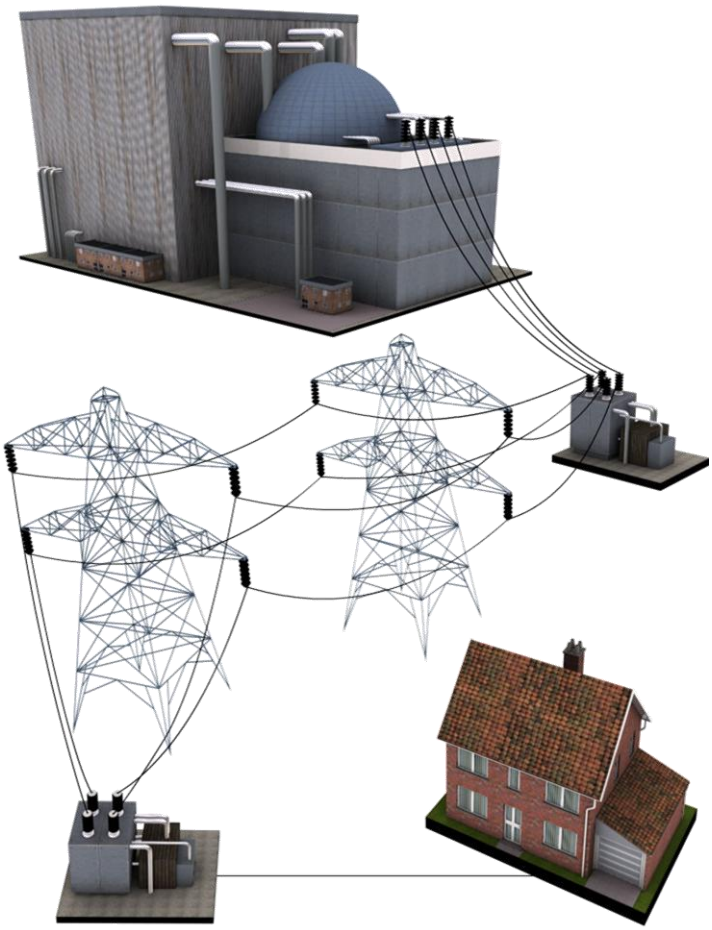
Transformers

Transformers are found in a wide range of devices. Small transformers are used in domestic appliance whilst huge transformers are used as part of the power distribution grid.

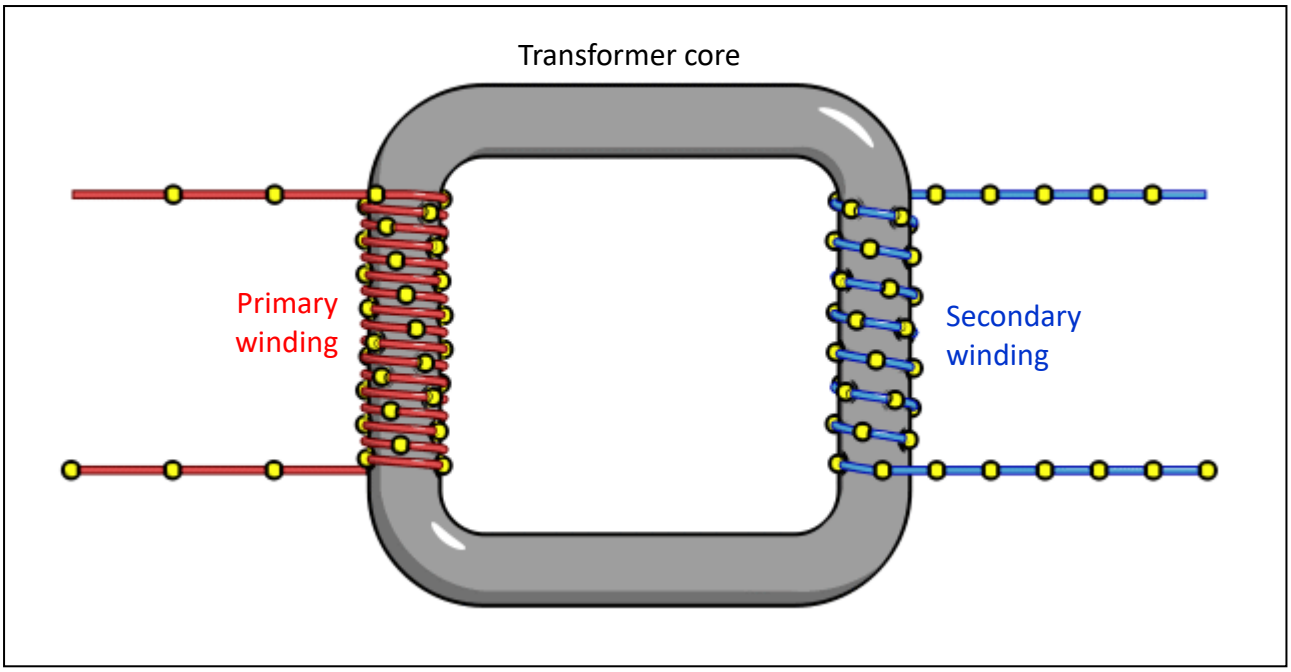
It is an electric device used to increase or decrease an AC voltage. It is made of two electric coils linked by a magnetic field. The electric current in one coil produces a magnetic field which induces a current in the other coil.
The size of the output voltage depends on the input voltage and the number of turns on the coils. The electronic devices that plug into your home supply have a transformer, usually to lower the voltage supplied to the device.



Transformers are also used as part of the electricity transmission system. The generator produces an alternating voltage that is then stepped up for transmission. This makes the transmission much more efficient. At the end of the transmission line the voltage is stepped down to the supply voltage needed in our homes.

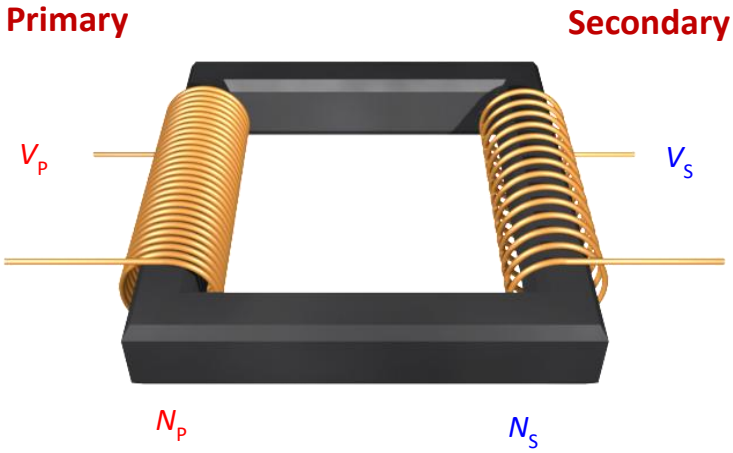


Transformer calculations



A few simple equations can be used to calculate the various parameters of a transformer.

The relationship between the voltages and the number of turns is given by this equation:



$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

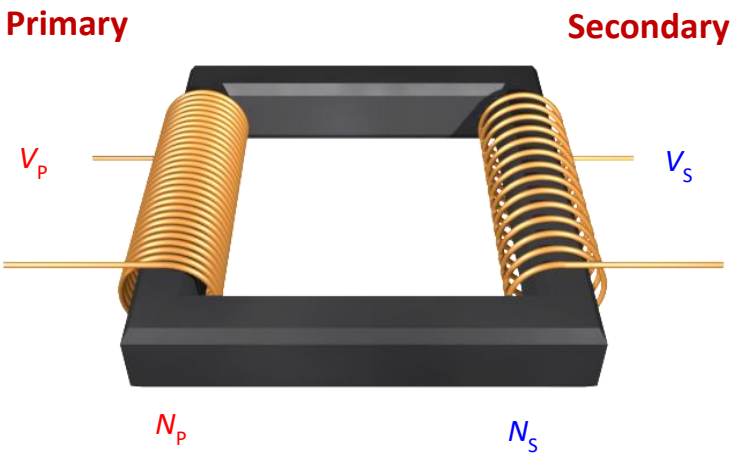
where:
V_P = voltage across primary coil in V

V_S = voltage across secondary coil in V

N_P = number of primary coil turns

N_S = number of secondary coil turns

If the voltage across the primary coil and the number of turns in each coil is known, the voltage across the secondary coil can be calculated.



$$V_S = \frac{N_S}{N_P} \times V_P$$

$$V_S = \frac{200}{2000} \times 230\ \text{V}$$
$$V_S = 23\ \text{V}$$

Turns Ratio

The ratio of turns on the primary coil to the number of turns on the secondary coil is called the turns ratio (n):

$$n = \frac{N_P}{N_S}$$

The secondary voltage can be calculated from the turns ratio for a given primary voltage:

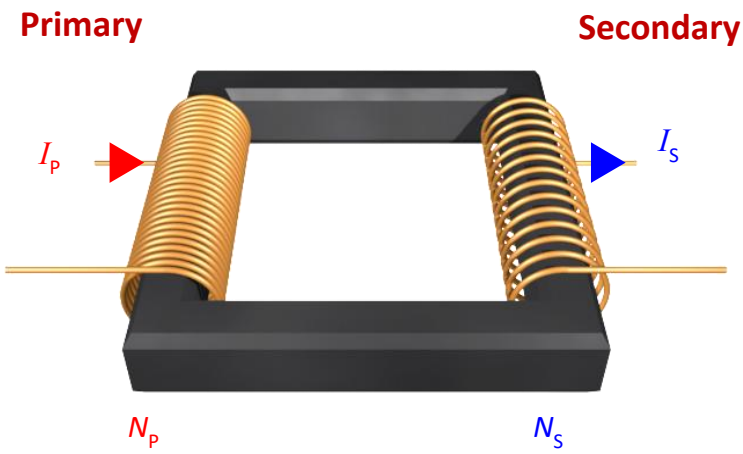
$$V_s = \frac{V_p}{n}$$

$$V_s = \frac{300\ \text{V}}{50}$$

$V_s = 6\ \text{V}$

Calculating Current

The relationship between the currents in the coils and their number of turns is given by this equation:



$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

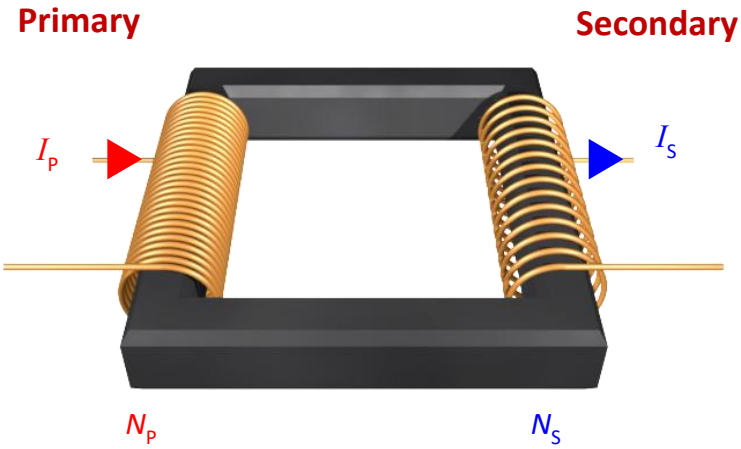
where:

I_P = current in primary coil in A

I_S = current in secondary coil in A

N_P = number of primary coil turns

N_S = number of secondary coil turns



If the current in the primary coil and the number of turns in each coil is known, the current in the secondary coil can be calculated.

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

Rearrange for I_s :

$$I_S = \frac{N_P}{N_S} \times I_P$$

$$I_S = \frac{2000}{200} \times 0.1\ \text{A}$$

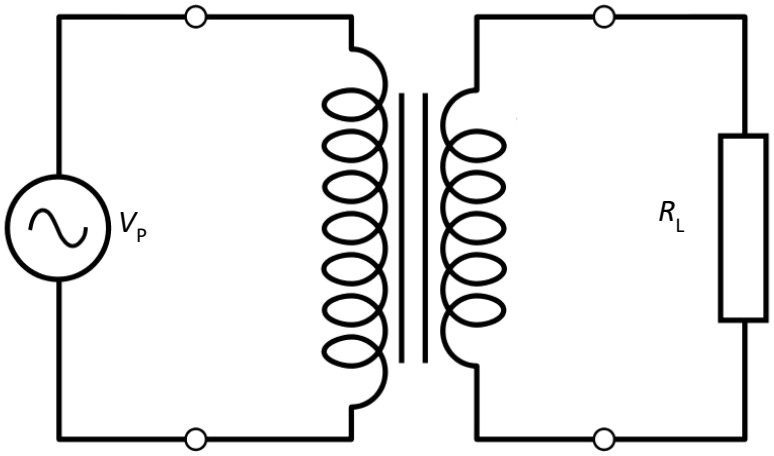
I_S = 1 A

Calculating Resistance

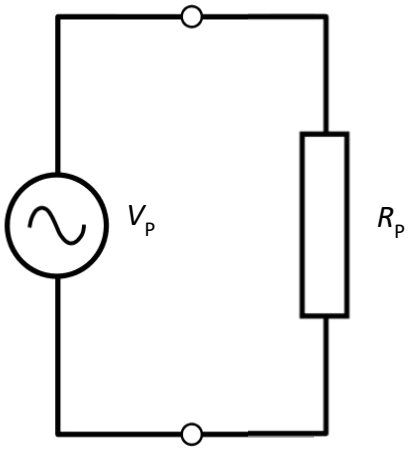
A transformer changes the size of the load seen by the supply source

Instead of the load resistance having the value of R_L , the source sees it as the effective load resistance (R_P):

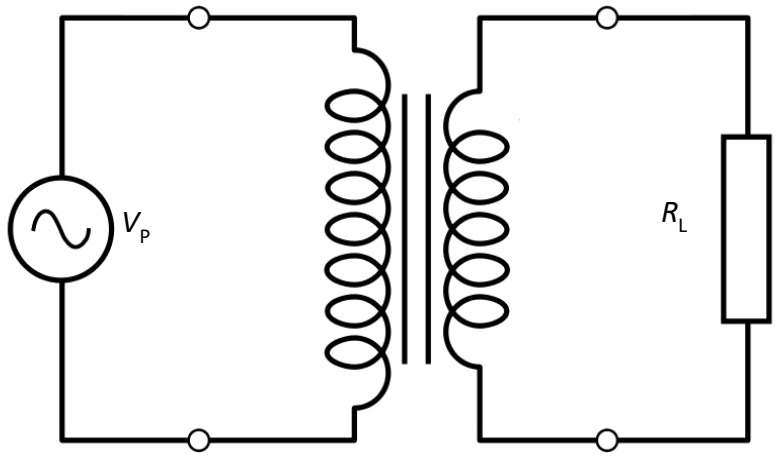
RP = RL □ n2



$$n = \frac{N_P}{N_S}$$



The resistance transfer formula comes from this:

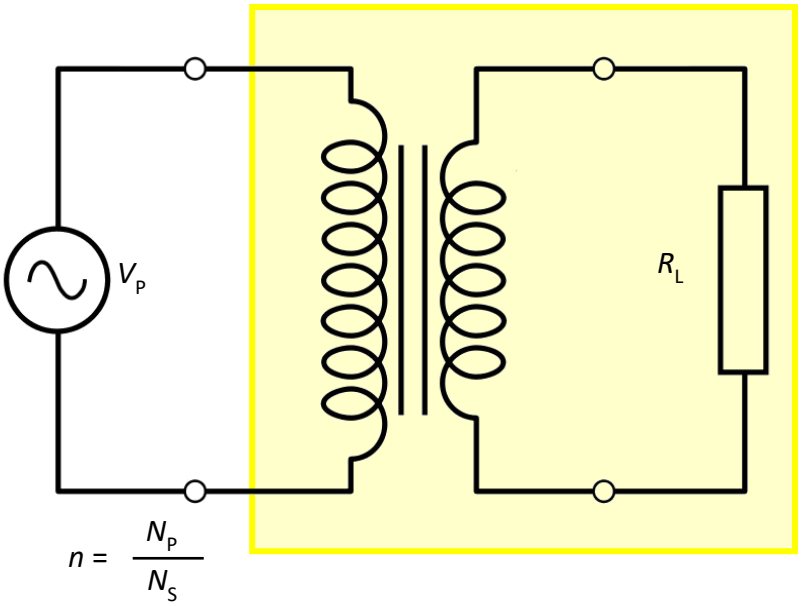


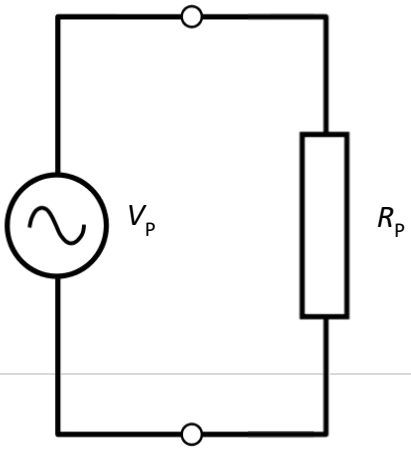
$$\frac{R_P}{R_L} = \frac{\left(\frac{V_P}{I_P}\right)}{\left(\frac{V_S}{I_S}\right)}$$

$$\frac{R_P}{R_L} = \frac{V_P}{V_S} \times \frac{I_S}{I_P}$$

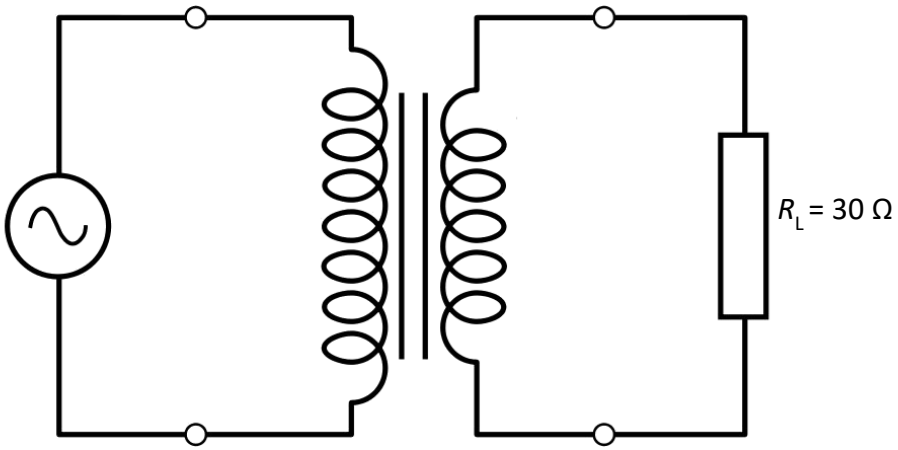
$$R_P = n \times n$$

$$R_P = R_L n^2$$





If the load resistance and the turns ratio is known, the effective resistance (R_P) can be calculated.

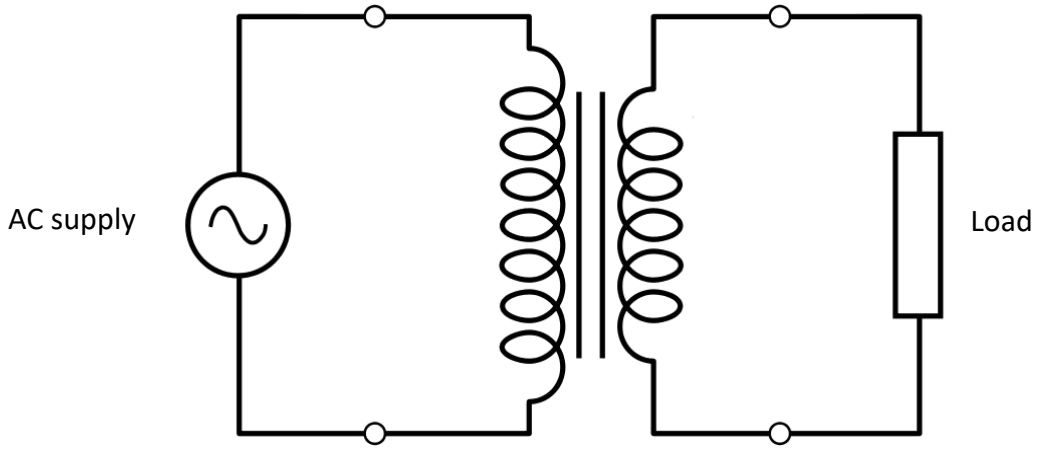


$R_P = R_L \times n^2$

R_P = 30 Ω × 40 × 40

R_P = 48000 Ω

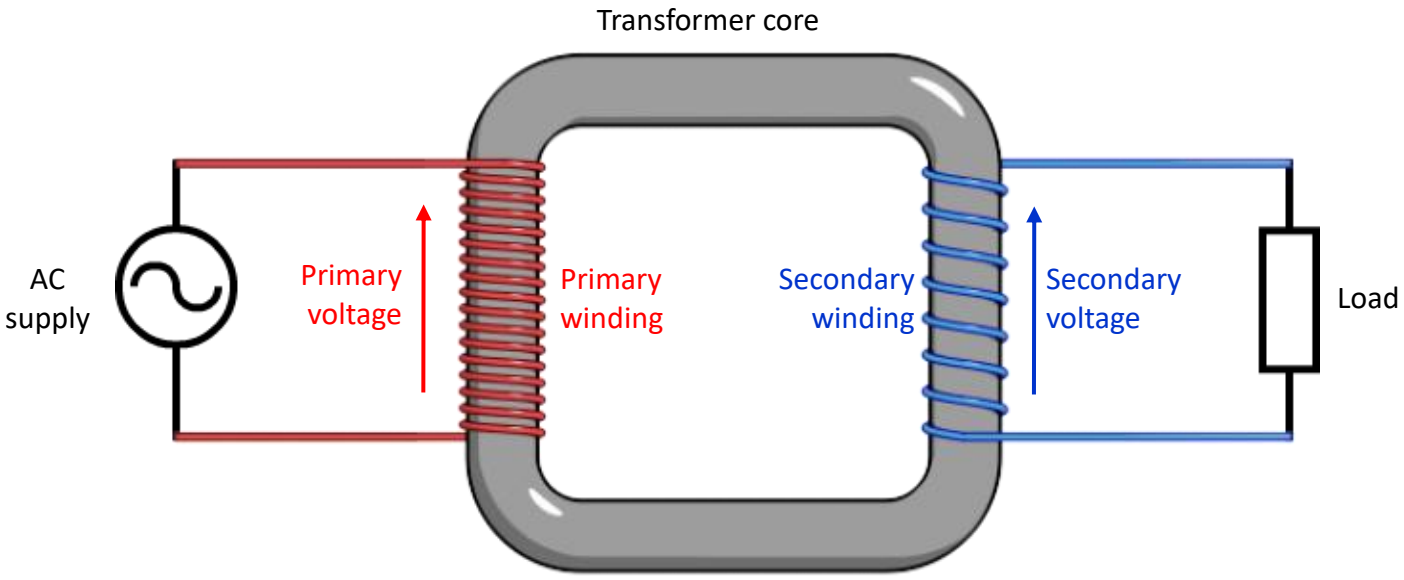
R_P = 48 kΩ



Transformer

Transformers are used to change an AC voltage to a higher or lower AC voltage.

Transformers work on the principle of magnetic induction, so they only work with AC voltages.



A transformer consists of two electrically isolated coils connected by an iron core that forms a magnetic circuit.

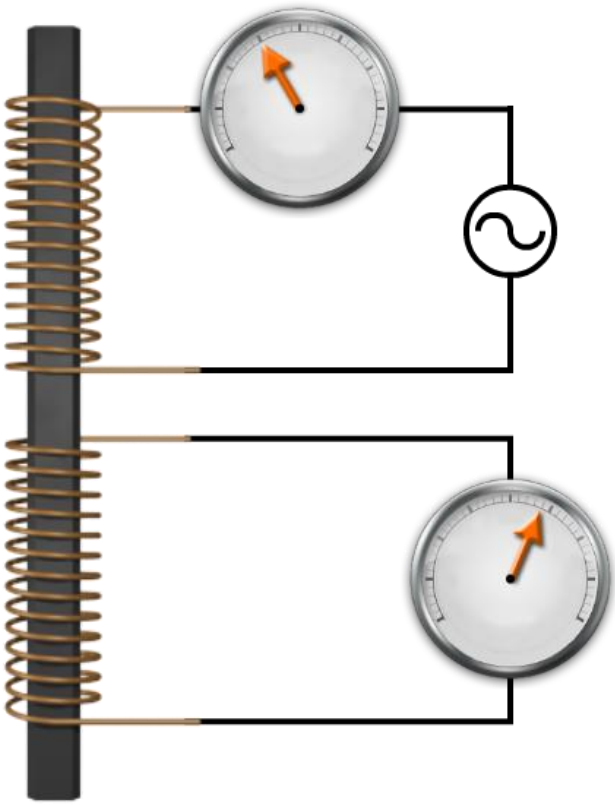
The input AC supply connects to the primary coil.
The load is connected to the secondary coil.

Mutual Inductance

A changing magnetic field will induce an emf in a coil

If two coils are close together, a changing current in one coil will induce an emf in the other coil.

A change in the current of one coil affecting the current and voltage in the second coil is called mutual inductance.



Basic Operation

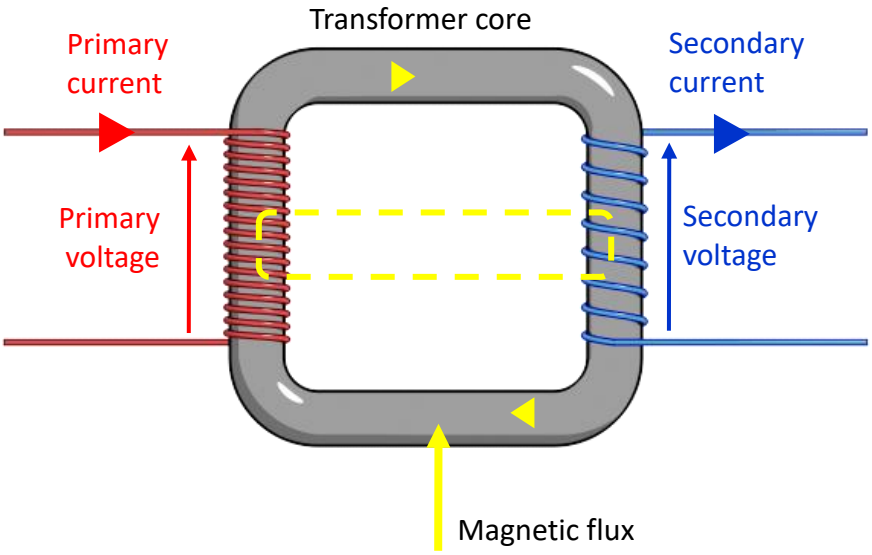
When an AC voltage
is applied to the primary winding, the current in the primary winding generates
a magnetic flux.

The core is magnetic, so the magnetic
flux stays in the core rather than spreading out.

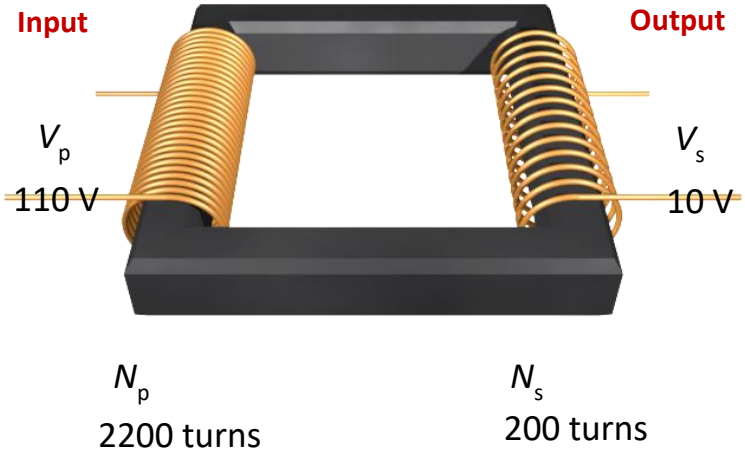
Therefore, the flux links through to the turns of the secondary winding.

According to Faraday's Law, a voltage will
be induced in the secondary winding.

The voltage in the secondary winding will be determined by the rate of change of flux passing through each turn multiplied by the number of turns.



Step-Down Transformers



$$V_s = \frac{N_s}{N_p} \times V_p$$

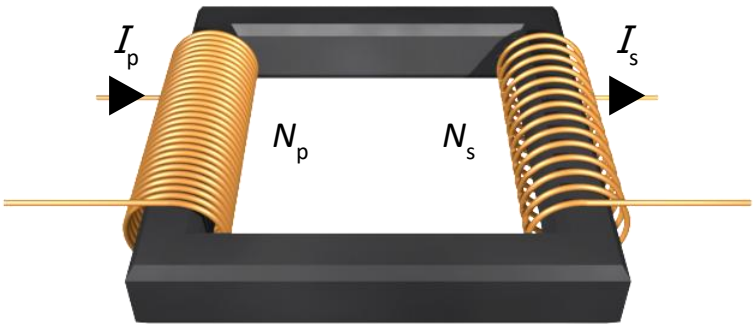
$$V_s = \frac{2200}{200} \times 110 \text{ V}$$

$$V_s = 1210 \text{ V}$$

If the number of turns on the secondary coil is less than the turns on the primary coil, the output voltage will be less than the input voltage.

This type of transformer is a step-down transformer because the output voltage has been stepped down.

Current and Turns Ratio



The relationship between the currents and the number of turns is given by:

$N_p I_p = N_s I_s$

$I_s = n I_p$

where:

I_p = primary current in A

I_s = secondary current in A

N_p = primary coil turns

N_s = secondary coil turns

n = turns ratio

One of the main benefits of AC transmission and distribution is the ease with which the voltage can be changed.

Power is generated at voltages around 11-22 kV and then stepped-up for transmission.

Other transformers are used to step-down the voltage for domestic or industry use.