

HIGA MODEL BOARDING SCHOOL (HMBS)

Short Notes in Physics Grade 10



March, 2012 E.C

Unit Three

Current electricity

Factors affecting the resistance of a conductor

1. Effect of heat on resistance

- The resistance of a metal increases in an approximate straight line against its temperature.
 - ✓ The increase in the value of the resistance as it warms up depends on: The rise in the wire's temperature, ΔT . (The greater the rise, the bigger the increase)
 - ✓ The quantity of the ohms of resistance it possesses. (The greater the number of ohms R_0 at the start, the greater the increase in resistance will be)
 - ✓ The metal it is made from

The increase in resistance is given by $R = \alpha R_0 \Delta T$

Alpha (α) is a constant, which varies from one metal to another.

It is the metal's temperature coefficient of resistance and its unit is K^{-1} (kelvin⁻¹)

2. Effect of length and diameter of resistor on resistance

The resistance of a metal wire at a given temperature is determined by three factors

- Its length l , in metres – the resistance is proportional to l , so if the length doubles so does the resistance.
- Its area of cross-section A , in m^2 – the resistance is inversely proportional to A , so a wire with twice the cross-sectional area will have only half the resistance.
- The material from which the wire is made (copper is a better conductor than iron)

The resistance R of a wire can be expressed as:

$$R = \frac{\rho l}{A}$$

Where ρ is rho that is a constant (the resistivity of the material), its value depends on the material from which the wire is made. The units of resistivity are Ωm – ohms x metres.

The relationship between resistivity and conductivity

The resistivities of most metals are in the range 10^{-7} to $10^{-8} \Omega m$. Those with larger resistivities conduct electricity less well.

The inverse of resistivity is called the conductivity σ , thus:

$$\sigma = 1/\rho$$

where, the SI unit of σ is $(\Omega.m)^{-1}$.

The resistance of a conductor can also be written in terms of the conductivity as follows:

$$R = \frac{1}{\sigma} \frac{L}{A}$$

Combinations of resistors

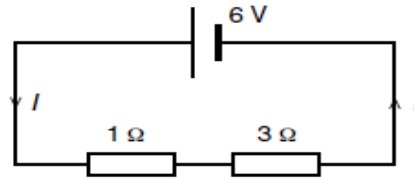
The resistors electrical components that limit or regulate the flow of electrical current in a circuit connected

- In series and parallel

- In practice, electrical circuits can be quite complicated and can consist of resistors and other electrical components connected both in series and parallel.

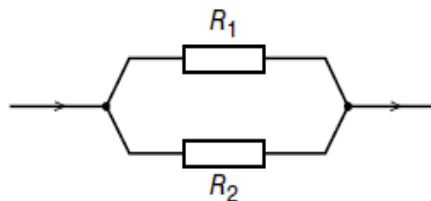
Resistors connected in parallel are thus seen to have a lower total resistance than resistors connected in series.

1. Series combination



- The potential difference V applied across the equivalent resistor, it must produce the same current I : $I = I_1 = I_2$
- The potential difference V is divided to V_1 and V_2 across the resistors R_1 and R_2 , respectively. Thus: $V = V_1 + V_2$
- The equivalent resistor R_{eq} has the same applied potential difference V and the same circuit current I flowing through it; thus: $R_{eq} = R_1 + R_2$ (Series combination)

2. Parallel combination

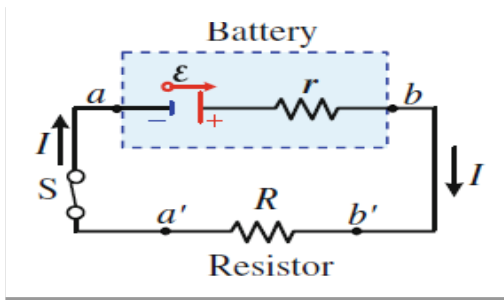
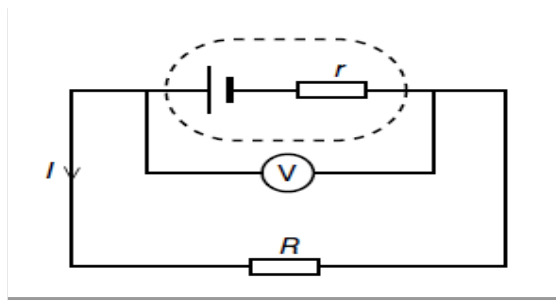


- The potential difference ΔV between the battery's terminals is the same as the potential difference across each resistor: $V = V_1 = V_2$
- When the current I reached junction point, it will split into two parts, I_1 in R_1 and I_2 in R_2 . Because electric charge is conserved, the current I that enters junction must equal the total current leaving that junction; that is: $I = I_1 + I_2$
- An equivalent resistor with the same applied potential difference V and total current I has a resistance R_{eq} given by: $1/R_{eq} = 1/R_1 + 1/R_2$ (Parallel combination)

E.m.f. and internal resistance of a cell

The emf E of a battery is the maximum possible potential difference that the battery can provide between its terminals, usually the voltage at zero current.

A real battery is made of matter; there is a resistance against the flow of charge within the battery. This resistance is called the **battery's internal resistance** and is denoted by r .



The relationship between a cell's e.m.f. ($\mathcal{E}$), internal resistance (r), the current (I) and resistance (R) in a circuit is given by the expression:

$$\mathcal{E} = \text{p.d. across } R + \text{p.d. across } r$$

$$\mathcal{E} = IR + Ir \quad \text{or} \quad \mathcal{E} = I(R + r)$$

It follows that $V = IR$ (Ohm's law) this can also be written as

$$\mathcal{E} = V + Ir \quad \text{or} \quad V = \mathcal{E} - Ir.$$

Solving for I , we get:

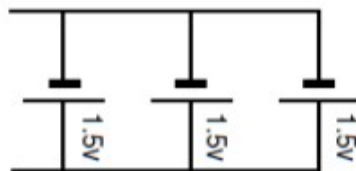
$$I = \frac{\mathcal{E}}{R + r}$$

Note that the current I depends on the resistance R of the external resistor (which is called the load) and the internal resistance r of the battery.

The total e.m.f. of cells connected in series is the sum of the e.m.f. of each cell: $\mathcal{E} = \mathcal{E}_1 + \mathcal{E}_2 + \dots$. Equipment requiring high power uses cells arranged in series. Examples for 3 cells in series: total e.m.f. = $1.5 + 1.5 + 1.5 = 4.5 \text{ V}$



The e.m.f. of cells connected in parallel is the e.m.f. of an individual cell: $\mathcal{E} = \mathcal{E}_1 = \mathcal{E}_2 = \dots$. Examples for 3 cells connected in parallel: total e.m.f. = 1.5 V



Electric energy and power

Power is the rate at which energy is being supplied or converted.

$$P = IV = I^2R = V^2/R$$

Power is measured in the units of joules per second (J/s), or watts (W).

The electrical energy produced by a current of I amperes flowing through a p.d. of V volts for a time t seconds is given by:

$$\text{Energy} = VIt = I^2Rt = V^2t/R$$

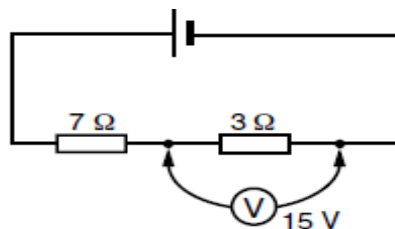
Cost of electrical energy Electricity

is distributed to homes and businesses and the quantity supplied is measured in kilowatt hours (KWh). A kilowatt hour is the energy used by a 1 kW appliance working for 1 hour. Consumers of electricity are charged for each kWh used.

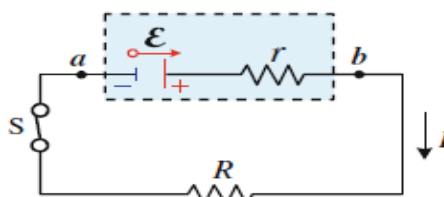
Worksheet Current electricity (Unit Three)

E.m.f. and internal resistance of a cell

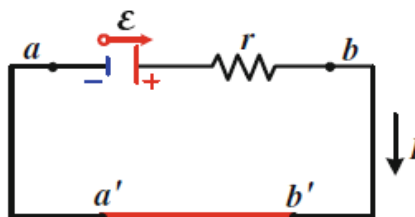
1. A battery has an e.m.f. of 3 V and an internal resistance of $1\ \Omega$. What current will it give if it is connected to a circuit of resistance: a) $2\ \Omega$ b) $4\ \Omega$? What current will it give if its terminals are short-circuited?
2. a) What current is flowing through the $3\ \Omega$ resistor in Figure below? b) If its internal resistance is $2\ \Omega$, what is the e.m.f. of the battery?



3. In figure below the circuit contains a battery that has an emf $E=11\text{V}$ and internal resistance $r=0.5\ \Omega$. The load in the circuit has a resistance $R=5\ \Omega$. (a) Find the current in the circuit. (b) Find the potential difference between a and b.



4. A device is connected to a battery that has an emf $E=9\text{V}$ and internal resistance $r=0.02\ \Omega$. Find the current in the circuit and the terminal voltage of the battery when the device is a: (a) light bulb that has a resistance $R=4\ \Omega$, see Fig below



Electric energy and power and Cost of electrical energy Electricity

1. A light bulb rated 60W at 240V is operated from a 240V source. (a) Find the current flowing through the bulb. (b) Find the resistance of the bulb. (c) Repeat (a) and (b) when the bulb is rated 100 W at 240 V.
2. A 550W electric heater is designed to operate from a 220V source. (a) What is the resistance of the heater? (b) What current does the heater draw from the source? (c) If the source voltage drops to 120V, what power does the heater consume from the source?
3. A 220V potential difference is maintained across an electric heater that is made from a nichrome wire of resistance 20. (a) Find the current in the wire and the power rating of the heater. (b) At an estimated price of 0.35 Ethiopian Birr per kilowatt-hour of electricity, what is the cost of operating the heater for 2h?
4. Two heating coils A and B produce heat at a rate of 1 kW and 2 kW, respectively, when connected to 250 V mains. a) Calculate the resistance of each resistor. b) Find the power they would produce when connected in series to the mains.
5. A 1.5 kW electric fire is accidentally left on overnight for eight hours. The cost of a unit of electrical energy is 0.273 Birrs. How much money has been wasted?
6. A toaster is rated at 600 W when connected to a 120-V source. What current does the toaster carry, and what is its resistance?

Unit Four Electromagnetism

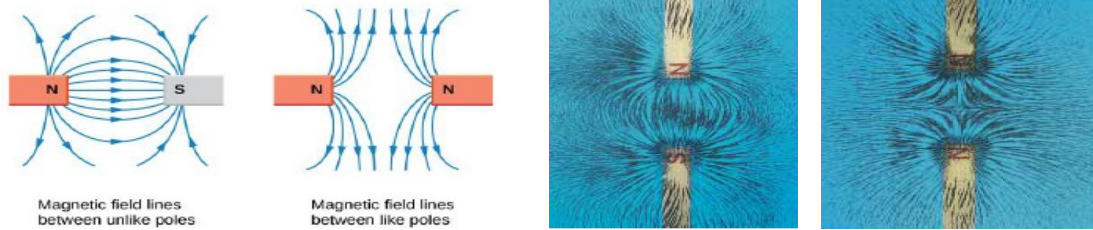
What are magnets? Magnets are metallic substances these attract magnetic materials or metallic substances.

Some properties of magnets:

- every magnet attracts pieces of iron
- magnet has two poles: a north pole (N) and a south pole (S)
“The poles received their names because of the way a magnet, such as that in a compass, behaves in the presence of the Earth’s magnetic field. If a bar magnet is suspended from its midpoint and can swing freely in a horizontal plane, it will rotate until its North Pole points to the Earth’s geographic North Pole and its South Pole points to the Earth’s geographic South Pole.”



- in magnets, like poles (N–N or S–S) repel each other, and opposite poles (N–S or S–N) attract each other



- if we cut a magnet in half, we do not obtain isolated north and south poles (i.e magnetic poles are not separated by breaking magnet in to smaller pieces or magnetic poles are always found in pairs)
- all atoms can exhibit magnetic effects, due to the motion of their electrons about their nuclei
- all magnetic phenomena result from forces arising from electric charges in motion

Magnetism

When an electric charge moves, it generates other forces and fields (other than electric force and field). These additional forces and fields are commonly known as magnetism.

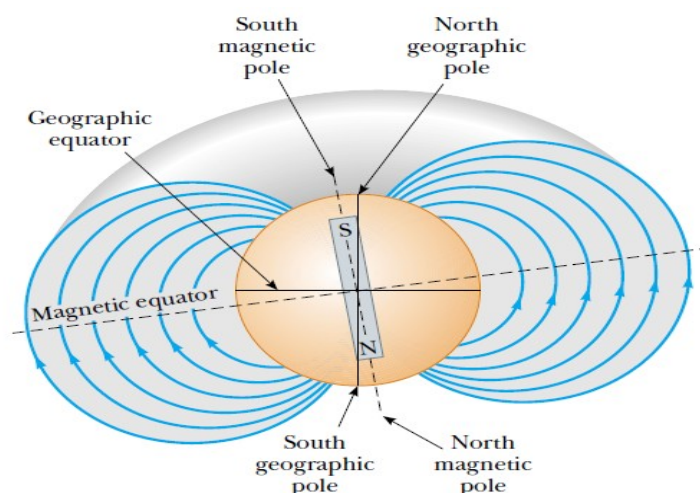
The Earth's magnetic field

The bar magnet has two 'poles' that are ends of a magnet, which are 'north seeking' - N and 'south seeking' - S. When we speak of a compass magnet having a north pole and a south pole, we should say more properly that it has a "north-seeking" pole and a "south-seeking" pole. By this we mean that one pole of the magnet seeks, or points to, the north geographic pole of the Earth. Because the north pole of a magnet is attracted toward the north geographic pole of the Earth, we conclude that the Earth's south magnetic pole is located near the north geographic pole, and the Earth's north magnetic pole is located near the south geographic pole.

The configuration of the Earth's magnetic field, is very much like the one that would be achieved by burying a gigantic bar magnet deep in the interior of the Earth. If a compass needle is suspended in bearings that allow it to rotate in the vertical plane as well as in the horizontal plane, the needle is horizontal with respect to the Earth's surface only near the equator. As the compass is moved northward, the needle rotates so that it points more and more toward the surface of the Earth.

It was known that, birds can detect the Earth's magnetic field, and use the field to find their way when they migrate from cold to warm climates or from warm to cold climates.

Figure-
field lines



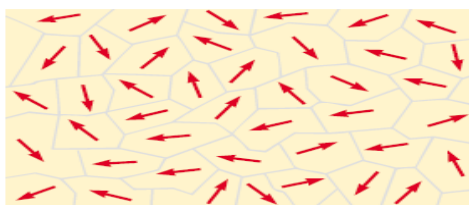
The magnetic
of the Earth

Note that a south magnetic pole is near the north geographic pole, and a north magnetic pole is near the south geographic pole.

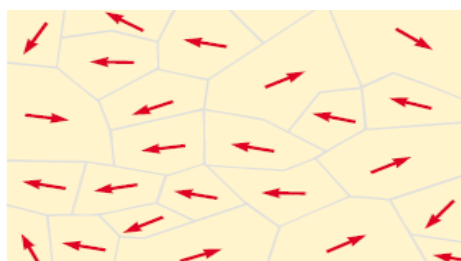
Magnetic domains

Magnetic materials have atoms that act as tiny magnets which we call domains. Magnetic domains are microscopic regions within which all magnetic moments are aligned. These domains have volumes of about 10^{-12} to 10^{-8} m^3 and contain 10^{17} to 10^{21} atoms.

In an un-magnetized sample, the magnetic moments in the domains are randomly oriented so that the net magnetic moment is zero, as in figure below.



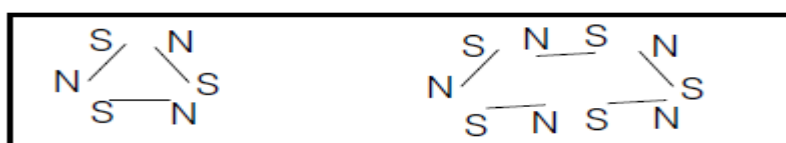
When the sample is placed in an external magnetic field, the size of those domains with magnetic moments aligned with the field grows, which results in a magnetized sample, as in figure below. That means the domains are lined up, then the material is magnetic. If the domains are arranged randomly, then the material loses its magnetism



—————> field direction

When the external field is removed, the sample may retain a net magnetization in the direction of the original field.

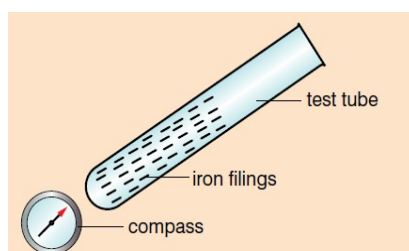
To define magnetic domains let us start with an ordinary un magnetised piece of steel. The little magnets are there in the piece of steel, but they are in clusters rather like thrown large number of small bar magnets into a box. That is the arranged as the ‘N’ end of one magnet is up against the ‘S’ end of another, and the two effectively cancel each other out see Figure below. These regions within a magnetic material which have uniform magnetisation are **magnetic domains**.



Determination of magnetic domains:

Fill a test tube two-thirds full with iron filings or shredded steel wool, the magnetic domains in the tube were arranged randomly so the end of the tube was not strongly magnetised.

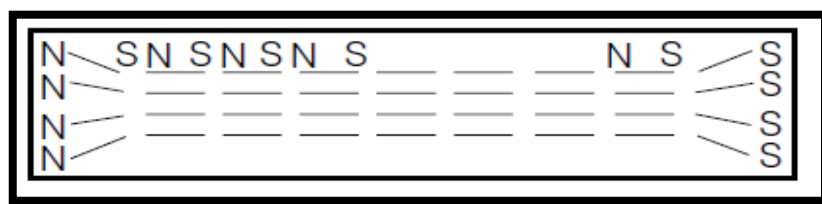
When the tube was stroked by a permanent magnet (the end of the tube is brought towards first the north end of a compass needle and then the south end), the magnetic domains inside the tube arranged themselves so that they were lined up.



In this case one end of the needle more attracted to the tube than the other end and to a greater angle to which the needle deflected the end of the tube was magnetised most highly. That means when the angle of deflection of the compass needle greatest the end of the tube was magnetised most highly.

On the other hand; shaking the tube vigorously disturbed this arrangement and demagnetised the end of the tube. If the steel is weakly magnetised, this means that some of its domains are lined up but some are still in clusters. This show there is a limit to how strongly a given bar can be magnetised ('magnetic saturation' has been reached). The magnetic saturation occurs when all those tiny magnets are in lines and there are no more domains left to break up.

Figure below shows the steel when it is fully magnetised. **Notice that** there are a large number of north poles at one end of the bar, and the same number of south poles at the other. This shows that it was not expect to find a magnet that had a north pole unless it also had a corresponding south pole somewhere else.



Magnetisation

Magnetisation is the extent or degree to which an object is magnetised (i.e is the vector quantity that describes the magnetic state of substances.)

Once steel was magnetised to give a magnet, it may not last in that state for ever. It is the repulsion between like poles that is forcing the tiny magnets to spread out there, and the whole situation is rather unstable. It will not take much for those tiny magnets repelling each other at the end of the steel to jump round and form a cluster again. In other words, a magnet is liable to become weaker as time passes.

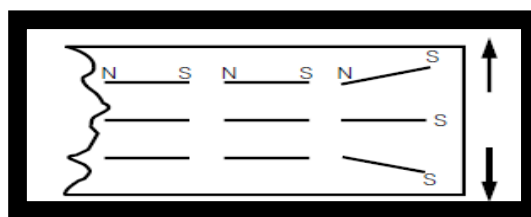
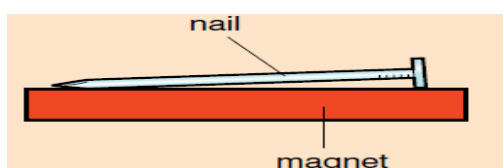


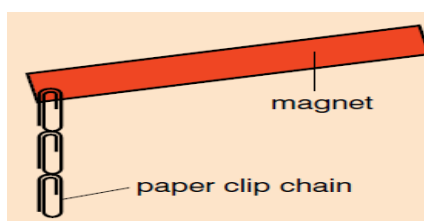
Figure- One end of a magnetised piece of steel

Magnetisation by heating and cooling

1. Use insulated tongs or pliers to heat a nail in the hottest part of the flame of a Bunsen burner until it glows. Use the tongs or pliers to remove the nail from the flame and place it lengthwise on a permanent bar magnet (see figure below).



The tiny magnets, or domains, of the nail are the individual atoms that make up the nail. These atoms will be moving slightly from a given position, and as the nail is heated they will move more and more. This movement is likely to encourage them to jump round out of line (think of a box containing a lot of bar magnets all nicely lined up, and imagine giving it a good shake). By heating the nail until it is red hot, causes all the domains to jumble up. As the nail cools on a permanent magnet, the jumbled up domains line up again and the nail becomes magnetised once more. The magnetic strength of this nail represented by number paper clips can be suspended from a chain at one end.



2. Use another nail that has not been heated and put in on the same bar magnet for the same length of time.

Some of the domains in the cold nail will be jumbled up as well, but some will be lined up before the nail is placed on the permanent magnet. As with the nail that has been heated, the permanent magnet will cause the rest of the domains to line up so that the nail becomes magnetised.

Magnetic shielding

Some types of equipment may not want to become magnetised as it could be damaged as a result. A magnetic shield stops the equipment from being affected by a magnet. Some

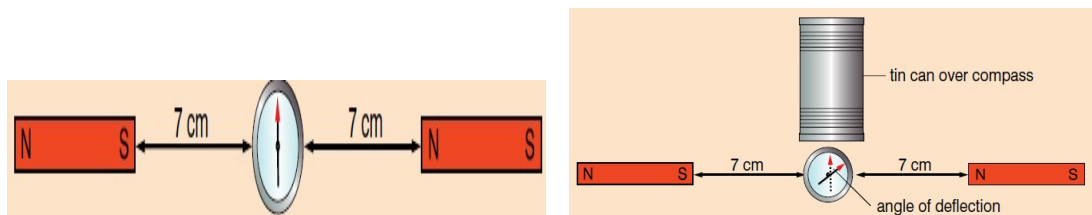
materials can be used as magnetic shields to protect equipment from becoming magnetised. Typical materials used are sheet metal, metal foam and plasma (ionised gas).

Magnetic shielding

- comes in various forms and depends on the equipment that needs to be protected
- limits the penetration of magnetic fields using a barrier of conductive material

If sheet of paper, plastic, a piece of aluminium foil, and the lid of a tin can placed in the gap between the paper clip and the magnet, it was a material used from sheet metals, is used as magnetic shielding.

Thus a magnetic shielding placed on the most top (over) the magnet results an angle of deflection of the direction of the magnet.



The angle of the direction varies with the type of the magnetic shielding material.

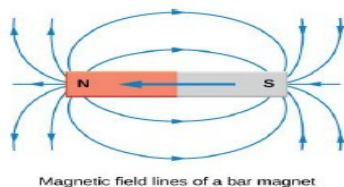
Magnetic field

A magnetic field is a region in which a magnetic force may be exerted. A magnetic field was introduced as a mechanism for exerting a magnetic force on a moving charge and a bar magnet. In the region of space around any moving charge, a magnetic field is established (as well as an electric field), and this magnetic field can exert a force on a second moving charge

If you put a compass down in a magnetic field, it will experience a force that makes it set in a particular direction. The magnetic field is usually mapped in a way suggested by Michael Faraday by using the lines are called lines of force or lines of magnetic flux. The lines of force or lines of magnetic flux indicate the direction a small compass would set at any point.

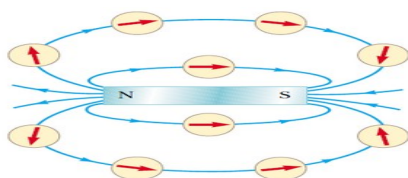
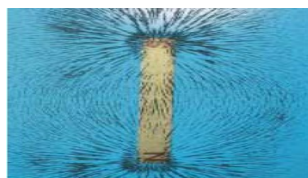
Properties of magnetic field lines:

- ❖ The field lines emerge from the north pole (N), loop around to the south pole (S), and continue through the bar magnet back to the north pole



Magnetic field lines of a bar magnet

- ❖ The direction of the magnetic field is tangent to the field line at any point in space
- ❖ The strength of the field is proportional to the closeness of the lines; it is proportional to the number of lines per unit area perpendicular to the lines
- ❖ Magnetic field lines can never cross
- ❖ Magnetic field lines are continuous, forming closed loops without a beginning or end

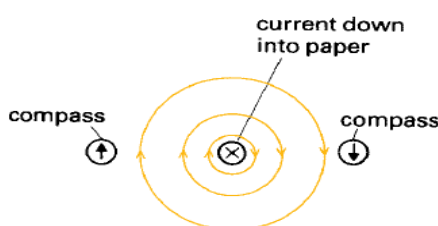
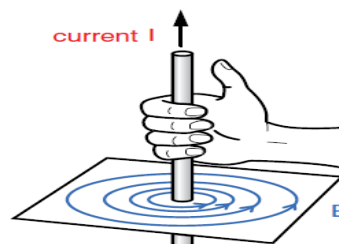


Magnetic field lines around a current-carrying wire

Magnetic field is produced by:

- ❖ metal magnets and,
- ❖ a single charged particle moves through in external magnetic field when the a magnetic force is exerted on it
- ❖ In addition current-carrying wire also experiences a force when placed in a magnetic field (that is an electric current will cause a compass needle to deflect or an electric current gives rise to a magnetic field.)
- ❖ This follows from the fact that the current is a collection of many charged particles in motion; hence, the resultant force exerted by the field on the wire is the vector sum of the individual forces exerted on all the charged particles making up the current.

The direction of magnetic field can be represented as a series of circles centred round the wire, their spacing increasing with distance as the field gets weaker (see figure below) and determined by the right-hand rule.



The right-hand rule:

It is the way to predict the direction of magnetic field due to current carrying conductor. In that case take your right hand and

- ✓ hold the wire with your thumb going in the direction of the conventional current and
- ✓ the way your fingers wrap round the current carrying wire is the way the field lines go

The magnetic field strength represented by symbol (magnetic flux density) **B**, produced at a point due to a current carrying wire depends on:

- the force, **F**
- the current flowing through the wire, **I**
- the length of the wire, **L**

The relationship is given by the formula:

Force = magnetic field strength × current flowing through the wire × length of wire

$$\mathbf{F} = \mathbf{B} \times \mathbf{I} \times \mathbf{L}$$

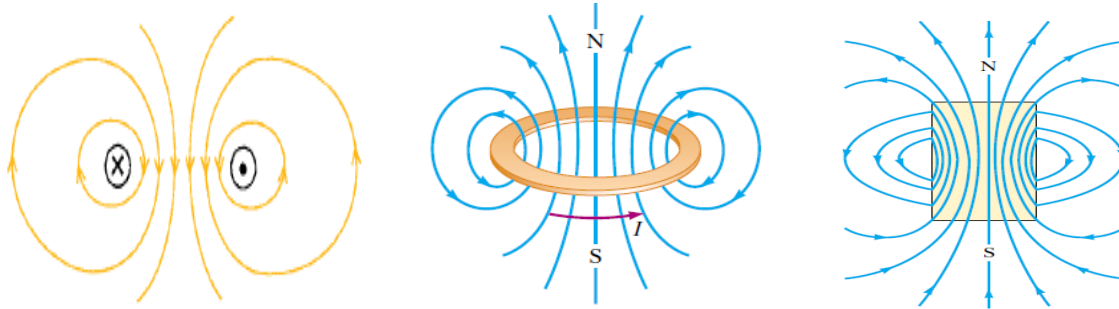
Where the units are newton's (N)... for the force,

amperes (A)... for the current,
metres (m) ...for the length and
Teslas (T)...for the magnetic field strength (magnetic flux density).

Magnetic Field of Circular Current Loop

Consider a circular wire loop carrying a steady current I and magnetic lines of the forces surrounding a current loop are, as shown in figure below.

⊗ means current into paper, ⊙ means current out of paper.



Figures- Representing the magnetic field lines pattern of a current loop

Magnetic field of a solenoid

Solenoid is a coil of wire in which a magnetic field is created by passing a current through it

- The currents in each side of the coil contribute to the overall magnetic field.
- The magnetic field is made up from that produced by each turn.
- Inside the solenoid the field is strong and uniform, while outside it is weak and the field resembles that of a bar magnet.

The direction of the magnetic nature of the solenoid is determined by right-hand rule the fingers point in the direction of the current the end of a solenoid is the North pole that is pointed by the thumb finger and opposite to this end is the South pole.

Magnetic field strength of solenoid

The strength of the magnetic field in a solenoid depends on:

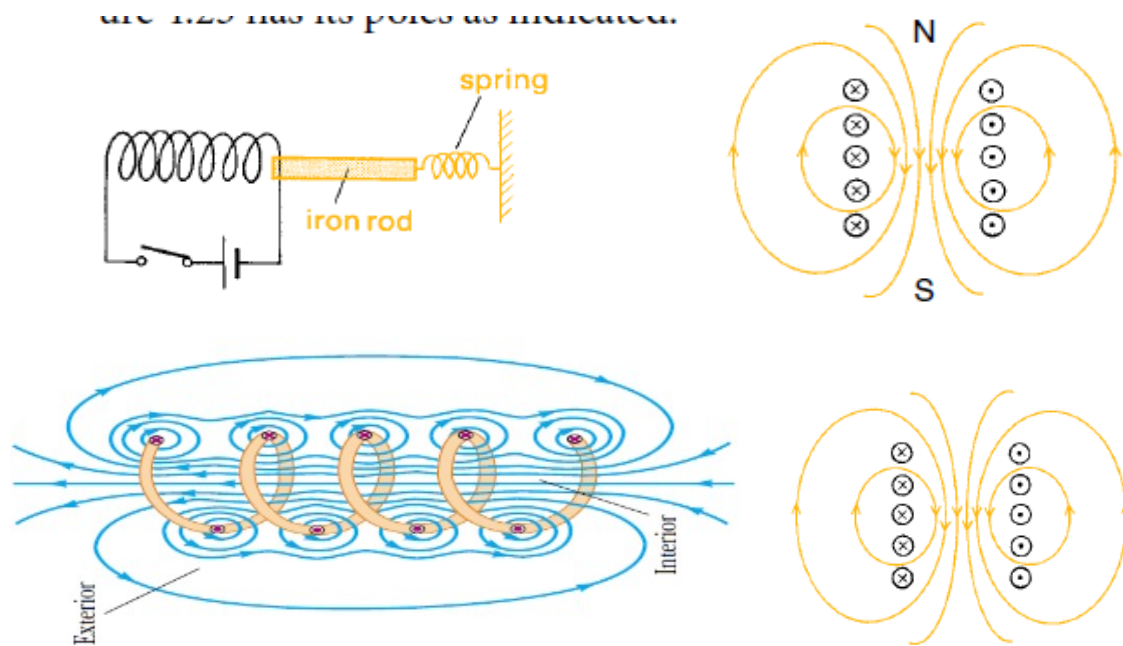
- ✓ the number of turns of wire per metre of length, n
- ✓ the permeability of free space, μ
- ✓ the current flowing through the wire, I

Thus, the field strength = permeability of free space $\times$ number of turns per metre of length $\times$ current

$$B = \mu_0 \frac{N}{\ell} I = \mu_0 n I$$

where $n = N/\ell$ is the number of turns per unit length

In SI units, permeability is measured in the henry per metre (H/m). The constant value μ_0 is known as the magnetic constant or the permeability of free space, and has the exact value of $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$.



Figures- Representing the magnetic field lines pattern of a solenoid and poles of the solenoid.

Magnetic fields and the centripetal force

The magnetic force experienced by the moving charge in external magnetic field is determined jointly by two factors:

- the size of the charge, q ,
- and its velocity, v

Thus from, $F = ILB$, $I = q/t$ and $L = V t$

Therefore, for a single moving charge, the force is given by

$$F = B q v$$

The centripetal force on a body of mass m moving in a circular path of circle of radius R can

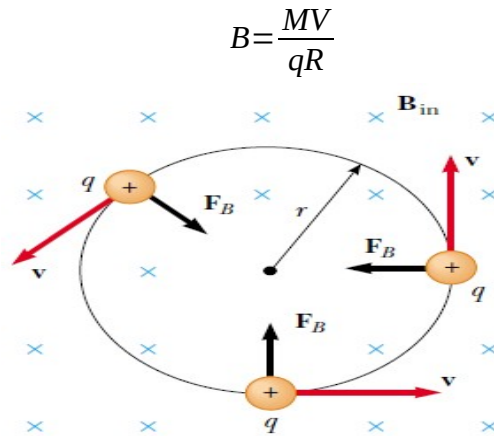
be found using the equation: $F = \frac{M V^2}{R}$

A charged particle moving in a magnetic field will move in a circular path has a magnetic force $F = B q v$

If we make the two equations equal (that is, we assume that the force is the same in both), we have:

$$\frac{M V^2}{R} = B q v$$

Where the magnetic field strength is given by:



If the velocity of a charged particle is perpendicular to a uniform magnetic field, the particle moves in a circular path perpendicularly to $\mathbf{B}$. The magnetic force acting on the charge is always directed toward the center of the circle as shown above.

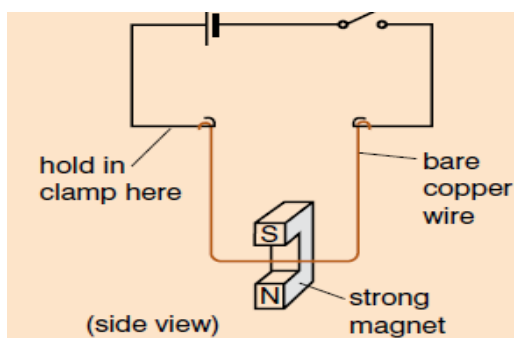
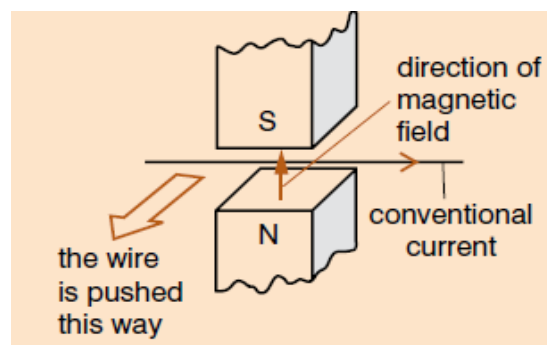
The motor effect

The motor effect can be demonstrated using:

- ✓ A length of fairly stiff copper wire is bent into a square U-shape and is hooked over at the ends.
- ✓ It is allowed to fit from the ends of the rest of the circuit as shown below, so it can swing freely but the electric current can still be flow into and out of it.
- ✓ Magnets are placed as shown and the magnetic lines of force experienced by the North pole of a magnet.
- ✓ The south pole of the magnet will be pushed the opposite way.

The magnetic field experiences a magnetic force on the current carrying wire is shown below. Thus current in the copper wire makes the wire move the opposite way, and so does reversing the direction of the magnetic field (by turning the magnet the other way up).

Notice that the wire moves not in the direction of the magnetic field, but at right angles to it.



Figures- Representing the U-shaped copper wire can swing freely and it moves at right angles to the direction of the magnetic field

When the current flows through the wire, both magnets will be pushed downwards. The magnets are usually fixed in position, but according to Newton's third law of motion, if they

are being pushed down, the current in the wire will experience an equal sized push force upwards. This is the motor effect.

In that case the factors that determine the force on a current carrying conductor:

- ❖ the current, the length of the wire, the strength of the magnet, $\mathbf{F} = \mathbf{B} \mathbf{I} \mathbf{L}$
- ❖ If the current is perpendicular to the field, the full BIL force is experienced, but if the current is in the same direction as the lines of the magnetic field (magnetic flux), there will be no force.
- ❖ In general, if there is an angle θ between the wire and the field, then: $\mathbf{F} = \mathbf{B} \mathbf{I} \mathbf{L} \sin\theta$

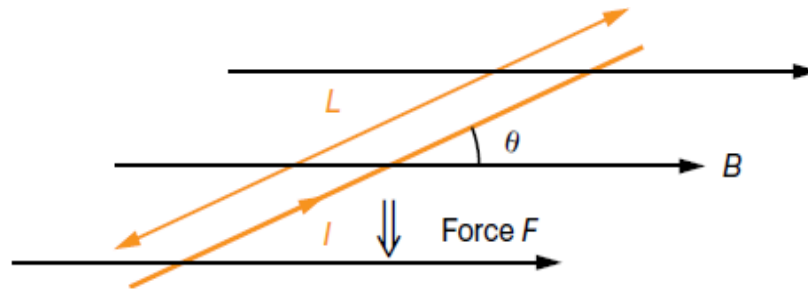


Figure Motor effect force

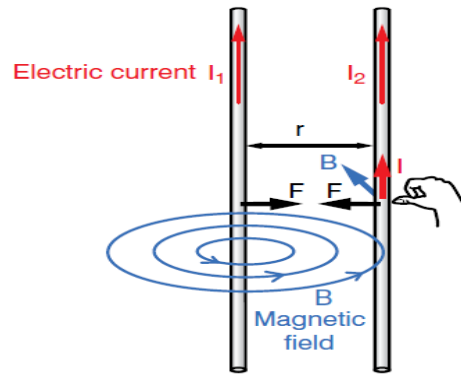
The Right-hand rule:

To predict the direction of the movement produced by the motor effect, we can use Right-hand rule. Hold the thumb and first two fingers of right hand at right angles to each other.

- ❖ If the first Finger points along the magnetic field and the second (middle) finger shows the, direction of the magnetic force then the Thumb points in the direction of the Conventional Current.

Magnetic force between two parallel current-carrying conductors:

Two parallel wires each carrying a current will interact with each other. Consider two long; straight, parallel wires separated by a distance 'r' and each carrying a steady current I_1 and I_2 . We can determine the force exerted on one wire due to the magnetic field set up by the other wire. Wire 2, which carry a current I_2 and are identified arbitrarily as the source wire, creates a magnetic field B_2 at the location of wire 1. The magnetic force on a length L which is perpendicular to B_2 of wire 1 is given as $F_1 = I_1 L B_2$. That means current in one wire creates a magnetic field that extends out to where the second wire is. The current in this second wire then experiences a force due to the motor effect.



The magnetic field in wire 2 from I_1 is given by

$$B = \frac{\mu_0 I_1}{2\pi r}$$

The force per unit length in terms of the currents is therefore

$$\frac{F}{\Delta l} = \frac{I_2 \mu_0 I_1}{2\pi r} \quad \text{rearranging this equation we have} \quad F = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

Defining the ampere

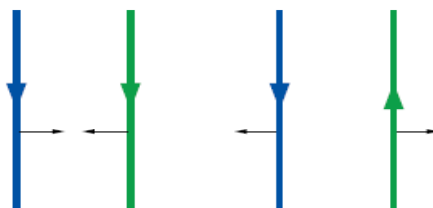
The size of a standard ampere has been fixed (**think of** a current of 1 ampere as meaning that 1 coulomb of charge is flowing past every second).

Ampere is defined by the force between two parallel wires as follows:

One ampere (1 A) is defined to be flowing of the identical current in each of two long parallel wires separated by 1 m (i.e $r = 1$ m) in a vacuum, then the magnitude of the force per unit length on each wire will be exactly 2×10^{-7} N/m.

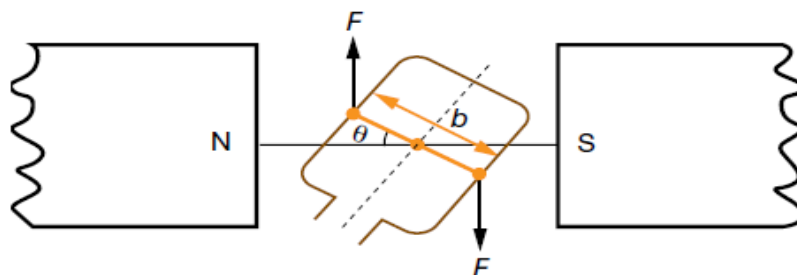
The value 2×10^{-7} N/m is obtained from Equation $F = \frac{\mu_0 I_1 I_2 l}{2\pi r}$ with $I_1 = I_2 = 1$ A, and the distance between the two wires is $r = 1$ m.

If the two parallel conductors carrying currents in the same direction then, they attract each other, and with currents going opposite ways they repel each other.



Force on a rectangular current-carrying wire

Consider a coil of length L and N turns carrying a current I as shown below.



When the current flows the same way in both coils, and the plane of the coil makes an angle θ with the magnetic field. If the current in the left-hand side of the coil is coming up out of the paper and that in the right-hand side is going down, the forces will be in the directions shown. The magnitude of each force F will be $F = BILN$.

- ❖ These two forces provide a torque, **a turning effect**, on the coil.
- ❖ The total torque is the sum of the two moments.
 - ✓ The distance the left-hand force acts from the pivot is d , which is $b/2 \cos\theta$ (where b is the full width of the coil). Therefore the moment due to each is $f \times b/2 \cos\theta$.
 - ✓ The two forces combined give double this moment, which is $F b \cos\theta$. $F = 2 (f \times b/2 \cos\theta)$
 - ✓ Now put using force ($f = BILN$) we get the torque to be given as

$$T = BILN b \cos \theta$$

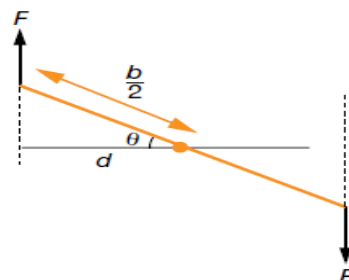
Since $L \times b = A$, is the area of the coil.

Therefore: **Torque on the coil is**

$$T = BIAN \cos \theta$$

When $\theta = 0$ the torque is a maximum.

When $\theta = 90^\circ$ the torque drops to zero, - the two sides of the coil are still being pushed up and down, but the distance between those forces has fallen to 0.



The electric motor

The principle of the direct current motor is the forced movement of a current carrying loop in a magnetic field. The torque on a current carrying loop will cause it to rotate. If it is free to move then the loop will rotate continuously. You can find the direction of the force using a right hand rule again: the thumb points in the direction of conventional current, the index finger in the direction of the magnetic field and the middle finger in the direction of the force. A direct current motor will have a coil with many turns of wire but Figure below simplifies the situation and just shows a single rectangular loop.

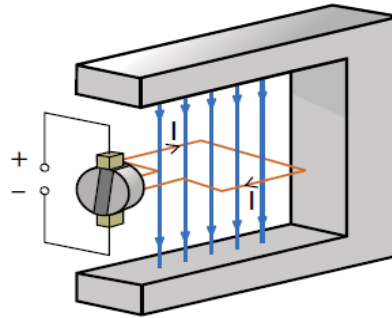
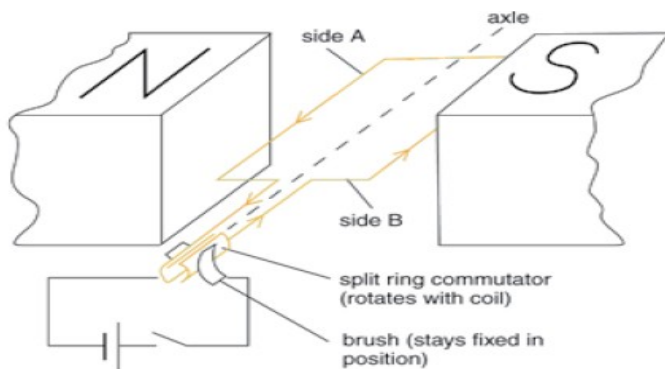


Figure- A direct current motor

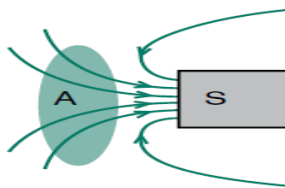
To lead the current into the coil, and to reverse its direction automatically at the right moment, the coil ends up in two segments of metal called a split-ring commutator (see Figure below). The two wires from the battery end in brushes which press against each of the segments of the commutator.



Magnetic flux

The strength of a magnetic field is also indicated by the quantity of flux (Φ) through any given area. Flux is measured in Webers (Wb). To find the flux for a particular region you multiply the area of the region by the flux density:

$$\Phi = B \times A$$



Electromagnetic induction

If a magnetic field moves (or changes) near a wire, the electrons in the wire will feel a force which will tend to make the conduction electrons move through the wire. This movement of conduction electrons is an induced e.m.f. and, if the wire is part of a complete circuit, then the electrons will move, producing a current. Thus electromagnetic induction is the production of voltage across a conductor moving through a stationary magnetic field. It is also known as the dynamo effect, is one way to cause a current to flow rounding that circuit. The dynamo effect means that a voltage will appear whenever a conductor cuts through a magnetic field.

An induced e.m.f. an e.m.f. produced when a magnetic field moves (or changes) near a wire

The laws of electromagnetic induction

The laws of electromagnetic induction

Faraday's law of electromagnetic induction: states that the magnitude of an induced e.m.f., ϵ , is proportional to the rate of change of flux.

Mathematically, we can write this as

$$\epsilon = N \Delta\Phi / \Delta t$$

where N is the number of turns of coil, $\Delta\Phi$ is change in magnetic flux, & Δt is change in time

Lenz's law: the direction of the induced e.m.f. is such as to oppose the change creating it. If we include this law about the direction of the induced e.m.f. with our mathematical expression for Faraday's law we get

$\epsilon = - \Delta\Phi / \Delta t$ For a coil with N turns this can be written as $\epsilon = - N\Delta\Phi / \Delta t$ and since $\Phi = BA$ for a coil of area A

$$\epsilon = - N \Delta(BA) / \Delta t$$

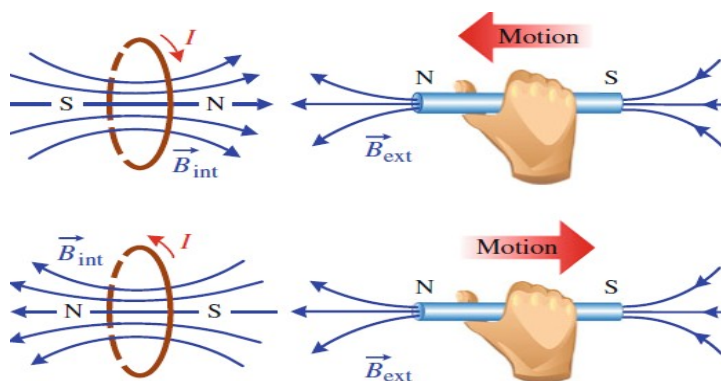


Figure- The internal magnetic field $\vec{B}_{int}$ opposes the increase in the flux of $\vec{B}_{int}$ and opposes the decrease in the flux of $\vec{B}_{int}$

Inductors

When an alternating current is made to pass through the inductor with an iron core the dynamo effect comes into play as the magnetic flux through it is changing. The iron core that becomes magnetised when a current through a solenoid is not part of the actual circuit, but instead relies on the magnetic field associated with the electric current flowing round the coil.



The symbol for an air-cored inductor

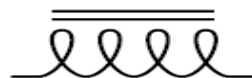


Figure represents an inductor with an iron core,

This shows that circuit the effect is not a direct part of the electrical circuit rather there exist change in current through the coil. All electromagnets possess inductance (i.e an inductor is essentially an electromagnet).

Inductance is defined as the property in an electrical circuit where a change in the electric current through that circuit induces an e.m.f. that opposes the change in current.

Self-induction

Any current, I , in an electrical circuit, produces a magnetic field and hence generates a magnetic flux, Φ , acting on the circuit. According to Lenz's law, this magnetic flux tends to act to oppose changes in the flux by generating a voltage (back e.m.f.) in the circuit which counters or tends to reduce the rate of change of current. The magnitude of the effect is specified by the coil's self-inductance, L . The self-inductance is usually referred to as the inductance of the circuit.

The self-inductance (L) of the circuit is the ratio of the magnetic flux (Φ) times turns of wire (N) to the current,

$$\text{In symbols this is written as } L = \Phi N / I$$

The factors which determine the magnitude of self-inductance are:

- ✓ the rate at which the current in the coil is changing
- ✓ magnetic flux
- ✓ number of turns on coil that is the geometry of the coil
- ✓ what its core is made from

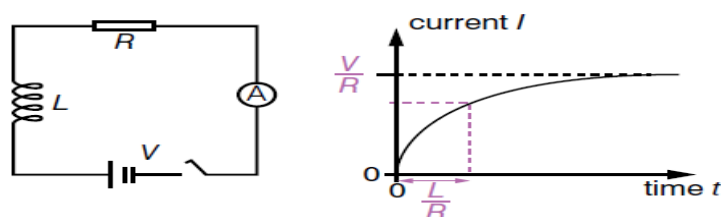
induced e.m.f. = a constant $\times$ the rate of change of the current.

$$\mathcal{E}_{\text{ind}} = L \Delta I / \Delta t$$

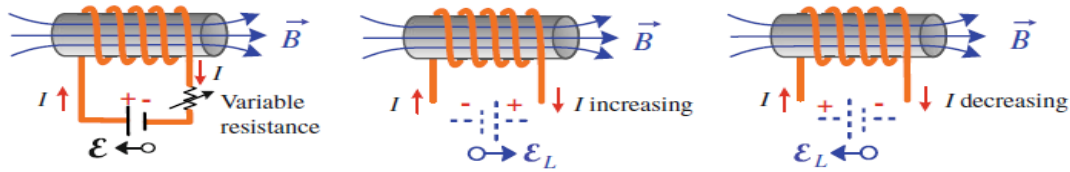
The rate of change of current is measured in A/s, so that the SI unit of inductance will be V/A s, = henry, H. That is $1\text{H} = 1 \frac{\text{V S}}{\text{A}} = 1 \Omega \cdot \text{S}$ or $1\text{H} = 1 \frac{\text{Wb}}{\text{A}} = 1 \text{Tm}^2/\text{A}$

When a circuit comprising a battery of e.m.f. V , an inductor (L) and a resistor (R) in series is turned on, the current builds up to its final steady value of V/R .

NOTE inductance the property in an electrical circuit where a change in the electric current through that circuit induces an e.m.f. that opposes the change in current self-inductance the ratio of the electromotive force produced in a circuit by self-induction to the rate of change of current producing it.



- ❖ The current is turned on at time $t = 0$. It then rises to its final value of V/R in the form of an inverted exponential curve, reminiscent of the build-up of charge as a capacitor fills up through a resistor.
- ❖ With a capacitor, the time constant of the circuit was given by CR and represented the time taken for the curve to rise to about 63% of its final value. Here the time constant is given by L/R .
- ❖ When you switch such a circuit off, the current cannot then die down exponentially to zero because the circuit has been broken. The current has to stop flowing almost instantaneously.



When the current I in the coil increases with time

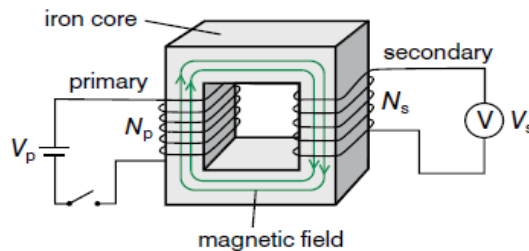
- ❖ The magnetic flux through the coil also increases
- ❖ The increasing magnetic flux creates an induced emf $\mathcal{E}_L$ in the coil
- ❖ The induced emf and its induced current are opposing the emf and current generated by the source

When the current I in the coil decreases with time

- ❖ The magnetic flux through the coil also decreases
- ❖ The decreasing magnetic flux creates an induced emf $\mathcal{E}_L$ in the coil
- ❖ The induced emf and its induced current are in the same direction as the emf and current I generated by the source

Mutual inductance

The change in a magnetic field due to one coil induces an e.m.f. in another coil; this type of induction is called mutual inductance. The faster the current in one changes, the greater the e.m.f. induced in the other. It will be small if the two circuits are well spaced apart; it will be large if a coil in one circuit is wound round a coil in the other circuit.



Mutual inductance is the ratio of the electromotive force in a circuit to the corresponding change of current in a neighbouring circuit. The rate of change of magnetic flux in coil 2, Φ_{21} , is proportional to the rate of change of current in coil 1 and

$$N_2 \frac{\Delta \Phi_{21}}{\Delta t} = M_{21} \frac{\Delta I_1}{\Delta t}$$

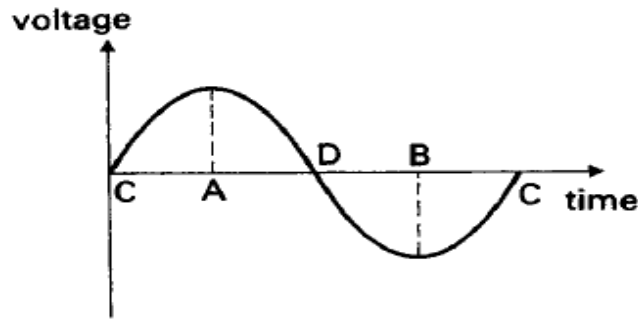
The mutual inductance M of a pair of circuits is given by: e.m.f. induced in one circuit = $M \times$ (rate of change of current in the other circuit)

$$\text{This is written } \mathcal{E}_{\text{mut}} = M \Delta I_2 / \Delta t$$

The unit of M will also be the henry, H.

A simple a.c. generator

It is difficult to generate a continuous current by swinging a wire in a magnetic field. The wire is going round at a steady speed, so it is cutting the lines of force at a maximum rate at points A and B. At these moments the voltage induced in the wire is at its greatest, one way round at A and the other way round at B. At stages C and D in the rotation, although the wire is moving, no lines of force are being cut, so at those instants the voltage is zero.



Suppose you have not a single wire but a rectangular coil which may be rotated about an axle. As the left-hand side moves up through the magnetic field, the right-hand side will move down. The voltages induced at that moment have been represented in Figure 4.58 by cells.

A practical arrangement by which the coil may be rotated and yet joined to a circuit in a very similar to the simple electric motor, but this time the coil has to be turned rather than turning by the motor effect.

The connection to the outside circuit is again made by sliding brush contacts. It is not necessary to reverse those connections every half a turn, however, so the commutator is replaced by a pair of slip rings.

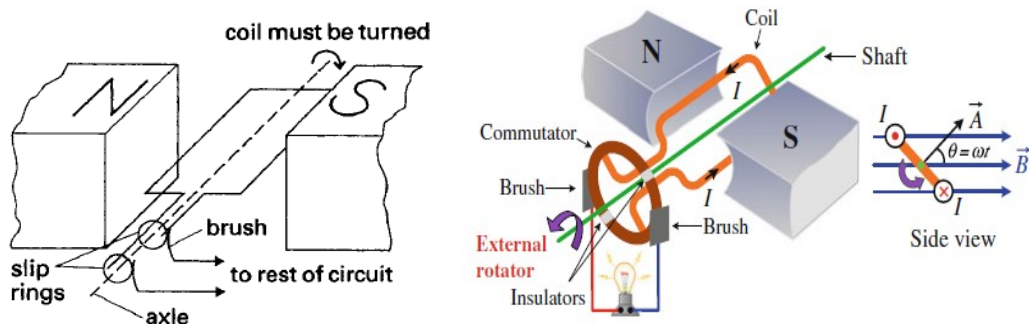
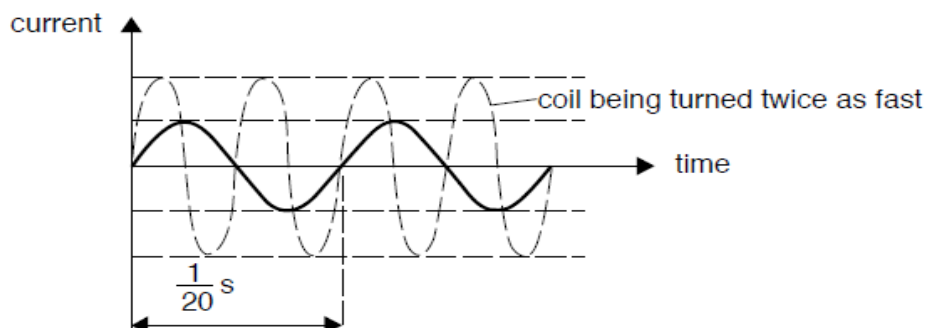


Figure- How the coil is joined to the circuit

The output of this dynamo will be in the form of an alternating current (the continuous line in Figure below) whose frequency is determined by the rate at which the coil is being rotated.



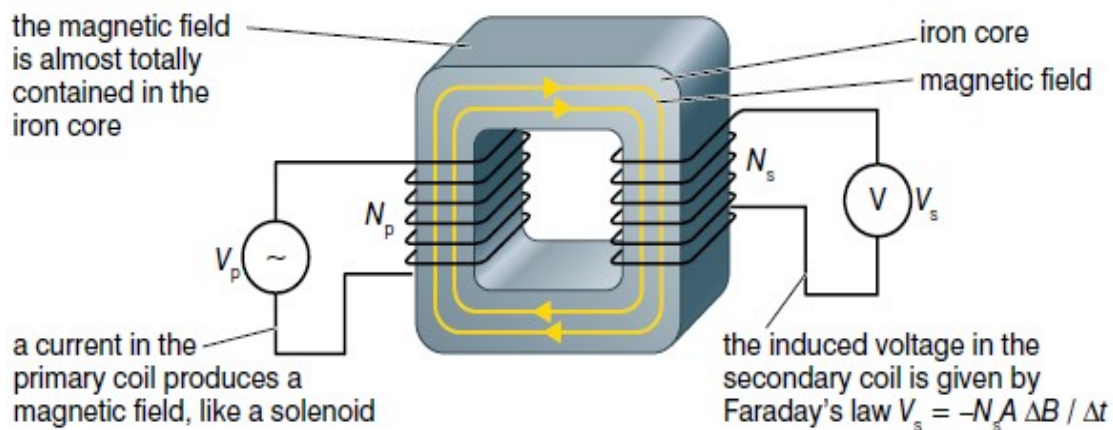
Suppose the coil takes 120 s to complete one revolution. It will then turn 20 times every second, so the frequency of the alternating current (a.c.) will be 20 Hz.

If the dynamo is turned at twice the rate, two things will change:

- the coil turns in half the time, so the frequency of the a.c. will double;
- by Faraday's law, since it cuts through the magnetic field twice as fast, the induced voltage will be doubled and so will the current (the dotted line on Figure above shows this)

In Ethiopia, several projects including renaissance dam have been initiated to generate more electricity using hydroelectric power. In hydroelectric power, the mechanical energy is supplied by water running through turbines which rotate and generate the electricity.

Transformers



Transformer is a device that transfers electrical energy from one circuit to another, usually with a change of voltage. It is used to change voltage. An alternating current (a current that varies with time) is supplied to the primary coil (alternating current (a.c.) is a current that periodically reverses direction). As this current is constantly changing, a constantly changing magnetic field is set up. This changing field induces an e.m.f. in the secondary coil which, unlike the situation in Figure below, does not decrease to zero, but varies constantly at the same rate as the alternating current supplied to the primary.

The magnitude of the induced e.m.f. depends on:

- ❖ the strength of the magnetic field (which depends on the number of turns on the primary coil)
- ❖ and the number of turns on the secondary coil

The ratio of the number of turns on the primary coil to the number of turns on the secondary coil is the same as the ratio of the voltage on the primary coil to the voltage on the secondary coil

Thus transformer equation relates the output (the secondary) to the input (the primary) is:

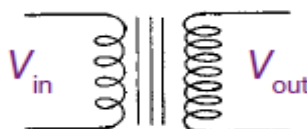
$$\frac{V_{out}}{V_{in}} = \frac{\text{number of turns on the secondary } (N_s)}{\text{number of turns on the primary } (N_p)} = \frac{I_{out}}{I_{in}}$$

$$\text{OR} \quad \frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

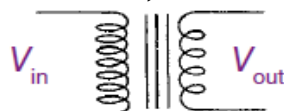
This relationship enables transformers to change voltage, for example, to decrease the mains supply down to a level suitable for use in an appliance.

Kind of transformers

❖ **Step-up transformer** in which $N_s > N_p$, then $V_s > V_p$



❖ **Step-down transformer** in which $N_s < N_p$, then $V_s < V_p$



For step-up or step-down ideal transformers, the power output is equal to the power input.

$$\text{For which} \quad I_p V_p = I_s V_s \text{ or } \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

Power delivered is $P = W/t = V q/t = VI$

Worksheet

Unit Four

Electromagnetism

Magnetic field, Force, and motion of charged particles in a uniform magnetic field

1. Why any suspended compass will show magnetic north direction.
2. a) What is a magnetic domain? b) Does domains be used to explain what happens when a piece of steel becomes magnetised? How? c) What happens to the domains when a magnetic material is heated?
3. How a nail can be magnetised?
4. a)What is magnetic shield? b) how you describe best magnetic shield materials?
5. Show that how to demonstrate the existence of a magnetic field around a current-carrying wire.
6. a) What are the force on which a moving charge in a magnetic field depends?
b) What are the factors that determine the size of a force on a current-carrying conductor?

7. A particle of mass m carries a charge q and is travelling with a velocity v , enters a region where there is a perpendicular magnetic field of flux density B .
 - a) Determine the magnitude and direction of the motor effect force that will act on the particle.
 - b) Why the path of the particle due to this force will be a circle.
 - c) Show that the particle moves in a circle of radius $r = \frac{mv}{Bq}$
8. Discuss about the basic motor effect.
9. Define an ampere.
10. Calculate the magnetic field strength when a current of 2 A flows in a wire 2 m long and produces a force of 8 N.
11. A solenoid has 2000 turns per metre and has a current of 1 A passing through it. Work out the field strength at its centre. The permeability of free space is $4\pi \times 10^{-7}$ H/m
12. A solenoid of length $L = 0.5\text{m}$ carries a current $I = 2\text{A}$. The solenoid consists of six closely-packed layers, each of 800 turns. What is the magnitude of the magnetic field inside the solenoid?
13. A solenoid of length $l = 0.25\text{m}$ carries a current $I = 10\text{A}$. The solenoid consists of twenty closely packed layers, each of 500 turns. What is the magnitude of the magnetic field inside the solenoid?
14. A solenoid has a length $L = 10\text{ cm}$. A superconducting fine wire (with almost zero resistance at low temperature) is wound in 10 layers such that $n = 4 \times 10^4$ turns per meter. (a) What is the number of turns per layer? (b) What is the magnitude of the magnetic field B produced inside the solenoid when the current I in the wire is 60A?
15. An electron in the hydrogen atom orbits a fixed proton at a radius $r = 5.29 \times 10^{-11}\text{ m}$ with a speed $v = 2.4 \times 10^6\text{ m/s}$. What is the magnitude of the magnetic field at the proton?
16. A particle of mass $2.7 \times 10^{-26}\text{ kg}$ and velocity $8.0 \times 10^6\text{ m/s}$ has a charge of 1 e and moves in a radius of 200 m. What is the magnetic field strength?
17. What is the radius for an electron moving in a vacuum entering a magnetic field of 0.02 T at a speed of $4.5 \times 10^7\text{ m/s}$. (The mass of an electron is $9.1 \times 10^{-31}\text{ kg}$ and it carries a charge of $-1.6 \times 10^{-19}\text{ C}$)?
18. What is the force on a coil in a magnetic field of 0.2 T, with a current of 1 A, an area of 0.025 m^2 and 100 turns?

Magnetic Flux and Electromagnetic induction

1. State the laws of electromagnetic induction
2. State the factors that affect the magnitude of induced e.m.f. in a conductor.
3. Show the link between electricity and magnetism.
4. Define the following
 - a) Inductance and give its SI unit.
 - b) Self-inductance and Mutual inductance
 - c) Magnetic flux
5. Explain the action and work of the simple a.c. generator
6. Explain why the magnetic field in a solenoid is greater if the solenoid has an iron core.
7. What is the magnetic flux when a magnetic field of strength $2 \times 10^3\text{ T}$ covers an area of 0.2 m^2 ?

8. A coil of wire has $N = 15$ turns and each turn has an area $A = 0.04 \text{ m}^2$. The coil is placed in a uniform magnetic field directed perpendicular to the plane of the coil and connected to a resistor of resistance $R = 2 \Omega$. The magnetic field changes linearly from 0.1 T at time $t = 0$ to 0.6 T at time $t = 0.5 \text{ s}$. (a) what is the magnitude of the induced emf in the coil during this time interval? (b) What is the magnitude and direction of the induced current?
9. A circular loop of radius $r = 5 \text{ cm}$ is perpendicular to a uniform magnetic field that is pointing out of the page and has an initial magnitude $B_i = 0.6 \text{ T}$. During a time interval of 0.2 s the field is changed to a final magnitude $B_f = 0.2 \text{ T}$ and now points into the page. What is the average induced emf in the loop?
10. A square loop of wire has a side $a = 5 \text{ cm}$ and is perpendicular to a uniform magnetic field of magnitude $B = 0.8 \text{ T}$. The orientation of the loop changes in a period of 0.4 s until the surface of its plane is parallel to the field. What is the average induced emf in the loop?
11. The magnetic flux through a loop of wire changes from -20 to $+20 \text{ Wb}$ in 0.2 s . What is the average induced emf in the loop?
12. What is the relationship between magnetic field strength, mass of particle, velocity of particle, charge on particle and radius of path?
13. In a machine called a mass spectrometer, charged particles follow a curved path. For these particles we have $Bqv = \frac{mv^2}{R}$ where R is the radius of the path.
 - a) Show that this gives $\frac{q}{m} = \frac{V}{BR}$.

The particles are accelerated to speed v by an electric field and their kinetic energy $\frac{1}{2}mv^2 = qV$

b) Show that this gives $v = \sqrt{\frac{2qV}{m}}$

By substituting this into the expression for q/m , show that $\frac{q}{m} = \frac{2V}{B^2 R^2}$

14. Find the radius of the path of $^{35}\text{Cl}^-$ ions in such a machine if $V = 3.0 \text{ kV}$ and $B = 3.0 \text{ T}$. ($q = 1.67 \times 10^{-27} \text{ C}$)

TRANSFORMER

1. Explain the works of transformer and give a simple explanation of the principles on which a transformer operates.
2. The transformer used to charge a laptop reduces 220-V ac to 19V ac . Assume that the primary coil contains 400 turns and the charger supplies 5A to the laptop. Find: (a) the number of turns in the secondary coil and the current in the primary coil, and (b) the power transformed.
3. A transformer has $N_P = 500$ turns in the primary coil and $N_S = 60$ turns in the secondary coil. (a) What kind of transformer is this? (b) By what factor does this transformer change the ac voltage and current?
4. Suppose the output is fed to a circuit of resistance 5Ω . The 10 V will supply an alternating current of 2 A to the circuit. How large will the current 'I' be that is drawn from the mains, if the output voltage is 100 V ?
5. The transformer of a neon lamp operates from an alternating source of 220V . The lamp requires 10 kV to operate. What is the ratio of the secondary to primary turns of the transformer coils?

