التكنولوجيا التطبيقية

APPLIED TECHNOLOGY

وزارة التربية والتعليم والتعليم الفني

جمهورية مصر العربية

وزارة التربية والتعليم والتعليم الفني

وحدة تشغيل وإدارة مدارس التكنولوجيا التطبيقية

Student guide

Physics

Year 2

(STEM)

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Contents

Competencies		**Skills (Be able to)**		**Knowledges**
TP1	**Explain The Magnetic Fields due to current passing through a conductor, and magnetic force and magnetic torque**	**TPC1.1**	Define the concept of Magnetic Field	TPK1 meaning of magnetic field and Magnetic Field Due to Current Passing Through a Straight Conductor, Circular Coil at Its Center and a Solenoid
		TPC1.2	Calculate the Magnetic Field density And Direction At A Normal Distance From A Straight Current-Carrying Wire	
		TPC1.3	Calculate The Magnetic Field Strength And Direction At The Center Of A Current-Carrying Loop (Circular Coil)	
		TPC1.4	Field Intensity At A Point On The Axis Of A Calculate The Magnetic Solenoid.	TPK2 The Magnetic Force Acting On a Wire Carrying Current Placed in A Magnetic Field and The Magnetic torque Acting On a coil Carrying Current Placed in A Magnetic Field
		TPC1.5	Calculate The Magnetic force acting on a wire carrying current	
		TPC1.6	Calculate The Magnetic torque acting on a coil carrying current	
TP2	**Explain Electromagnetic Induction and faraday's law and Lenz's law and some concepts related to induction**	**TPC2.1**	Explain the meaning of induction and faraday's law	TPK3 Meaning of Electromagnetic Induction and Faraday's Law
		TPC2.2	Determine The Polarity of Induced Current in A Coil by Using Lenz's Rule.	
		TPC2.3	Understanding the concept mutual and self-induction	TPK4 Lenz's Law.
		TPC2.4	Identify The Factors That Affect The Induced EMF In Coil	TPK5 Mutual and Self-Induction and: The Electric Generator (Dynamo) and The Electric Transformer
		TPC2.5	Identify the structure and operation of electric generator	
		TPC2.6	Identify the structure and operation of electric transformer	

Unit one
Magnetic effect of electric current

Dear student, By the end of this lessons you should have the following skills and knowledges

Understand the concept of magnetic field
Identify the shape of magnetic field due to current in a straight wire, circular coil and solenoid
Calculate the magnetic flux density at a point from a wire carrying current
Calculate the magnetic flux density at center of circular coil carrying current
Calculate the magnetic flux density at a point along axis of the solenoid carrying current
Identify the factors affecting the magnetic force acting on a straight wire carrying current placed in a uniform magnetic field
Identify the factors affecting the magnetic torque acting on a coil carrying current placed in a uniform magnetic field

Lesson 1
Meaning of magnetic field

Introduction

The magnetic effect of electric current (electromagnetism) is defined as
(Magnetic field is produced around a conductor when an electric current passing through it)

- The magnetic effect of current was discovered by **Oersted (Danish physicist) in 1820**.

Experiment

a) Hans Christian Oersted brought a compass near a metallic wire carrying an electric current; he noticed that the compass was deflected.

b) When he turned the current off, the compass returned to its original position.

Conclusion

When the electric current flowing in a wire (conductor) always produces a magnetic field around it

The deflection of the compass while current was flowing through the wire indicated that the magnetic field is produced

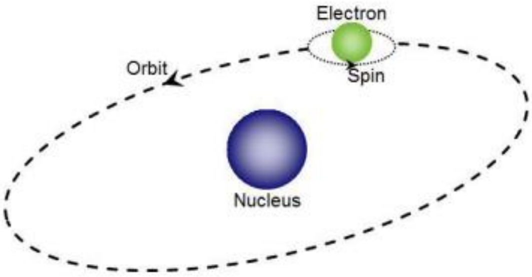
This discovery started a chain of events that has helped shape our industrial civilization.

The origin of the magnetic field (magnetism)

Magnetic field is generated due to motion of electrons (electric charges) (charged particles) within its atoms. So, Magnetism arises from two types of motions of electrons in atoms

1) The motion of the electrons in an orbit around the nucleus, similar to the motion of the planets in our solar system around the sun

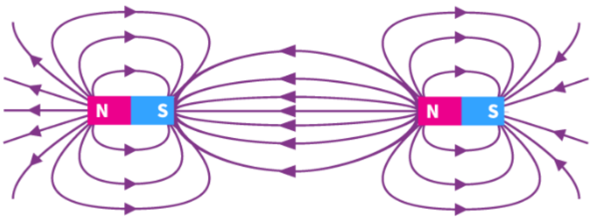
2) The spin of the electrons around its axis analogous to the rotation of the Earth about its own axis.



The magnetic field

(**The magnetic field** is the area around a magnet (or a current – carrying a conductor) where magnetic forces can act)

The magnetic field lines are imaginary lines to represent magnetic fields



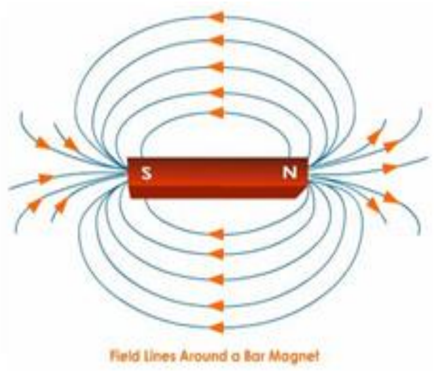
a) **The shape of a magnetic field**

b) **The direction of the magnetic field (from N to S)**

c) **The magnetic field density (B)**

Properties of magnetic field lines

a) Magnetic field lines never cross each other
b) Magnetic field lines always make closed loops (continuous curves) and will continue inside a magnetic material
c) Magnetic field lines always emerge or start from the North Pole and terminate at the South Pole.
d) The direction of the magnetic field is taken to be the direction in which a north pole of the compass needle moves inside it. Therefore it is taken by convention that the field lines emerge from North Pole and merge at the South Pole. Inside the magnet, the direction of field lines is from its south pole to its north pole.

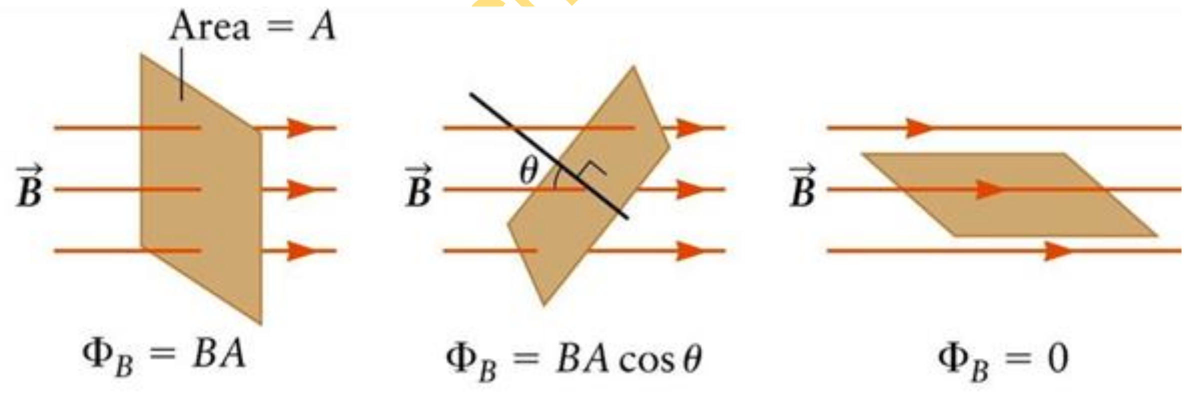


Magnetic flux (Φ_m)

Magnetic flux is a measurement of the total magnetic field which passes through a certain area. It is a useful for helping describe the effects of the magnetic force on something occupying a certain area
We can define the magnetic flux as follows
(It is the total number of magnetic flux lines passing through a surface)

$$\Phi_m = B\ A\cos\theta$$

Φ_m: The magnetic flux through a surface (Weber)
B: the magnetic flux density (Tesla)
A: the surface area (m^2)
θ: the angle between the perpendicular to (normal to) surface and direction of magnetic field

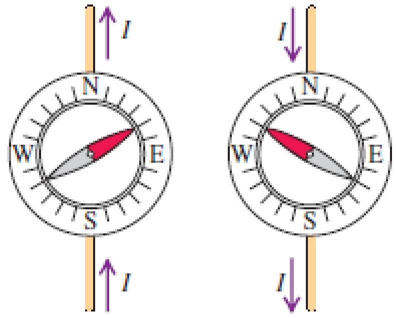


Lesson 2
Magnetic field due to current passing through a straight conductor

Introduction

Every electric current produces a magnetic field. The magnetic field can be visualized as a pattern of circular field lines surrounding the wire.

Early experiments:



In 1819, Oersted showed that an electric current was able to cause a magnetic needle, placed close to a current-carrying conductor, to be deflected.
When the electric current to flow in the conductor, a magnetic needle placed above the conductor is deflected. As soon as the current stops flowing, the needle returns to its original position. If the direction of the current is reversed, as in the diagram on the right, the needle is deflected in the opposite direction.
You have to distinguish between two experssions are magnetic flux and mmagnetic flux density

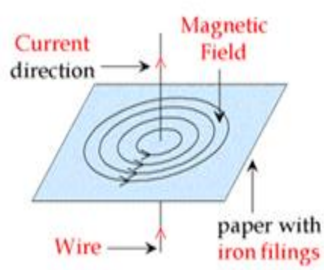
The magnetic flux density B

- It describes the density and direction of the field lines that passes through a certain area **A**. The denser the field lines, the larger the magnetic flux density, which is measured in tesla (T) that equivalent to Weber/ m^2 (Wb /m^2).
- When the magnetic flux lines are closer to each other, so the magnetic flux density will be large and vice versa.
- (It is the total number of magnetic flux lines passing **normally** through a unit area around the point)

$$\mathbf{B = \frac{\Phi_B}{A}}$$

Magnetic field due to a current in a straight wire:

The shape of the magnetic field:

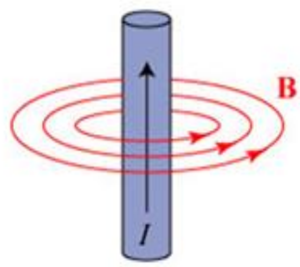


We can examine the shape of magnetic field by using iron fillings sprinkled on a paper surrounding the wire in a vertical position,

a) The magnetic lines of force around a straight wire carrying current are concentric circles **whose centers lie on the wire**

b) The circular magnetic flux lines are closer together near the wire and farther apart from each other as the distance from the wire increases.

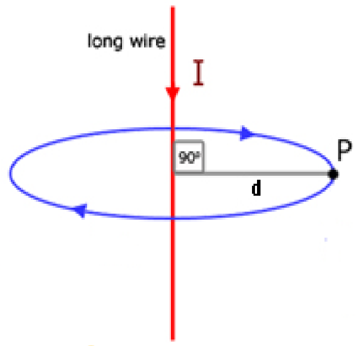
c) The current passing through the wire increases, the concentric circles more crowded



The magnitude of the magnetic field density (B):

The density of magnetic field at a certain point can be given by the following relation

$$B = \frac{\mu I}{2\pi d}$$



This relation is called **Ampere's circular law**

Where:

B: the magnetic field density **(Tesla)**

I: intensity of current passing through the wire **(Ampere)**.

d: The distance of the point from the wire **(meter)**.

μ: magnetic Permeability of medium **($\mu_{air} = 4\pi \times 10^{-7}$ Wb/m.A)**

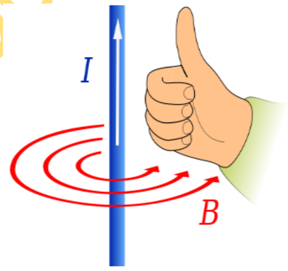
The magnetic permeability

(It is the ability of medium to penetrate the magnetic flux lines)

The measuring unit

Wb/m.A = T.m. /A

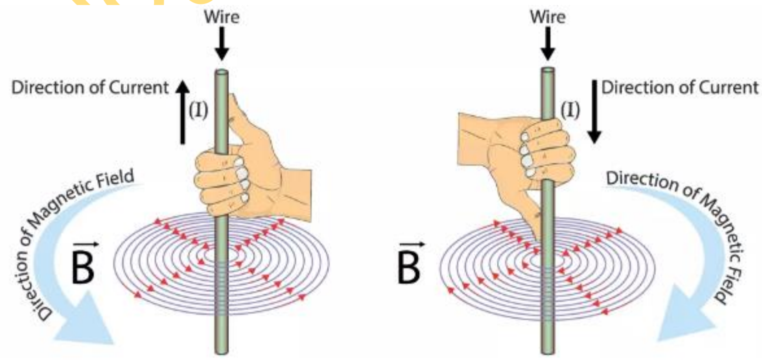
The direction of magnetic field

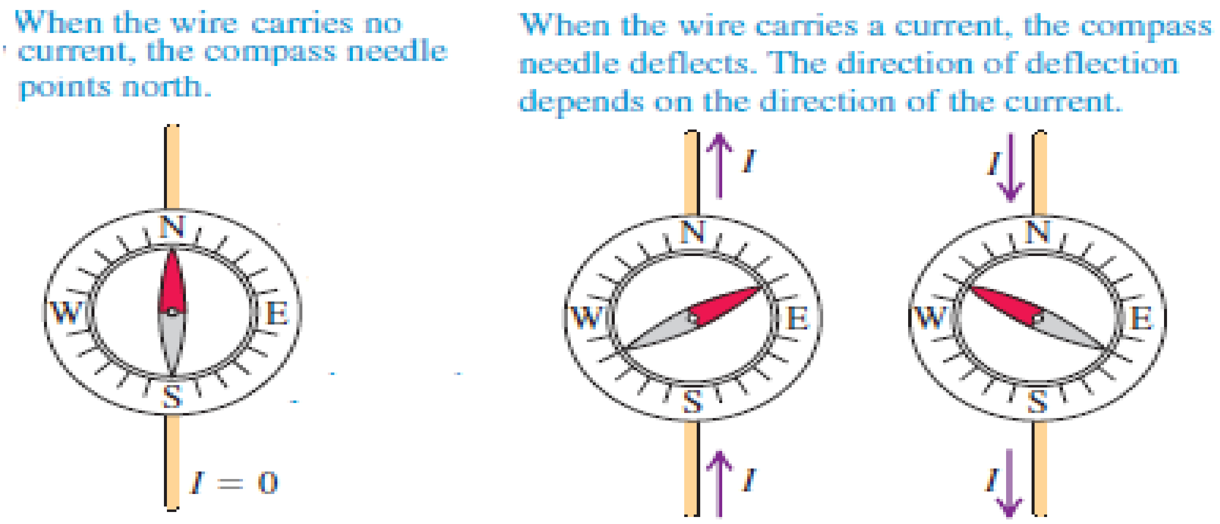


To determine the direction of the magnetic field resulting from an electric current in a wire, by using Ampere Right Hand Rule

Ampere Right Hand Rule.

If the thumb points in the direction of the current, the rest of the fingers around the wire will indicate the direction of the magnetic field due to the current.





Lesson 3
Magnetic field due to current passing through a circular coil (loop)

Introduction

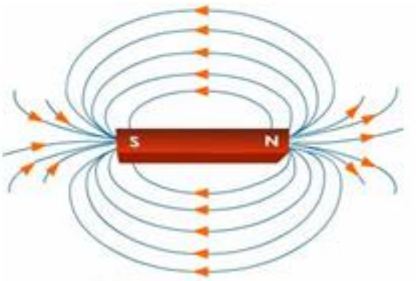
A circular coil of wire can be used to generate a nearly uniform magnetic field similar to that of a short bar magnet.

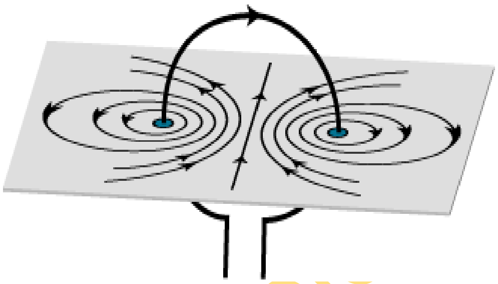
Magnetic field due to a current in a circular coil:

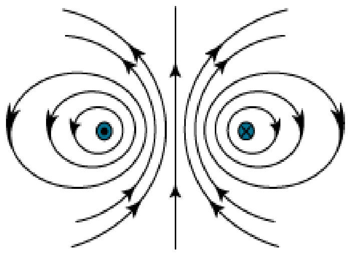
The shape of the magnetic field

When a current is passed through a circular coil, a magnetic field is produced around it which is more concentrated in the center of the loop than outside the loop.

1) The flux lines are circular surrounding the two sides
2) The flux lines are no longer circular near the center
3) The flux lines become straight and parallel lines perpendicular to the plane of the coil at the center of the coil. This means that the magnetic field in this region is uniform.







The magnitude of the magnetic field density (B):

The magnetic field density at center of the circular coil can be given by the following relation

$$B = \frac{\mu NI}{2r}$$

Where:

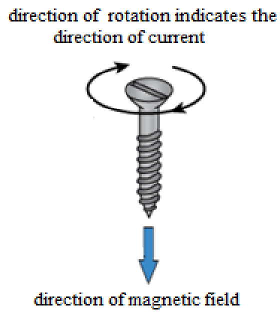
B: the magnetic flux density **(Tesla)**

I: intensity of current passing through the wire **(Ampere)**.

r: the radius of the circular coil **(meter)**.

μ: Permeability of medium **($\mu_{air} = 4\pi\times10^{-7}$ Wb/m.A)**

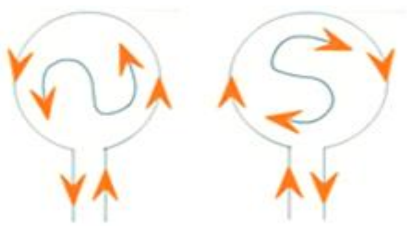
The right Cork Screw rule (Maxwell's Screw Rule)

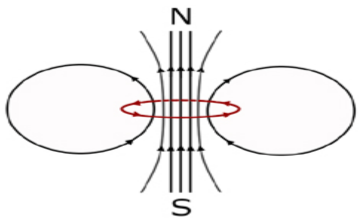


The right Cork Screw rule used to determine the direction of the magnetic field resulting from an electric current in a circular coil.
If the direction of rotation **(right-handed screw is turned)** points in the direction of the current **(from + to -)**.The direction of motion will give the direction of the magnetic field

Clockwise rule (polarity coil):

The side at which the current is in a clock wise direction is the **South Pole** while the side of which the current is an antilock wise direction is the **North Pole.**





the current is an antilock wise direction,so the near side is the north pole

- When direction of the current flow reversed, the direction of magnetic field will be reversed
- If a straight wire of length (l) is bent to form circular coil of radius (r) and of turn's number (N), then

$$l = \text{circumference of the circular coil} = 2\pi r N$$

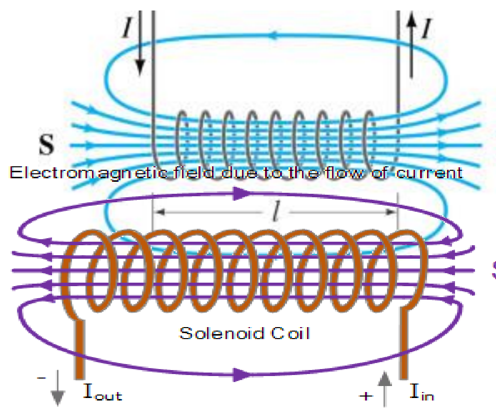
Lesson 4
Magnetic field due to current passing through a solenoid

Introduction

- A solenoid is considered as a long straight coil of wire can be used to generate a magnetic field similar to that of a bar magnet.
- Solenoids have large number of practical applications in our daily life.

Magnetic field due to a current in a solenoid

The shape of the magnetic field:



a) When a current is passed through a solenoid, a magnetic field is produced around it

1) The lines of magnetic flux outside the solenoid are closed coils moving from the North Pole to the South Pole
2) The lines of magnetic flux through the middle of the solenoid (In a solenoid) are straight and parallel to the axis, so the magnetic field is uniform

The magnitude of the magnetic field density (B):

The density of magnetic field at a point on its interior axis can be given by the following relation

$$B = \frac{\mu N I}{L}$$

Where:

B: the magnetic field density at the center of the circular coil **(Tesla)**

I: intensity of current passing through the coil **(Ampere)**.

L: the length of the solenoid **(meter)**.

μ: Permeability of medium **($\mu_{air} = 4\pi \times 10^{-7}$ Wb/m.A.)**

N: the number of turns of wire in the solenoid

OR

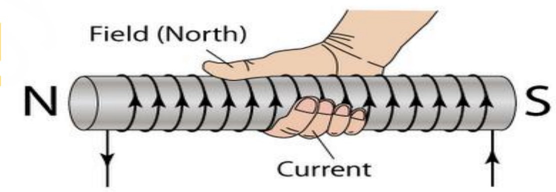
$$B = \mu \; n \; I$$

Where **n** is the number of turns per unit length $\mathbf{n} = \frac{N}{L}$

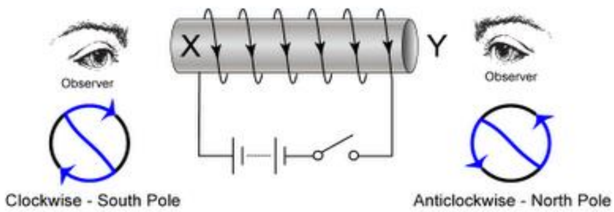
Note that:
The density of magnetic field produced by a solenoid carrying a current at a point on its interior axis **increases** when a **soft iron bar inserted in it** because soft iron has **high permeability, so the magnetic flux lines will be concentrated.**

The direction of magnetic field
To determine the direction of the magnetic field resulting from an electric current in a solenoid

a) Amperes right hand rule:
If **the wrapped fingers** (along the coil) points to the direction of conventional current (from + to -) while the thumb points **to the North Pole** (the direction of magnetic field within the solenoid.



b) Clockwise rule (polarity coil):
The side at which the current is in a clock wise direction is the **South Pole** while the side of which the current is an antilock wise direction is the **North Pole.**



Neutral point

(It is the point at which the total magnetic flux density vanishes)

The neutral point may be formed when two magnetic fields equal in magnitude and opposite in directions are met at a point

Note that:
When a magnetic needle is placed at a point then there is no deflection (moves freely), so the total magnetic field at this point is zero (neutral point)

$$B_t = \text{zero}$$
$$B_1 - B_2 = \text{zero}$$
$$B_1 = B_2$$

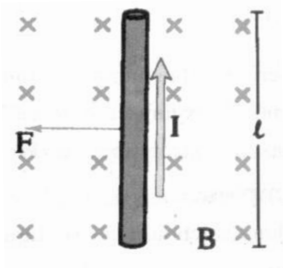
Where
B_t: the total magnetic flux density at a point.

B_1: the magnetic flux density of the first conductor.
B_2: the magnetic flux density of the second conductor.

Lesson 5
The magnetic force acting on a wire

The magnetic force acting on a wire carrying current placed in a uniform magnetic field

a) If we place a straight wire carrying current **I** between the poles of a magnet of magnetic flux density **B**, a magnetic force **F** results which acts on the wire and is perpendicular to both the wire and the field.

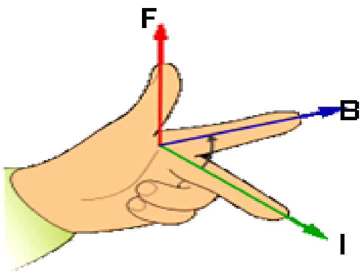


b) The direction of the force is reversed if we reverse the current or the magnetic field. In all cases, the force is perpendicular to both electric current and the magnetic field.

c) In case the wire is allowed to move due to this generated force, the direction of motion is perpendicular to both the electric current and the magnetic field.

Fleming left hand rule

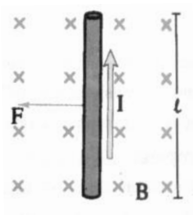
Used to determine the direction of the force (motion) of a straight wire carrying current



Fleming's left hand rule

The thumb, first finger and second finger of the left hand are all perpendicular to each other.
The thumb points in the direction of motion of the wire.
The pointer (first finger) points in the direction of the field
The middle (second finger) points in the direction of the current through the wire

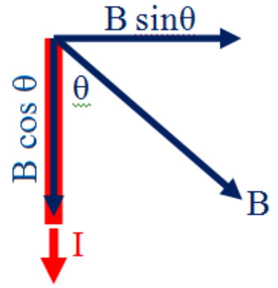
The factors affecting the force acting on a current - carrying wire suspended at right angles to a magnetic field:



1) The length of the wire (L) $F \propto L$
2) The current in the wire (I) $F \propto I$
3) The magnetic flux density (B) $F \propto B$

$$F \propto I B L$$

So $F = \text{Constant} \times I B L$



The constant equals one when (B) is in Tesla (Weber / m^2), (I) is in ampere, (L) is in meter and (F) is in Newton.

Thus **F = I B L**

In general, when a wire carrying current placed in a uniform magnetic field makes an angle (θ) with the magnetic field, then

$$F = B\,I\,l\,\sin\theta$$

Where **θ** is the angle between the wire and the magnetic field

Note that

a) When a wire makes an angle θ with the magnetic field

$$F = l\,I\,B\sin\theta$$

b) When the wire is placed perpendicular to the magnetic field (θ = 90° or 270°)

$$F = l\,I\,B_\perp$$

Therefore the force is maximum value

c) The wire is placed parallel to the magnetic field (θ = 0° or 180°) Therefore the wire does not move $F = 0$

The magnetic flux density

When the wire is placed perpendicular to the magnetic field

$$F = B_\perp I\,l$$

$$B_\perp = F/(I\,l)$$

The magnetic flux density can be defined

(It is the magnetic force exerts on a wire of **1m** length carrying a current of intensity **1 A** and placed perpendicularly to the magnetic field)

Tesla

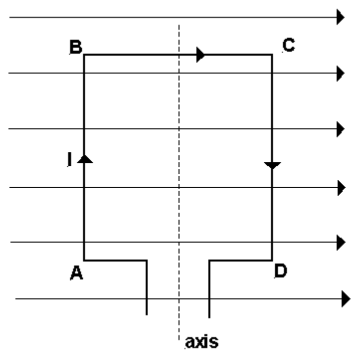
(It is the magnetic flux density which exerts a force of **1 N** on a wire of **1m** length carrying a current of intensity **1A** placed perpendicularly to the magnetic field.)

Or

It is the magnetic flux density when the total number of magnetic flux lines passing normally through a unit area around the point is 1 Wb

Lesson 6
The magnetic torque acting on a coil

The magnetic torque acting on a coil carrying current placed in a uniform magnetic field



Consider a rectangular coil of wire (ABCD) carrying a current **(I)** is placed in a magnetic field of flux density **(B)** , with its plane **parallel to** the field direction, as shown in the opposite figure

1) Wires (AD) and (BC) are parallel to the magnetic flux lines, so force acting on them = 0

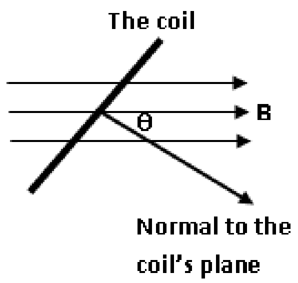
2) Wires (AB) and (CD) are perpendicular on magnetic flux lines so, they are acted by two forces equal in magnitude and opposite in direction

$$\mathbf{F = B\,I\,L_{AB} = B\,I\,L_{CD}}$$

Thus the coil is acted by a torque **(τ)** which will cause the coil to rotate around its axis.

$$\boldsymbol{\tau} = \textbf{Force} \times \textbf{perpendicular distance}$$

$$\tau = B\,I\,L_{AB} \times L_{AD} = B\,I\,A$$



A (area of the coil) = $L_{AB} \times L_{AD}$

If the coil consists of (N) turns, the total torque becomes:

$$\boldsymbol{\tau} = \mathbf{B\,I\,A\,N}$$

If the coil is inclined on the direction of magnetic flux lines such that the normal on coil's plane makes an angle (θ) with direction of magnetic flux lines then

$$\boldsymbol{\tau} = \mathbf{B\,I\,A\,N\,\sin\theta}$$

θ: the angle between the normal (perpendicular)to coil's plane and direction of magnetic field

The magnetic torque measured in **$N.m = T.A.m^2$**

The factors affecting Torque of couple on a rectangular coil carrying current in a magnetic field: (τ)

1) magnetic flux density **(τ α B)** (at constant other factors)

2) the current intensity **($\tau \propto I$)** (at constant other factors)
3) the area of the coil's plane **($\tau \propto A$)** (at constant other factors)
4) number of turns of the coil **($\tau \propto N$)** (at constant other factors)
5) the angle between perpendicular to coil's plane and the magnetic flux lines

Note that

When the perpendicular to coil's plane makes an angle θ with the magnetic field

$$\tau = B\,IAN \sin\theta$$

b) When the perpendicular to coil's plane perpendicular to the magnetic field
($\theta = 90^o$ or 270^o) (the coil's plane is parallel to the magnetic field)

$$\tau = B\,IAN$$

Therefore the magnetic torque is maximum value

c) When the perpendicular to coil's plane parallel to the magnetic field ($\theta = 0^o$ or 180^o)
(the coil's plane is perpendicular to the magnetic field)

$$\tau = 0$$

Therefore the coil does not rotate

The magnetic dipole moment (|md|)(magnetic moment of the loop)

Magnetic dipole moment = normal to the coil's plane

(It is a vector emanating (خارج) from North Pole of the coil and perpendicular to its area)

$$|m_d| = IAN = \tau_{max}/B$$

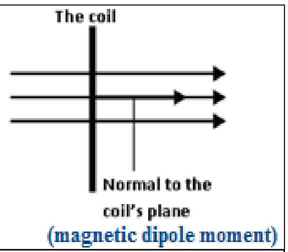
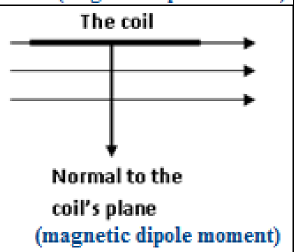
The magnetic dipole moment can be defined by another way

(It is the magnetic torque acting on a coil carrying current placed parallel to a uniform magnetic field of flux density of 1 tesla)

The magnetic dipole moment measured in **$A.m^2$. = N.m./ T**

The magnitude of mutual force depends on

1) the current intensity **($|m_d| \propto I$)** (at constant other factors)
2) the area of the coil's plane **($|m_d| \propto A$)** (at constant other factors)
3) number of turns of the coil **($|m_d| \propto N$)** (at constant other factors)

(Magnetic dipole moment is parallel to magnetic flux lines) (The coil's plane is perpendicular to magnetic flux lines) $\tau = 0$ $\theta = 0^o$	
(Magnetic dipole moment is perpendicular to magnetic flux lines) (The coil's plane is parallel to magnetic flux lines) $\tau_{max} = B\,IAN$ $\theta = 90^o$	

Applications:

The concept of the couple (magnetic torque) acting on the coil carrying current is the idea on which is based many instruments as the galvanometer and the electric motors.

Unit two
Electromagnetic induction

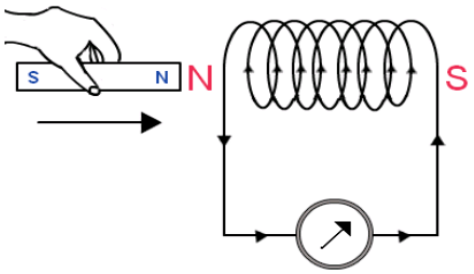
Dear student, by the end of this unit you should have the following skills and knowledges

Understanding the concept of electromagnetic induction
Explain faraday's law
Explain Lenz's law
Understanding the concept mutual and self-induction
Identify the mutual and self-inductance and the factors affecting each of them
Calculate the induced emf in a moving straight wire
Identify the structure and operation of electric generator
Calculate the instantaneous value of induced electromotive force
Identify the structure and operation of electric transformer

Lesson 1
Meaning of electromagnetic induction and faraday's law

Introduction

It has been noticed that the passage of an electric current in a conductor produces a magnetic field. Soon after Oersted's discovery that magnetism could be produced by an electric current, a question arose, namely, could magnetic field produce an electric current?



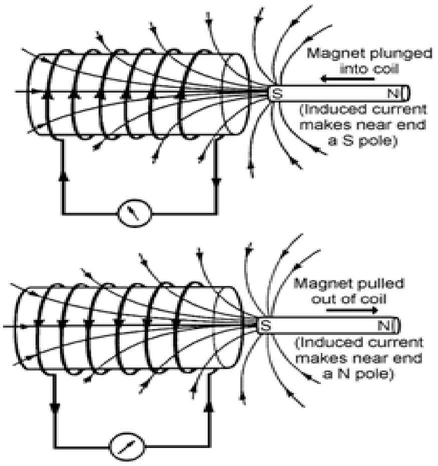
This problem was addressed by Faraday through a series of experiments which led to one of the breakthroughs in the field of physics, namely, the discovery of electromagnetic induction. On the basis of such a discovery, the principle of operation and function of most of the electric equipment - such as the electrical generators (dynamos) and transformers - depend.

Electromagnetic Induction was **discovered by Michael Faraday**. An electromotive force (current) is induced in a conductor while it is moving (cutting) across the magnetic field

Meaning of electromagnetic induction

Faraday's Experiment:

Michael Faraday made a long straight solenoid of insulated copper wire, such that the coil turns were separated from each other. He connected the two terminals of the coil to a sensitive galvanometer having its zero reading at the midpoint of its graduated scale, as shown in Fig. When Faraday plunged a magnet into the coil, he noticed that the pointer of the galvanometer was deflected momentarily in a certain direction. On removing the magnet from the coil, a deflection of the pointer was noticed in the opposite direction. This phenomenon is called electromagnetic induction"



Electromagnetic Induction

(It is a phenomenon in which an induced electromotive force and also an induced current are generated in the conductor by a changing magnetic field **(magnetic flux)**)

Moreover, the action of the magnet is met by a reaction from the coil.

a) If the magnet is plunged into the coil, the induced magnetic field acts in a way to oppose the motion of the magnet.

b) If the magnet is pulled out, the induced magnetic field acts to retain (or keep) the magnet in.

Conclusion

Faraday concluded that the induced emf and current were generated in the circuit as a result of the time variation of magnetic field lines as they cut the windings of the coil while the magnet was in motion.

Faraday's laws:

From the above Faraday's observations, one can conclude the following:

1) The relative motion between a conductor and a magnetic field in which there is time variation of the magnetic flux linked with the conductor, induces an electromotive force in the conductor. Its direction depends on the direction of motion of the conductor relative to the field.
2) The magnitude of the induced electromotive force is proportional to the rate by which the conductor cuts the lines of the magnetic flux linked with it.
3) The magnitude of the induced electromotive force is proportional to the number of turns N of the coil which cut (or link with) the magnetic flux.

$$\mathbf{emf} = \frac{-\mathbf{N}\,\Delta\boldsymbol{\Phi}_{\boldsymbol{m}}}{\Delta\,\mathbf{t}}$$

Where $\mathbf{\Delta\Phi_m}$ is the variation in the magnetic flux intercepted by the conductor through the time interval Δ t

The negative sign in the above relation indicates that the direction of the induced electromotive force or the induced current tends to oppose the cause producing it. This rule is known as Lenz's rule.

Lesson 2
Lenz’s law

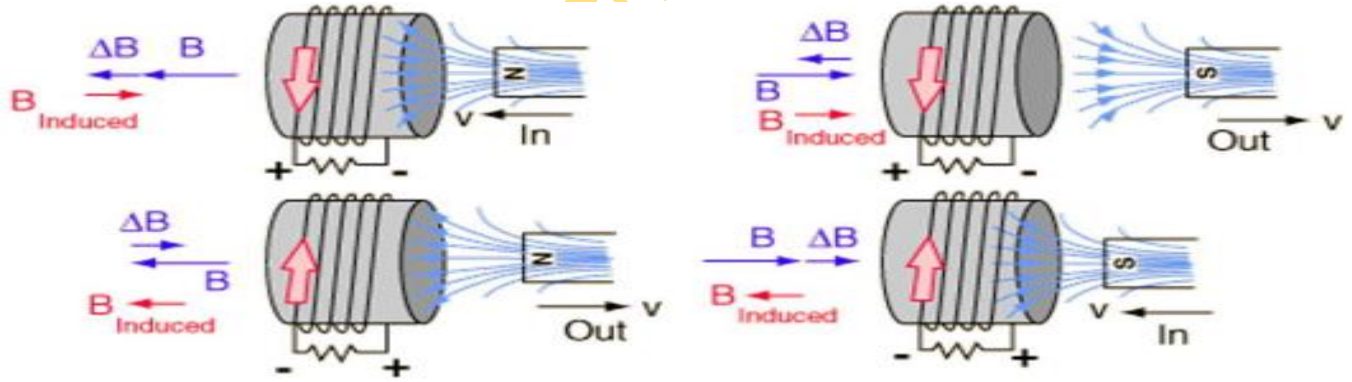
Lenz’s law

Lenz’s law used to determine the direction of induced current in a coil

Lenz’s law of electromagnetic induction states that

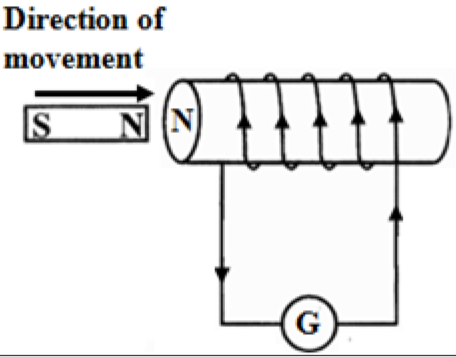
(The induced current must be in a direction such as to oppose the change producing it)

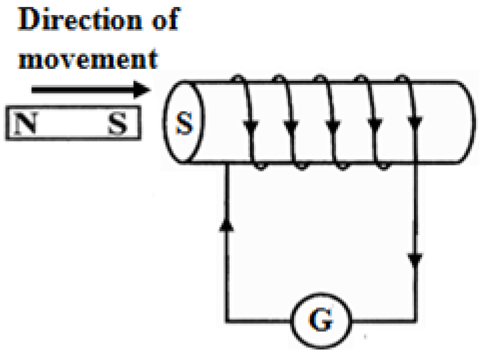
i.e. the direction of the current induced in a conductor by a changing magnetic field (as per Faraday’s law of electromagnetic induction) is such that the magnetic field created by the induced current ***opposes*** the initial changing magnetic field which produced it.



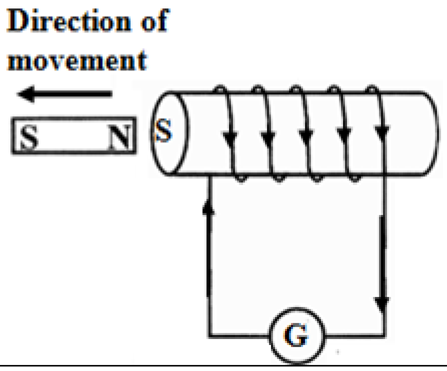
Explanation of Lenz's law:

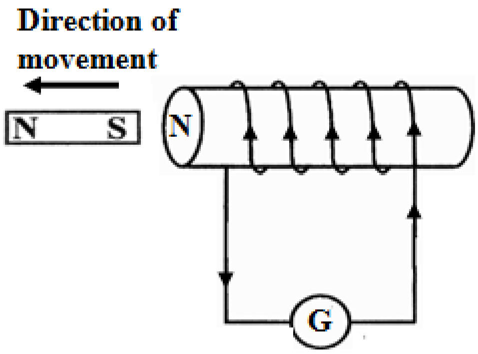
1) When we **approach** a **North Pole** or **South Pole**, the induced current in the coil will be in such direction **forming a like pole** opposing the motion of magnetic. **(Repulsing force).**





2) When **moving back** a **North Pole** or **South Pole,** the induced current in the coil. Will be in such direction **forming unlike pole** opposing the motion of magnetic **(attraction force).**





<u>From Lenz's rule, the direction of induced current in generated in the conductor depends on</u>

1) The direction of the motion.

2) The direction of the magnetic field.

<u>Remember</u>

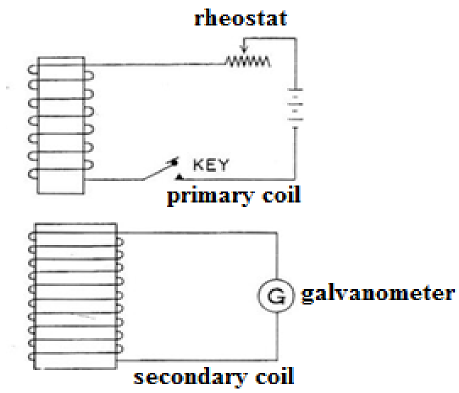
a) When the **magnet is moved towards the solenoid,** magnetic flux link with the coil increases, the coil's near end forms like pole which tends to repel it

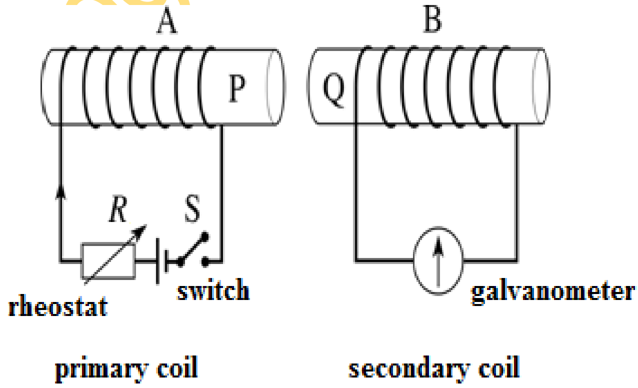
b) When the **magnet is moved away from the solenoid,** magnetic flux linked with the coil decreases the coil's near end forms unlike pole to that which is drown away, as if it tends attract it

Lesson 3
Mutual and self-induction

Mutual induction between two coils:

(It's the electromagnetic effect takes place between two coils when an induced emf generated in one of them (secondary coil) due current variation in the other coil (primary coil), which opposes the change causing it).





Production of iduced electromotive force (emf) on secondary coil

The induced emf generated in the secondary coil by many ways

1) Plunge or take away the primary coil from inside the secondary coil.
2) Using rheostat, increase or decrease the intensity of the current in the primary coil.
3) Using switch, switch-on or switch-off the primary circuit

Remember

1) There is an induced emf in the secondary coil only when

a) The current in the primary coil is changing.

b) The relative motion between the primary and secondary coils

(The flux lines in the primary coil cut across the wires in the secondary coil. This cutting induces an emf in the secondary coil that causes the galvanometer pointer will be deflected.

2) If the switch in the primary has been closed for a few seconds there is no induced emf in the secondary coil. Because the magnetic field is constant (there is no change in magnetic flux)

There are two types of the induced emf generated in the coil

First: Back induced emf

a) Switching on the current in primary coil
b) Increasing the current intensity in primary coil by using rheostat.
c) moving the primary coil near to or inside secondary coil

First: Forward induced emf

a) Moving the primary coil away from (take out) secondary coil
b) Decreasing the current intensity in primary coil by using rheostat.
c) Switching off the current in primary coil

The induced emf generated in the secondary coil $(emf)_2$ can be calculated

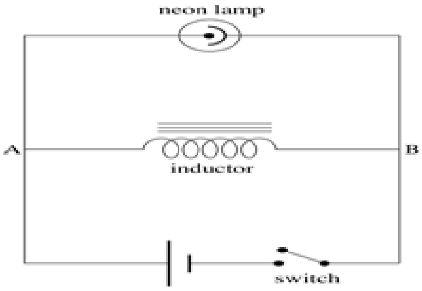
$$emf_2 = -M \times \frac{\Delta I_1}{\Delta t} = -N_2 \frac{\Delta \varphi_2}{\Delta t}$$

$(emf)_2$: The induced emf in the secondary coil (volt)
$\frac{\Delta I_1}{\Delta t}$: The rate of change of current in the primary coil (ampere/sec)
M : Coefficient of mutual induction (mutual inductance) (Henery)
N_2 : Number of turns of the secondary coil
$\frac{\Delta \varphi_2}{\Delta t}$: The rate of change of magnetic flux linking with the secondary coil (Wb/sec)

The coefficient of mutual inductance between two coils depends on.

a) The presence of an iron core inside the coil.
b) The volume of the coil and the number of its turns.
c) The distance separating them.

The transformer is considered as a clear example of mutual induction

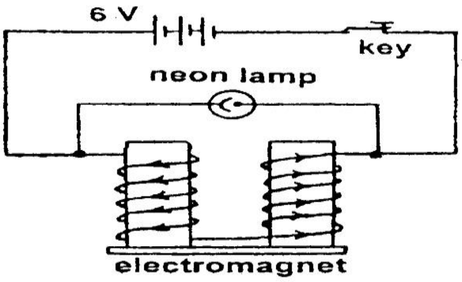


Second: Self-induction in a coil:

When a current is present in a circuit, it sets up a magnetic field that causes a magnetic flux through the same circuit; this flux changes when the current changes. Thus any circuit that carries a varying current has an emf induced in it by the variation in its own magnetic field.

(The phenomenon of inducing emf in a coil due to change in current in the same coil and hence the change in magnetic flux in the coil)

Note that:



1) This induced electromotive force generated due to the self-induction of the coil on **switching off** or **switching on** its circuit, according to **Lenz's rule.**
2) A neon lamp requires a potential difference about 180 volt to glow.
3) When the number of turns of the coil is large, the induced emf on switching off the circuit will be much larger than that of the battery this causes a neon lamp connected in parallel between the two terminals of the coil to glow

The self-induced emf generated in the coil (emf) can be calculated

$$\text{emf} = -L \times \frac{\Delta I}{\Delta t} = -N\frac{\Delta \varphi}{\Delta t}$$

(emf): The induced emf in the secondary coil (volt)

$\frac{\Delta I}{\Delta t}$ **:** The rate of change of current in the coil (ampere/sec)

L **:** coefficient of self-induction (self-inductance) (Henery)

The self-inductance (coefficient of self-induction) of a coil depends on

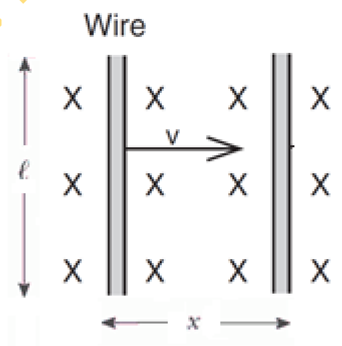
1) The geometry of the coil (size, length and the number of turns)
2) The distance between the turns
3) The presence of an iron core inside the coil (magnetic permeability)

Lesson 4
The electric generator (dynamo)

The induced emf in a straight wire moving normal to a magnetic field:

If a wire cuts through a magnetic field, or vice -versa, a voltage (potential difference) is produced between the ends of the wire. This induced voltage causes a current to flow if the wire is a part of closed circuit

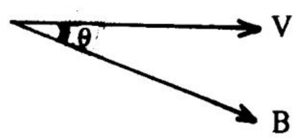
When the wire of length (l) is moved in a direction perpendicular to the magnetic field of density (B) at velocity (v), so that it is displaced a distance (Δ x) in time (Δt). ($\frac{\Delta x}{\Delta t} = v$).an induced emf generated between two ends of the wire is given by



$$\text{emf} = Blv$$

Wire moving with velocity making an angle (θ) with the magnetic field:

If the wires moves by an angle along the direction of the magnetic field

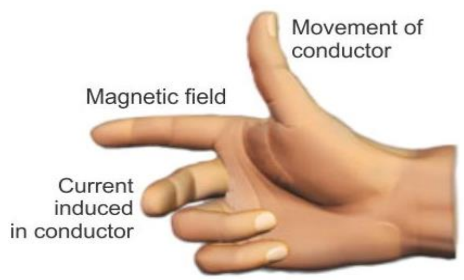


$$\text{emf} = B\,l\,v\sin\theta$$

Fleming Right Hand Rule

It is used to determine the direction of induced current in the wire

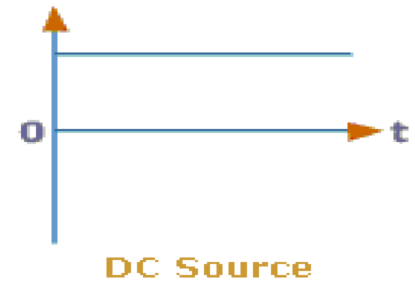
Extend the thumb, pointer and the middle finger of the right hand, mutually perpendicular to each other. Let the pointer points to the direction of the field, and the thumb in the direction of motion, and then the middle finger (with the rest of the fingers) will point to the direction of the induced current or voltage as shown in Fig.



Electricity flows in two ways;
1) Alternating current (AC)
2) Direct current (DC).

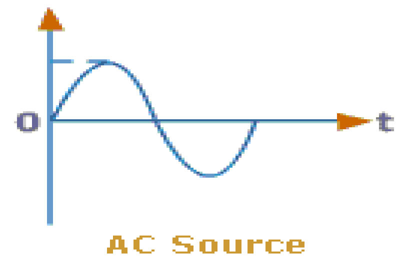
Direct current (DC).

1) The current that flows in one direction only in a circuit
2) It has constant intensity and constant direction
3) It produces constant (steady) magnetic field
4) Its frequency = zero
5) It is produced by battery or DC dynamo



Alternating current (AC)

1) The current which flows to and fro in two opposite directions in a circuit
2) It changes its direction and its intensity periodically
3) It produces variable magnetic field
4) It has frequency
5) It is produced by AC dynamo.

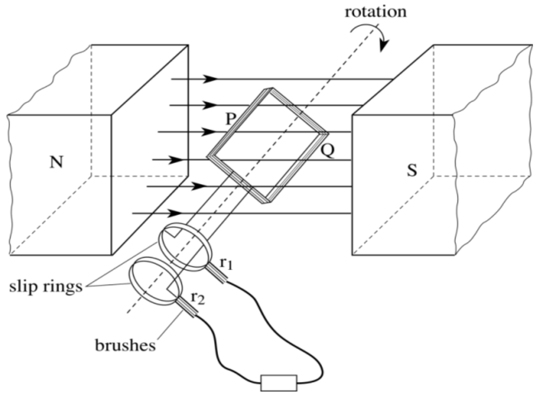


First: AC generator (Dynamo)

The ac generator is a device used for converting mechanical energy into electrical energy.

Principle

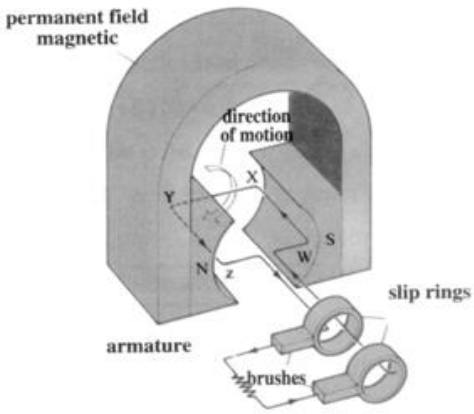
It is based on the principle of electromagnetic induction, according to which an emf is induced in a coil when it is rotated in a uniform magnetic field.



Essential parts of an AC generator

A field magnet:

Strong field magnet (permanent magnet or an electromagnet) with concave poles
The concave poles produce a radial magnetic field (uniform magnetic field).

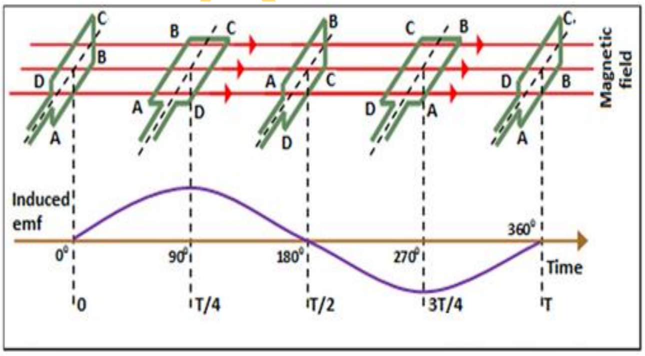


<u>An armature</u>:
It is a rectangular coil of large number of turns of wire wound on laminated soft-iron core of high permeability

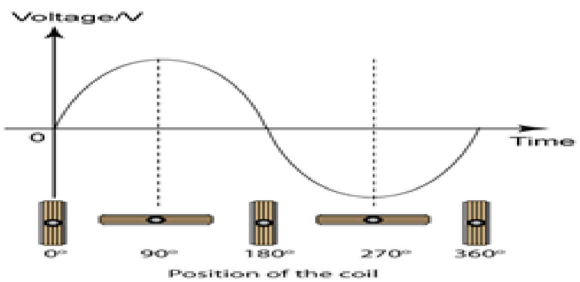
<u>Two slip rings</u>:
The two ends of the coil are connected to two slip rings which rotate with the coil.
Each slip ring is always in contact with the same carbon brush.

<u>Two graphite brushes:</u>
Two carbon brushes touched each of the rings which form the terminals of the external circuit
The induced currents in the coil pass to the external circuit through them
Two brushes do not rotate with the coil.

<u>Working</u>



When the coil rotates, its sides cut across the magnetic field lines, the magnetic flux linked with the coil changes, and induced current flows in the coil, therefore the induced current has variable intensity and changing .The direction of the induced current is given by Fleming's right hand rule.



The induced current in the external circuit keeps changing its direction for every half a rotation of the coil. Hence the induced current is alternating in nature. As the armature completes number of rotations in one second, alternating current of frequency **f** is produced

<u>The induced emf in a dynamo</u>

Consider a rectangular coil of area **A** containing **N** turns , rotating around its axis in a circle with frequency **f** in a uniform magnetic field **B starting its rotation from <u>zero position when its plane normal to flux lines</u>** with its sides moving with constant linear velocity making an angle (θ) with the direction of magnetic field. Then the instantaneous value of induced emf generated in the coil

$$emf_{coil} = AB\,N2\pi f \sin\theta$$

emf_{coil} : represents the instantaneous value of induced emf

θ: the angle between normal on coil's plane (axis of the coil) and magnetic flux lines.

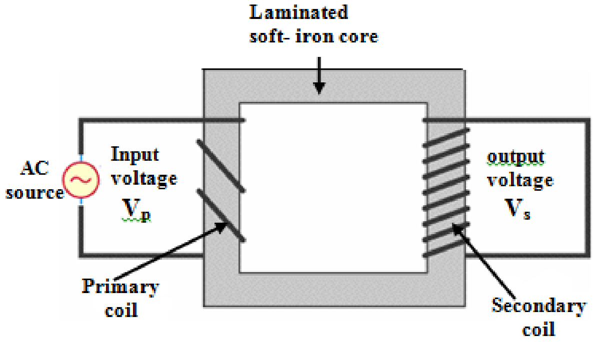
The instantaneous value of induced current **I** generated in the coil of total resistance **R** can be obtained from the following relation

$$I = \frac{emf_{coil}}{R}$$

Lesson 5
The electric transformer

The electric transformer

Transformer is an electrical device used for converting low alternating voltage into high alternating voltage and vice versa. It transfers electric power from one circuit to another. The transformer is based on the principle of electromagnetic induction (mutual induction between two coils).



A transformer consists of primary and secondary coils insulated from each other, wound on a soft iron core. To minimize eddy currents a laminated iron core is used.

Eddy currents

(They are induced currents that circulate in closed paths due to the change in magnetic flux through a solid conductor associating with heating effect)

Working

The a.c. input is applied across the primary coil. The continuously varying current in the primary coil produces a varying magnetic flux in the primary coil, which in turn produces a varying magnetic flux in the secondary. Hence, an induced emf is produced across the secondary.

Let V_P and V_S be the induced emf in the primary and secondary coils and N_P and N_S be the number of turns in the primary and secondary coils respectively.

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

For an ideal transformer, input power = output power

$$V_p I_p = V_s I_s$$

Where I_p and I_s are currents in the primary and secondary coils.

$$\frac{V_S}{V_P} = \frac{I_P}{I_S} \quad \text{, Thus} \quad \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s} = K$$

Where K is called transformer ratio (For step up transformer K > 1 and for step down transformer K < 1)

In a step up transformer $V_s > V_P$ implying that $I_s < I_p$. Thus a step up transformer increases the voltage by decreasing the current, which is in accordance with the law of conservation of energy. Similarly a step down transformer decreases the voltage by increasing the current.

Efficiency of a transformer

Efficiency of a transformer is defined as the ratio of output electric power to the input electric power.

$$\eta = \frac{\text{output power}}{\text{input power}}$$

$$\eta = \frac{V_S I_S}{V_P I_P} \times 100$$

$$\frac{\eta \, V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

The efficiency η = 1 (i.e. 100%), only for an ideal transformer where there is no power loss. But practically there are numerous factors leading to energy loss in a transformer and hence the efficiency is always less than one.