ELEMENTARY PHYSICS AND DIGITAL ELECTRONICS

UNIT-2

Bar Magnet:

A magnet appearing like a bar, and hence called a bar magnet has two poles, the poles of the bar magnet are protected from demagnetizing the magnet using iron plates on both the poles.

A bar magnet is composed of ferromagnetic material that retains its magnetic properties even in the absence of an external field and hence is a permanent magnet.

On hanging freely in the air, the bar magnet aligns itself in the North-south direction. The magnetic dipoles inside the bar magnet experience the magnet force due to the Earth's magnetic field and align in the direction of the field. Hence, a bar magnet can therefore be used to find the direction same as a compass.

Types of Bar Magnet:

There are two types of the bar magnet, they are:-

1. Rectangular bar magnet:

This magnet has four rectangular faces painted and two square shape poles. The edges of this bar magnet are rectangular in shape and hence the name rectangular bar magnet.

2. Cylindrical bar magnet:

The edges of the magnet are circular and therefore called cylindrical bar magnets. The outer curvature of this magnet is coloured.

Where is the Magnetic Field of a Bar Magnet Strongest and Why?

The magnetic field is strongest at the edges of the poles of the bar magnet.

If we take a simple example that we probably have performed as the first experiment at schools when were introduced about the magnetic field, an experiment with a bar magnet and an iron foils. The bar magnet when placed in a tray of iron foils, the iron foils are arranged around the bar magnet in well-aligned concentric circles without overlapping.

Where is the Magnetic Field of a Bar Magnet Weakest?

If we look into the same experiment as mentioned above; we shall see, there are hardly any iron foils attached on the middle portion of the bar magnet, nor you will find any field lines originating from this part of the magnet and are almost parallel to the length of the bar magnet.

Is a Bar Magnet Surrounded by a Magnetic Field?

The dipoles inside the ferromagnetic material of what the bar magnet is comprising of, possesses the magnetic dipole moments which are responsible for the generation of a magnetic field of a bar magnet. Being a permanent magnet, it will attract ferromagnetic materials towards it, while showing some force of attraction or repulsion on other magnetizing material when placed near the bar magnet and not too far.

The magnetic force around the bar magnet will act only when the substance is placed in its field. Outside the magnetic field of the bar magnet, evidently, the strength of the field is zero as there are no magnetic flux lines flowing in this region.

How to Draw Magnetic Field Lines Around a Bar Magnet

The magnetic field lines are represented as the flux lines. These flux lines form concentric closed loops. The magnetic field produced by the bar magnet is represented by flux lines that are originating from one pole and terminate into another pole of the bar magnet.

Hence, the magnetic field lines can be drawn originating from the North Pole and entering in the South pole forming close loops, and these loops are separated from one another at a certain distance while running parallel to the length of the bar magnet and this gap widens for every loop, on the contrary, the magnetic lines are drawn dense at the poles.

No magnetic field lines should touch the middle section of the bar magnet as the magnetic field is negligible in this area and has a weak force of attraction or repulsion.

Is the Magnetic Field Same all Around a Bar Magnet

The magnetic field depends upon the strength and density of the magnetic flux lines and varies with respect to the distance from the poles. The intensity of the magnetic field is directly proportional to the magnetic flux density. The flux density varies with distance.

The magnetic field produced by the bar magnet is at a peak near the edges of the poles. The weak force of attraction and repulsion is experienced at the middle part of the bar magnet.

Thus, the magnetic field strength is highest at the edges of the poles of the magnet. The strength decreases as the distance from the poles across the length of the bar magnet increases. The same is the effect around the bar magnet. As the distance from the magnetic poles increases the strength of the field will also decrease as we go far from the poles.

Biot Savart's Law:

The magnitude of magnetic induction at a place caused by a tiny element of a current-carrying conductor is stated in the law.

- Directly proportional to the current

- Directly proportional to the length of the element
- Directly proportional to the sine of the angle between the element and the line joining the center of the element to the point and,
- Inversely proportional to the square of the distance of the point from the center of the element

$dB \propto I$

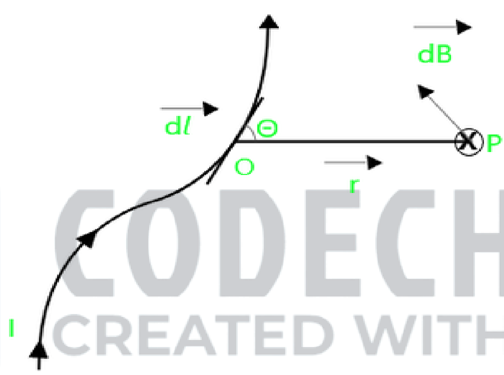
$dB \propto dl$

$dB \propto \sin\Theta$

$dB \propto 1 / r^2$

$\therefore dB \propto Idl\sin\Theta / r^2$

$\therefore dB = KIdl\sin\Theta / r^2$ *(K is constant)*



Derivation:

Consider a conductor of any form carrying a current (I) and a tiny length element (dl) (refer to below image). The current flow is depicted vertically upward.

Let (P) be any point a distance (r) from the current-carrying element, and (r) be the position vector of (P) with respect to the current element, and be the angle between (dl) and (r), in the direction of the current.

According to Biot – Savart Law, the magnetic induction at point (P) is given by,

$$dB = KIdl\sin\Theta / r^2 \dashrightarrow (1)$$

Here, K is Constant and its value depends on the system of units and also the medium in which the conductor is situated.

In the SI system, the constant K for vacuum or air is written as $[\mu_o / 4\pi]$ where μ_0 is called the permeability of vacuum or free space.

Substituting K in Eq (1) We get,

$dB = \mu_0 / 4\pi\ [Idl\sin\Theta / r^2]$ ⇢ (2)

SI unit of μ_0 Wb / Am. It`s value is $4\pi \times 10^{-7}$ Wb / Am

($\mu_0 / 4\pi = 10^{-7}$ Wb / Am)

The direction of magnetic induction is perpendicular to the plane of the figure and directed inside the plane. (as per the right-hand Thumb rule.)

Applications of Biot – savart law

- We may utilize Biot–Savart law to determine magnetic responses at the atomic or molecule level.
- It may be utilized in aerodynamic theory to determine the velocity promoted by vortex lines.
- This rule may be used to compute the magnetic field produced by a current element.

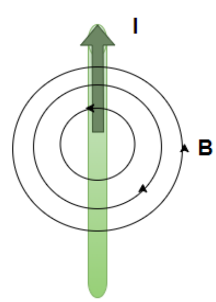
Importance of Biot-Savart Law

- In electrostatics, the Biot-Savart law is analogous to Coulomb's law.
- The legislation also applies to extremely tiny conductors that convey current.

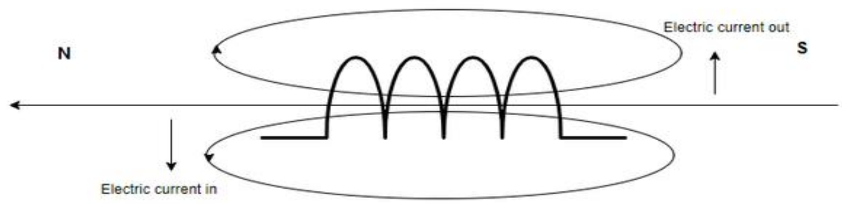
Magnetic Field due to Current in Straight Wire:

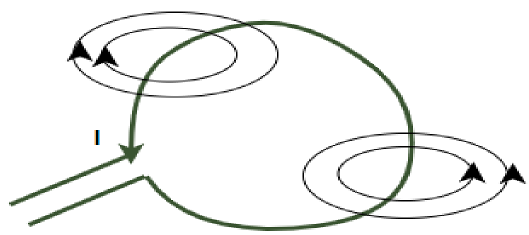
Magnetic Fields due to Moving Charges:

Moving charges produce a magnetic field. In a conductor carrying current, charges are always moving and thus such conductors produce magnetic fields around them. The field that is produced by these charges can be visualized in the figure below. The direction of this magnetic field is given by the right-hand thumb rule. In this rule, the thumb of the right-hand points in the direction of the current. The curled fingers give the direction of the magnetic field around the wire.



The magnetic fields produced by a current loop and solenoid are shown in the figure below:





Similarities between Coulomb's law and Biot-Savart Law

Biot-Savart law has some similarities as well as some differences with Coulomb's law from electrostatic theory. Both the laws depend on the inverse of the squared distance. The principle of superposition is applicable to both of these laws. The only difference comes in the fact that the electrostatic force is a scalar quantity while the magnetic field is a vector quantity that depends on the cross product.

Magnetic Field due to a straight current-carrying wire

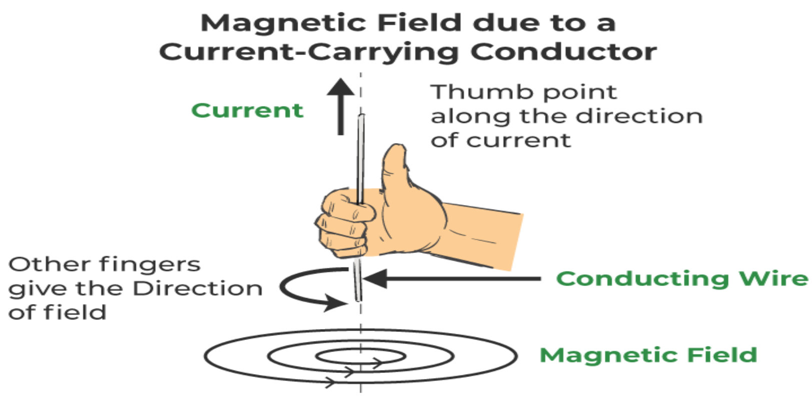
The magnitude and the direction of the magnetic field due to the straight current-carrying wire can be calculated using the Biot-Savart law mentioned above. Consider "I" as the current flowing in the straight wire, and "r" be the distance. Then the magnetic field produced by the wire at that particular point is given by.

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

Since the wire is assumed to be very long, the magnitude of the magnetic field depends on the distance of the point from the wire rather than the position along the wire.

Magnetic Field due to Current carrying Coil:

When current is passed through a straight current-carrying conductor, a magnetic field is produced around it. The field lines are in the form of concentric circles at every point of the current-carrying conductor. And we can find the direction of the magnetic field, in relation to the direction of electric current through a straight conductor can be depicted by using the Right-Hand Thumb Rule also called as Maxwell Corkscrew Rule.



This rule states that 'If a current-carrying conductor is held by the right hand, keeping the thumb straight and if the direction of electric current is in the direction of thumb, then the direction of wrapping of other fingers will show the direction of the magnetic field.'

Magnetic field due to current through a circular loop

The right-hand thumb rule can be used for a circular conducting wire as well as it comprises small straight segments. Every point on the wire carrying current gives rise to a magnetic field around it would become larger and larger as we move away from the wire and by the time we reach the center of the circular loop, the arcs of these circles would appear as a straight line

Magnetic field and number of turns of the coil

The magnitude of the magnetic field gets summed up with the increase in the number of turns of the coil. If there are 'n' turns of the coil, the magnitude of the magnetic field will be 'n' times the magnetic field in case of a single turn of the coil.

The strength of the magnetic field at the center of the loop (coil) depends on:

- **The radius of the coil:** The strength of the magnetic field is inversely proportional to the radius of the coil. If the radius increases, the magnetic strength at the center decreases
- **The number of turns in the coil:** As the number of turns in the coil increase, the magnetic strength at the center increases, because the current in each circular turn is having the same direction, thus, the field due to each turn adds up.
- **The strength of the current flowing in the coil:** As the strength of the current increases, the strength of three magnetic fields also increases.

Force between Two Parallel Current Carrying Conductor:

A magnetic field is created around a conductor due to the current flowing through it. An external magnetic field exerts a force on a current-carrying conductor. Thus, we can say that any two current-carrying conductors when placed near each other, will exert a magnetic force on each other.

There are two types of Force between two parallel currents:

- **Attractive:** If the currents have the same direction or Currents are flowing in the same direction.
- **Repulsive:** If the currents are in the opposite direction or they are flowing in the opposite direction.

Consider two parallel current-carrying conductors, separated by a distance 'd', such that one of the conductors is carrying a current I_1 and the other is carrying I_2. From previous studies, we can say that conductor 2 experiences the same magnetic field at every point along its length due to conductor 1. The direction of magnetic force can be found using the right-hand thumb rule.

From Ampere's circuital law, the magnitude of the field due to the first conductor can be given by,

$\mathbf{B_a = \mu_0 I_1 / 2\pi d}$

The force on a segment of length L of conductor 2 due to conductor 1 can be given as,

$\mathbf{F_{21} = I_2 L B_1 = (\mu_0 I_1 I_2 / 2\pi d)\ L}$

Similarly, we can calculate the force exerted by conductor 2 on conductor 1. We see that conductor 1 experiences the same force due to conductor 2 but the direction is opposite. Thus,

$\mathbf{F_{12} = -F_{21}}$

Also, the currents flowing in the same direction make the conductors attract each other and that showing in the opposite direction makes the conductors repel each other. The magnitude of the force acting per unit length can be given as,

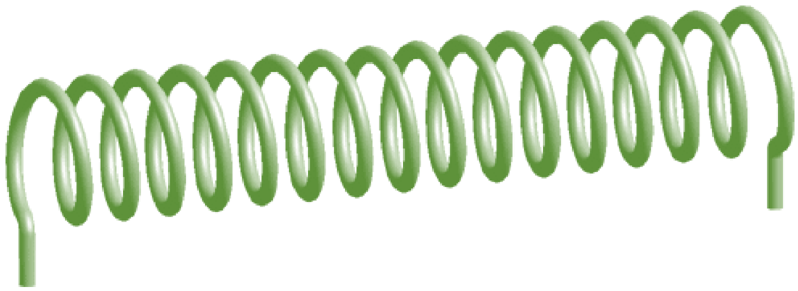
$$F_{ba} = \mu_0 I_a I_b / 2\pi d$$

where,
d is the distance between two conducor,
I_a is the current in a conductor,
I_b is the current in b conductor,

Magnetic Field Due to Solenoid and Toroid:

Solenoid:

The solenoid is a wire coil that works as an electromagnet when electricity flows through it. Electromagnetic solenoids are used in a variety of applications across the world.



Solenoid

Types of Solenoids:

Solenoids are available in a variety of designs, materials, and functions. However, they all operate on the same electrical principles:

1. **AC laminated solenoid –** What makes an AC solenoid renowned is the amount of force it can generate in its initial stroke. They emit a crisp buzz while in operation and are available in a variety of combinations and ranges. The stroke of an AC solenoid can be longer than that of a DC solenoid.
2. **DC C-frame solenoid –** A DC C-frame solenoid has merely a frame enclosing the coil in the shape of the letter C. They are most commonly used in a DC arrangement, although they may also be utilized in an AC power system.
3. **DC D-frame solenoid –** The coil is covered by two sections of frames in the DS D-frame solenoid. They're frequently utilized in industrial settings. These solenoids may also be made to work with AC power.
4. **Linear solenoid –** These solenoids are used for metering activities and can apply a pulling or pushing force to mechanical equipment. These are the most popular solenoids, and they're utilized in motor vehicle starters. These solenoids move linearly when an electrical force is applied to them, bringing two contacts together. This lets electricity from the battery flow into various sections of the vehicle, allowing it to start.
5. **Rotary solenoid –** This solenoid is utilized for applications that need a simple and automated control procedure. Among all varieties of solenoids, it is the most durable. They were originally intended for defense mechanisms, but they may today be found in a variety of automated industrial operations such as shutters and lasers.

A long solenoid:

The term "long solenoid" refers to a solenoid with a longer length than the radius. It is made out of a long wire coiled in the shape of a helix with closely spaced neighboring turns. As a result, each turn may be thought of as a circular loop. The net magnetic field is the vector sum of all the turns' fields. The turns are isolated from one other by using enameled wires for winding.

The magnetic field within a long solenoid is,

$B = \mu_0 n I$

where, n denotes the number of turns per unit length and I denote the current flowing through the solenoid.

The magnetic field at one end of the long solenoid is as follows:

$B = (\mu_0 n I)/2$

Applications of Solenoid:

They're suitable for a certain type of door locking mechanism. Electromagnets are used in these locking systems, making them extremely secure.

- It has a wide range of applications, including medical, industrial, locking systems, and automotive.
- They're utilized in inductors, valves, and antennas, among other things.
- In automobiles, solenoids are utilized in fuel injection gears.
- The solenoid is mostly used as a power switch.
- They're commonly seen in computer printers.
- It is used to electronically operate a valve.

Advantages of Solenoid:

- A solenoid offers a number of benefits that you won't find in a regular coil:
- When electricity is introduced to a solenoid, it causes it to respond instantly.
- There is no pollution in the air when a solenoid engine is used in vehicles.
- Solenoid engines can be utilized to replace fossil fuel engines.

Toroid:

A toroid is a doughnut-shaped hollow circular ring with numerous turns of enamelled wire coiled so close together that there is no room between them. When high inductances are required at low frequencies, a toroid can be thought of as a circular solenoid utilised in an electric circuit as an inductor.

A toroid is a coil of insulated or enamelled wire coiled around a powdered iron donut form. Toroid uses include low-level inductors, power inductors, low-level transformers, current transformers, and power transformers.

Toroid

An infinite solenoid in the shape of a ring is known as a toroid. The magnetic field within a toroid may be calculated as follows:

$B = (\mu_0 N I/2 \pi r)$

where, I denote the amount of current passing through the solenoid.

Let r be the toroid's average radius and n be the number of turns per unit length, then:

N = 2rn = the toroid's (average) perimeter number of turns per unit length.

Applications of Toroid:

1. It is used in the creation of musical instruments.
2. A toroid is used in modern medical equipment.
3. It's utilized in the telecommunications industry.

Magnetic Flux:

The number of magnetic field lines flowing through a closed surface is known as magnetic flux. It calculates the total magnetic field that travels across a specific surface area.

The region under consideration might be any size and can be oriented in any direction about the magnetic field direction. The Greek letter Phi or the Phi suffix B is often used to represent magnetic flux. The symbol for magnetic flux is **φ or φ_B**.

Magnetic Flux Formula:

The magnetic flux formula is given as:

$\varphi_B = B.A = B A \cos\vartheta$

where

- *A is the surface area,*
- *B is the magnetic field,*
- *ϑ is the angle at which lines pass through the area, &*

- *ϕ_B is the magnetic flux.*

Unit of Magnetic Flux:

A flux metre is used to measure the magnetic flux. The following are the SI and CGS units of magnetic flux:

- Weber is the SI unit for magnetic flux (Wb).
- Volt-seconds are the fundamental unit.
- Maxwell is the CGS unit.

Measurement of Magnetic Flux:

The Weber (Wb) or tesla meter squared (T m^2) unit of magnetic flux is named after German scientist Wilhelm Weber. A magnetometer may be used to measure the magnetic flux. Assume a magnetometer probe is moved over a 0.9 m^2 region near a huge sheet of magnetic material and shows a constant reading of 10 mT. The magnetic flux through that area is then computed using the formula $(10 \times 10^{-3}\ T)\ (0.9\ m^2) = 0.0090$ Wb. It would be essential to find the average measurement in the event of shifting magnetic field readings across a large region.

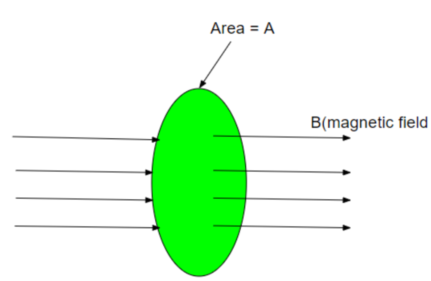
Magnetic Flux Density:

The force operating per unit current per unit length on a wire positioned at right angles to the magnetic field is described as magnetic flux density(B).

- Tesla (T) or Kg s^{-2} A^{-1} are the SI units of B.
- Gauss (G or Gs) is the CGS unit of B.
- Magnetic Flux Density, B is a vector quantity.

Faraday's Law of Electromagnetic Induction:

Magnetic flux through any surface placed in a magnetic field is defined as the number of magnetic lines of force crossing the surface normally. It is denoted by 'ϕ' and its unit is weber (Wb). Electromagnetic induction is the phenomenon of production of induced emf due to a change of magnetic flux (number of magnetic field lines) connected to a closed circuit is called electromagnetic induction.



Faraday's laws of electromagnetic induction:

First law:

It states that whenever the magnetic flux is linked with a closed-circuit change, an emf is induced in it which lasts only as long as the change in flux is taking place. If the circuit is closed then current also gets induced inside the circuit which is called" Induced current".

Magnetic fields can be changed by:

- Moving a bar magnet towards or away from the coil.
- Moving the coil into the magnetic field or outside the magnetic field.
- Rotating the coil relative to the magnet.
- Changing the area of a coil placed in the magnetic field.

Second law:

It states that the magnitude of the induced emf is equal to the rate of change of magnetic flux linked with the closed circuit.

$|\in| = d\phi/dt$

$E = -N\ d\phi/dt$

$E = -N\ (\phi_2-\phi_1)/t$ ⇢ (" t "is time)

Lenz's law:

Lenz states that the direction of induced current in a circuit is such that it opposes the change in magnetic flux. Lenz's is named after the German physicist "Emil Lenz ", who formulated it in 1834. It is a scientific law that specifies the direction of induced current but states nothing about its magnitude.

$E = -N(d\emptyset/dt)$ ⇢ (negative sign indicates that the direction of induced emf is such that it opposes the change in magnetic flux)

Applications of Faraday's law:

- Induction motors
- Transformers
- Electric generators
- Hall effect meters
- Current clamps
- Induction cooking
- Induction welding
- Induction sealing
- Electric guitar and violin.

Inductance:

Inductance is an electrical circuit attribute that opposes any change in current in the circuit. Electrical circuits have an intrinsic feature called inductance. Whether desired or not, it will always be found in an electrical circuit. The inductance of a straight wire carrying electricity with no iron element in the circuit will be lower. Because the inductance of an electrical circuit opposes any change in current in the circuit, it is equivalent to inertia in mechanics.

Magnetic flux that is proportional to the rate of change of the magnetic field is known as induction. The induced EMF across a coil is related to the rate at which the current through it changes. Inductance is the proportionality constant in that relationship. H is the SI unit for inductance (henry). It is denoted by the letter L. The amount of inductance required to produce an EMF of 1 (V) volt in a coil when the current change rate is 1 Henry is defined as 1 H (Henry).

Factors affecting Inductance:

The following are some of the factors that influence inductance:

1. The inductor's wire has a specific number of turns.
2. The material that was used to make the core.
3. The core's appearance.

Faraday established the Electromagnetic Induction Law, which states that by altering the magnetic flux, an electromotive force is induced in the circuit. The concept of induction is derived from Faraday's law of electromagnetic induction. The electromotive force generated to counteract a change in current at a specific time interval is known as inductance.

Derivation of Inductance:

Take a look at a DC source that has the switch turned on. When the switch is turned on, the current flows from zero to a specific value, causing a change in the flow rate. Consider the flux shift caused by current flow. The flux change is measured in terms of time, as follows:

$d\phi/dt$

Use Faraday's law of electromagnetic induction to solve the problem.

$E = N(d\varphi/dt)$

Where, N is the coil's number of turns, and E is the induced EMF across the coil.

Write the above equation as follows using Lenz's law:

$E = -N(d\varphi/dt)$

For computing the value of inductance, the previous equation is adjusted.

$E = -N(d\varphi/dt)$

$\therefore E = -L(di/dt)$

$N = d\Phi = L\, di$

$N\Phi = Li$

Therefore,

$Li = N\Phi = NBA$

Where, B denotes the flux density and A denotes the coil area.

$Hl = Ni$

Where H denotes the magnetic flux's magnetizing force.

$B = \mu H$

$Li = NBA$

$L = NBA/i = N2BA/Ni$

$N^2BA/Hl = N^2\mu HA/Hl$

$\mathbf{L = \mu N^2A/l = \mu N^2\pi r^2/l}$

Types of Inductance:

There are two types of inductance. They are self-induction and mutual induction. Let's learn about them in more detail with proper definitions,

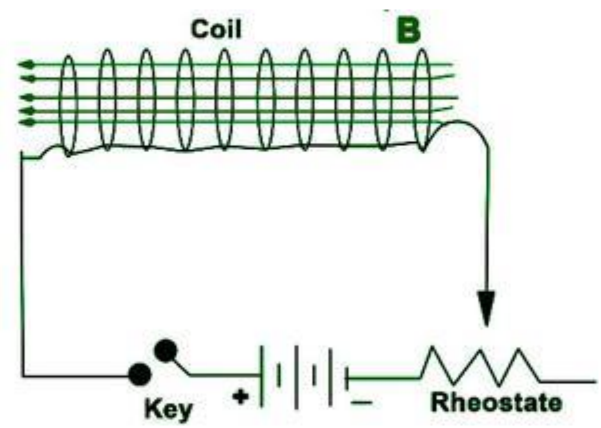
1. Self Induction

The magnetic flux associated with a coil or circuit changes anytime the electric current running through it changes. As a result, an emf is induced in the coil or circuit, which opposes the change that creates it, according to Faraday's laws of electromagnetic induction. This phenomenon is known as 'self-induction,' and the induced emf is referred to as back emf, while the current created in the coil is referred to as induced current.

- **Coefficient of self-induction:** The current is proportional to the number of flux linkages with the coil, i.e., $N\varphi$ is directly proportional, or $N\varphi = Li$ (N is the number of turns in coil and $N\varphi$ – total flux linkage). Hence The coefficient of self-induction is $L = (N\varphi/i)$.
- If i = 1amp, N = 1 then, $L = \varphi$ i.e. When the current in a coil is 1 amp, the coefficient of self-induction is equal to the flux associated with the coil.

- Faraday's second law induced emf e = -N(dφ/dt). Which gives e = -L(di/dt); If di/dt = amp/sec then |e| = L. When the rate of change of current in the coil is unity, the coefficient of self induction is equal to the emf induced in the coil.
- Units and dimensional formula of 'L' : It's S.I. unit, weber/Amp = (Tesla × m^2)/ Amp = (N × m)/Amp^2 = Joule/Amp^2 = (Coulomb × volt)/Amp^2 = (volt × sec)/amp = (ohm × sec).

But practical unit is henry (H). It's dimensional formula [L] = [$ML^2T^{-2}A^{-2}$]



- **Dependence of self-inductance (L):** 'L' is determined by the number of turns (N), the area of cross section (A), and the permeability of the medium, not by the current flowing or changing, but by the number of turns (N), the area of cross-section (A), and the permeability of the medium (μ). 'L' does not play a role in the circuit until there is a steady current running through it. Only when there is a change in current does 'L' enter the picture.

- **The magnetic potential energy of inductor:** In order to create a continuous current in the circuit, the source emf must work against the coil's self-inductance, and any energy expanded for this work is stored in the coil's magnetic field, which is referred to as magnetic potential energy (U).

$$U = 1/2\ (Li)i = N\varphi i/2$$

The various formulae for L

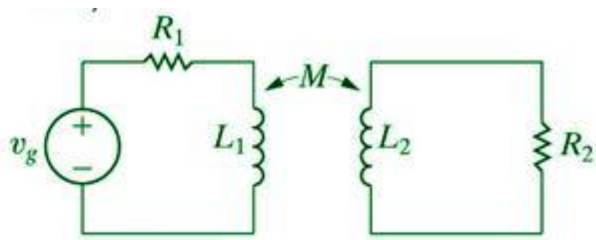
1. **Circular coil,** $L = \mu_0 \pi N^2 r/2$
2. **Solenoid,** $L = \mu_0 N^2 r/l = \mu_0 n^2 A l$
3. **Toroid,** $L = \mu_0 N^2 r/2$
4. **Square coil,** $L = 2\sqrt{2}\mu_0 N^2 a/\pi$

2. Mutual Induction

When the current going through a coil or circuit varies, so does the magnetic flux coupled to a neighboring coil or circuit. As a result, an emf will be induced in the next coil or circuit. Mutual induction is the term for this occurrence.

- **Coefficient of mutual induction:** $N_2\varphi_2$ is the total flux linked with the secondary due to current in the primary, and $N_2\varphi_2$ is directly proportional to $i_1 = N_2\varphi_2 = Mi_1$, where N_1 is the number of turns in the primary, N_2 is the number of turns in the secondary, φ_2 is the flux linked with each turn of the secondary, i_1 is the current flowing through the primary, and M is the mutual inductance coefficient.
- According to Faraday's second law emf induces in secondary $e_2=-N(d\varphi_2/dt)$; $e_2=-M(di_1/dt)$
- If di_1/dt = 1Amp/sec then $|e_2|=M$. When the rate of change of current in the main coil is unity, the mutual induction coefficient is equal to the emf induced in the secondary coil.
- Units and dimensional formula of 'M': It's S.I. unit, weber/Amp = (Tesla × m^2)/ Amp = (N × m)/Amp^2 = Joule/Amp^2 = (Coulomb × volt)/Amp^2 = (volt × sec)/amp = (ohm × sec).

But practical unit is henry (H). It's dimensional formula $[M] = [ML^2T^{-2}A^{-2}]$.



Dependence of mutual inductance:

1. Both coils have the same number of turns (N_1, N_2).
2. Both coils' self-inductance coefficients (L_1, L_2).
3. Coils cross-sectional area.
4. The nature of the material on which two coils are coiled or the magnetic permeability of the medium between the coils (μ_r).
5. Two coils are separated by this distance. (As d grows larger, M shrinks.)
6. Orientation of main and secondary coils (no flux relation M=0 for 90 degree orientation).
7. Between the primary and secondary coils, there is a 'K' coupling factor.
8. Relation between M, L_1, and L_2: For two magnetically coupled coils $M = K\sqrt{L_1L_2}$, where k – coefficient of coupling or coupling factor which is defined as,

K = Magnetic flux linked in secondary / Magnetic flux linked in primary

$$0 \le K \le 1$$

The various formulae for M

6. Two concentric coplanar circular coils, $M = \pi\mu_0 N_1 N_2 r^2/2R$
7. Two Solenoids, $M = \mu_0 N_1 N_2 A/l$
8. Two concentric coplanar square coils, $M = \mu_0 2\sqrt{2} N_1 N_2 l^2/\pi L$

Combination of Inductance

1. series

If two mutually inducing self-inductance coils L_1 and L_2 are connected in series and separated by a large enough distance that mutual induction between them is insignificant, then net self-inductance $L_s = L_1 + L_2$.

When they're near together, the net inductance is $L_s = L_1 + L_2 \pm 2M$.

2. Parallel

When two mutually inducting self-inductance coils L_1 and L_2 are linked in parallel and separated by a large distance, the net inductance L is $1/L_p = 1/L_1 + 1/L_2$.

$\therefore L_p = L_1L_2/L_1 + L_2$

When they are in close proximity to one another,

$L_p = L_1L_2 – M^2/L_1 + L_2 \pm 2M$

Self Vs Mutual Inductance:

Self Induction	Mutual Induction
The coil's self-inductance is a property of the coil.	The characteristic of a pair of coils is mutual inductance.
When the main current in the coil declines, the induced current resists the decay of current in the coil.	When the main current in the coil declines, the induced current created in the nearby coil opposes the decay of the current in the coil.
When the coil's primary current grows, the induced current opposes the expansion of current in the coil.	When the coil's primary current grows, the induced current created in the adjoining coil opposes the coil's current development.

Energy Stored in an Inductor and Capacitor:

Capacitor:

A capacitor is a device that stores electrical energy in an electric field. It's a two-terminal passive electrical component.

Inductor:

When electric current travels through it, an inductor, also known as a coil, choke, or reactor, stores energy in a magnetic field. An inductor is made out of a coil of insulated wire.

Energy stored in capacitor:

Electrical potential energy is stored in a capacitor and is thus related to the charge QQ

and voltage VV on the capacitor. When using the equation for electrical potential energy

ΔqVΔqV to a capacitor, we must be cautious. Remember that a charge q passing through a voltage ΔVΔV has a potential energy of ΔPEΔPE. The capacitor, on the other hand, begins with no voltage and progressively increases to its full value as it is charged. Because a capacitor has zero voltage when it is uncharged, the first charge placed on it causes a voltage change of ΔV=0ΔV=0. Because the capacitor now has its full voltage V, the final charge is placed on its experiences ΔV=VΔV=V.

During the charging process, the average voltage on the capacitor is V2V2.

So, the average voltage experienced by the full charge qq is V2V2.

Thus, the energy stored in a capacitor, EcapEcap

Ecap=QV2Ecap=QV2

where QQ represents the charge on a capacitor when a voltage V is applied. (It's worth noting that the energy is QV2QV2, not QVQV). Because the capacitance CC of a capacitor is connected to charge and voltage by Q=CVQ=CV, the expression for EcapEcap can be algebraically manipulated into three equivalent expressions:

Ecap=QV2=CV22Q22CEcap=QV2=CV22Q22C

WhereQQ is the charge on a capacitor CC and VV is the voltage. For a charge in coulombs, the voltage in volts, and capacitance in farads, the energy is measured in joules.

Energy stored in Inductors:

The magnetic field in an inductor stores energy when an electric current flows through it. In the case of a pure inductor LL, the instantaneous power required to start the current in the inductor is,

P=iv=LididtP=iv=Lididt

As a result, the integral gives the energy input to build up to a final current ii.Energy stored =∫0tPdt=∫0ILi’di’=12LI2=∫0tPdt=∫0ILi’di’=12LI2

Resonance Condition in Series LCR Circuit:

This is an interesting characteristic of LCR circuits. This phenomenon of resonance is common in the case of natural systems too, where these systems have a natural tendency to oscillate at a particular frequency. This frequency is called the system’s natural frequency. If these systems are driven by a source supplied energy at a natural frequency, then the amplitude of the oscillations is found to be large. This phenomenon is called resonance.

For an RLC circuit the current is given by,

$$i_m = \frac{v_m}{\sqrt{R^2+(X_C-X_L)^2}}$$

with $X_C = 1/\omega C$ and $X_L = \omega L$.

In case the frequency is varied, then at a particular frequency, the impedance is minimum.

$$X_C = X_L$$

In this case, $Z = \sqrt{R^2 + (0-0)^2} = R$

$$X_C = X_L$$

$$\Rightarrow 1/\omega C = \omega L$$

$$\Rightarrow \omega^2 = 1/LC$$

$$\Rightarrow \omega = 1/\sqrt{(LC)}$$

This frequency is called resonance frequency.

At this point, $i_m = v_m/R$