Nadar Saraswathi College of Engineering & Technology

NSCET
E-LEARNING
PRESENTATION

LISTEN … LEARN… LEAD…

ELECTRICAL AND ELCTRONICS ENGINEERING

II nd YEAR / III rd SEMESTER

EE8391 – Electromagnetic Theory

G.Sujitha M.E
Assistant Professor
Nadar Saraswathi College of Engineering & Technology,
Vadapudupatti, Annanji (po), Theni – 625531.

UNIT 03 – Magnetoststics

Attitude is a little thing that makes a gig difference.

-Winston churchill

UNIT-3

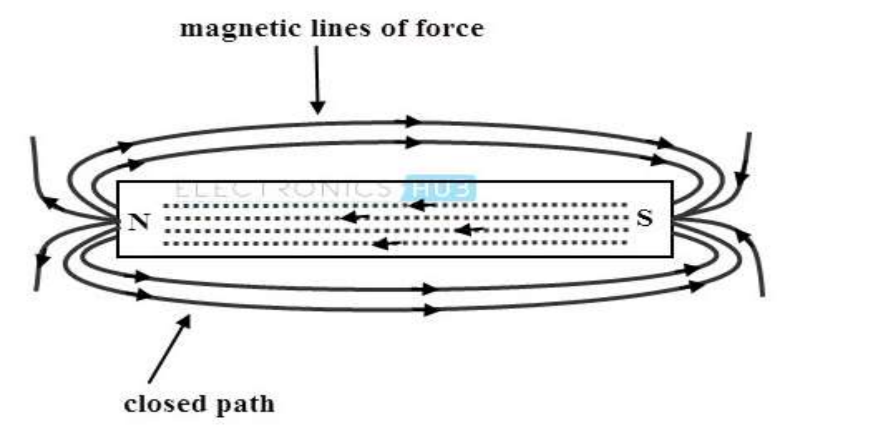
- Magnetic field intensity
- Lorentz force
- Biot savart law, Ampere’s law
- Magnetic flux density
- Magnetic material
- Magnetisation, boundary condition
- Scalar and vector potential
- Magnetic force, torque, inductance

Fundamentals of magnetic fields

- Consider a permanent magnet that has two poles namely North (N) and South (S). The region within which the influence of a magnet is experienced around the magnet is called as a magnetic field.

- This field is nothing but a representation of imaginary lines around the magnet which are also called as magnetic lines of force or magnetic flux lines.

- The magnetic flux lines always exist in the form of a closed loop; that means the flux lines starting from N pole must be terminated at S pole irrespective of the field i.e. either due to the current carrying conductor or due to permanent magnet.



Magnetic flux density(B)

- The magnetic flux density is denoted as $\bar{B}$ and is defined as the total magnetic lines of force or the magnetic flux per unit area in a plane that is perpendicular to the direction of the magnetic field.
- It is a vector quantity and is measured in Weber per meter square (Wb/m2) also called as Tesla (T).

Magnetic field intensity(H)

- The magnetic field strength or magnetic field intensity gives the quantitative measure of weakness or strongness of the magnetic field. It is the force experienced by a unit north pole of one Weber strength when placed at any point in the magnetic field.

- It is denoted as $\bar{H}$ and is measured in Newton/Weber (N/Wb) or Ampere- turns /meter (AT/m) or amperes per meter (A/m).

- In magnetostatics the magnetic field intensity $\bar{H}$ and magnetic flux density $\bar{B}$ are related to each other by a property of permeability of the region in which the conductor is placed.

- The permeability of this region allows the current carrying conductor to force the magnetic flux around it. It is denoted as μ and measured in Henries per meter (H/m).

- These two variables are related as

$(\bar{B}) = \mu \bar{H} = \mu_o \mu_r (\bar{H})$

Where $\mu = \mu_o \mu_r$

For a free space, the permeability is denoted as μ_o and its value is $4\pi \times 10^{-7}$ H/m.

- μ_r is the relative permeability and its value is unity for nonmagnetic media and greater than unity for magnetic materials.

Lorentz force

- A steady magnetic field is produced by a static current not by a static charge. Hence moving charges in a magnetic field also experience a magnetic force.

- The Lorentz's force equation facilitates to determine the force experienced by a charged particle in the presence of electromagnetic fields.

- It states that if an electric charge q is subjected to an electric field, then it experiences a force equal to the product of q and electrical field intensity E.

- The direction of the force is along the direction of magnetic field intensity. The total force experienced by a charge q moving with a velocity v is given by

$$\mathbf{F = q\,(E + v \times B)\ Newton}$$

Where B is called as magnetic flux density. This is called as Lorenz force equation.

- It comprises of two parts,

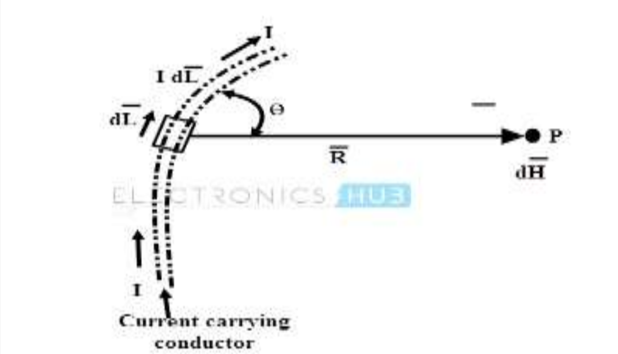
electric force $F_e = qE$

magnetic force $F_m = qv \times B$.

Biot-Savart Law

- The Biot-Savart law gives the expression describing the magnetic field produced by an electric current.

- Consider a direct current is applied to a conductor. It produces a steady magnetic field around it. The Biot-Savart law is used to find the differential magnetic field intensity produced dH¯at point P due to a differential current element IdL.



Mathematically

$$\bar{dH} \; \alpha \; (I \; dL \; Sin \; \theta) / R^2$$

$$\bar{dH} = k \; (I \; dL \; Sin \; \theta) / R^2$$

Where K is the proportionality constant and is equal to 1/4π

Thus,

$$\bar{dH} = (I \; dL \; Sin \; \theta) / 4\pi R^2$$

dL = magnitude of vector length $\bar{dL}$

$\bar{(aR)}$ = unit vector in the direction from differential current element to P

According to the cross rule product,

$$\bar{dL} \times \bar{(aR)} = dL \; |\bar{(aR)}| \; Sin \; \theta$$

$$= dL \; Sin \; \theta \quad \text{since} \quad |\bar{(aR)}| = 1$$

Substituting in the equation we get,

$$\bar{dH} = (I \; \bar{dL} \times \bar{(aR)}) / 4\pi R^2 A/m$$

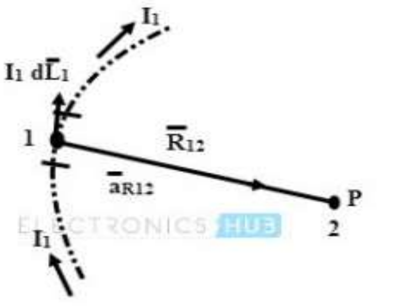
But $\overline{(aR)} = \overline{R}/R$

Therefore, $d\overline{H} = (I\, d\overline{L} \times \overline{R}) / 4\pi R^3$ A/m

To obtain the entire magnetic field intensity, the equation 2 has to be integrated as

$$\overline{H} = \oint (I\, d\overline{L} \times \overline{(aR)}) / 4\pi R^2 \text{ A/m}$$

By considering the closed path of the circuit as shown in figure, the field intensity between the two points is given as,



$$\overline{H}_2 = \oint \frac{I_1\, d\overline{L}_1 \times \overline{a}_{R12}}{4\pi R_{12}^2} \text{ A/m}$$

Ampere's Circuital Law

- This law is analogous to the Gauss law in electrostatics. By using this law, complex problems are solved in magnetostatics.

- This law can be used to find the magnetic field intensity due to any current distributions.

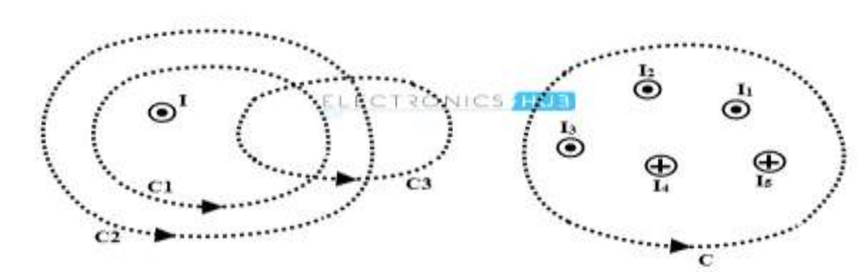
- According the Ampere circuital law, the line integral of magnetic field intensity $\bar{H}$ around a closed path is equal to the direct current enclosed by that path.

Mathematically,

$$\oint \bar{H}.(\bar{dL})=I$$

The above relation is called as an integral form of Ampere's circuital law.

Where I is the current enclosed by the closed path.



- The concept of enclosed current is shown in below figures where the current I is enclosed by the closed paths C1 and C2. So along the either paths, the line integral of field intensity will give same result as I..

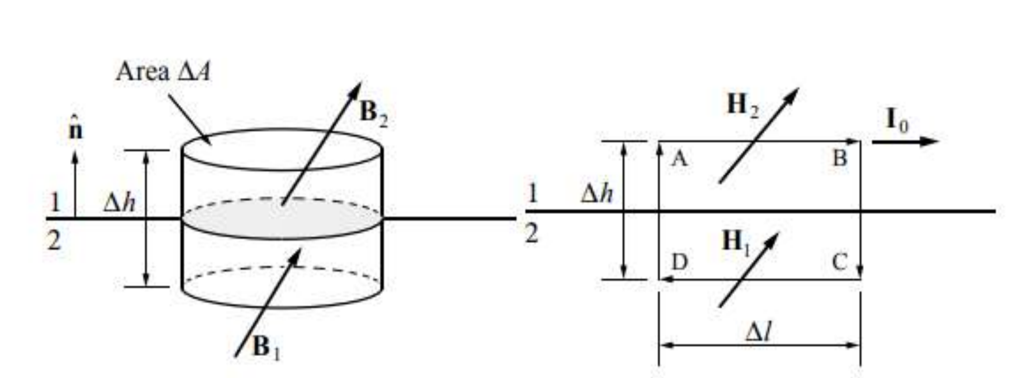
Magnetic material

- The origin of magnetism lies in the orbital and spin motions of electrons and how the electrons interact with one another.
- The best way to introduce the different types of magnetism is to describe how materials respond to magnetic fields.
- It's just that some materials are much more magnetic than others.
- The main distinction is that in some materials there is no collective interaction of atomic magnetic moments, whereas in other materials there is a very strong interaction between atomic moments.

The magnetic behavior of materials can be classified into the following five major groups:

- Diamagnetism
- Paramagnetism
- Ferromagnetism
- Ferrimagnetism
- Antiferromagnetism

Magneto static boundary condition



A Gaussian pill-box at the interface between two different media, arranged as in the figure above.

- The net enclosed (free) magnetic charge density is zero so as the height of the pill-box Δh tends to zero so the integral form of Gauss's law tells us that,

$$(\mathbf{B}_2 \cdot \hat{\mathbf{n}})\Delta A - (\mathbf{B}_1 \cdot \hat{\mathbf{n}})\Delta A \approx 0$$

- which becomes exact in the limit $\Delta A \rightarrow 0$ when

$$(\mathbf{B}_2 - \mathbf{B}_1) \cdot \hat{\mathbf{n}} = 0$$

- Therefore the component of B normal to the interface is continuous. To find the H-field boundary condition we apply Ampère's circuital law to the path ABCD shown in the diagram above. I0 is the unit vector in the direction AB parallel to the surface so $\text{as } \Delta h \rightarrow 0 \quad \text{so} \quad (\mathbf{H}_2 - \mathbf{H}_1) \cdot \mathbf{I}_0 \Delta l = \mathbf{j}_c \cdot (\hat{\mathbf{n}} \times \mathbf{I}_0) = (\mathbf{j}_c \times \hat{\mathbf{n}}) \cdot \mathbf{I}_0$

or equivalently

$$\left(\mathbf{H}_2 - \mathbf{H}_1\right)_{\|} = \mathbf{j}_c \times \hat{\mathbf{n}}.$$

One can take the cross-product of this expression to obtain a form that is useful for deducing $\mathbf{j}_c$ if **H** is known on each side of the boundary.

$$\hat{\mathbf{n}} \times \left(\mathbf{H}_2 - \mathbf{H}_1\right) = \mathbf{j}_c.$$

To summarise, the component of **H** tangential to the interface is continuous across the interface unless there is a conduction surface current density $\mathbf{j}_c$.

Note also that although the flux of **B** is continuous everywhere, the flux of **H** is not.

Magnetic potential

Magnetic field can be related to a potential by two methods which give rise to two possible types of magnetic potentials used in different situations:

1. Magnetic Scalar Potential

2. 2. Magnetic Vector Potential

Magnetic scalar potential

In Electrostatics, electric field E is derivable from the electric potential V.

$$\nabla \times \mathbf{E} = 0, \qquad \vec{E} = -\vec{\nabla} V$$

V is a scalar quantity and easier to handle than E which is a vector quantity.

In Magnetostatics,

the quantity Magnetic scalar potential can be obtained using analogues relation

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j}$$

In regions of space in the absence of currents, the current density j =0

$$\nabla \times \mathbf{B} = 0$$

B is derivable from the gradient of a potential

Therefore B can be expressed as the gradient of a scalar quantity

φm B = - ∇φm φm is called as the Magnetic scalar potential.

Magnetic vector potential

- The magnetic scalar potential is useful only in the region of space away from free currents.
- If J=0, then only magnetic flux density can be computed from the magnetic scalar potential
- The potential function which overcomes this limitation and is useful to compute B in region where J is present is . Magnetic Vector Potential
- Magnetic fields are generated by steady (time-independent) currents & satisfy Gauss' Law

$$\nabla \cdot \mathbf{B} = 0$$

Since the divergence of a curl is zero, B can be written as the curl of a vector A as

$$\mathbf{B} = \nabla \times \mathbf{A}$$

Any solenoidal vector field (e.g. B) in physics can always be written as the curl of some other vector field (A).
The quantity A is known as the Magnetic Vector Potential.

Magnetic force

- **Magnetic force**, attraction or repulsion that arises between electrically charged particles because of their motion.
- It is the basic force responsible for such effects as the action of electric motors and the attraction of magnets for iron.
- Electric forces exist among stationary electric charges; both electric and magnetic forces exist among moving electric charges.
- The magnetic force between two moving charges may be described as the effect exerted upon either charge by a magnetic field created by the other.

Magnetic torque

- A **magnetic** field exerts a force on a straight wire carrying current; it exerts a torque on a loop of wire carrying current.
- Torque causes an object to spin around a fixed axis.
- A magnetic field exerts a torque which tries to align the normal vector of a loop of current with the magnetic field.

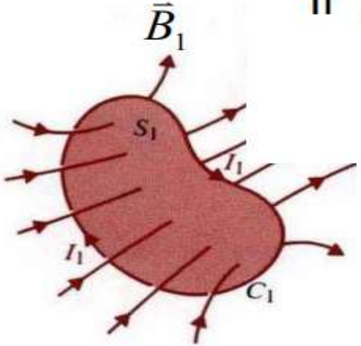
Inductance

Self inductance

Closed loop C_1 carrying current I_1 will create $\vec{B}_1$

$\Rightarrow$ flux: $\Phi_{11} = \int_{S_1} \vec{B}_1 \cdot d\vec{s}$, flux linkage: $\Lambda_{11} = N_1 \Phi_{11}$

If $I_1' = rI_1$, by $\vec{B} = \oint_{C'} \frac{\mu_0 I}{4\pi} \frac{d\vec{l}\,' \times \vec{a}_R}{R^2}$ Only depend on geometry



$\Rightarrow \vec{B}_1' = r\vec{B}_1,\ \Phi_{11}' = \int_{S_1} \vec{B}_1' \cdot d\vec{s} = r\Phi_{11},$

$\Lambda_{11}' = r\Lambda_{11}$

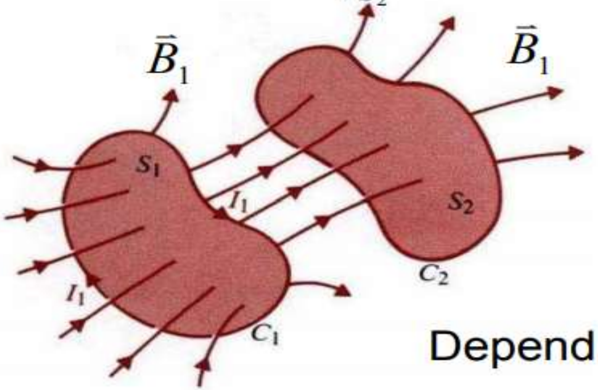
$\Rightarrow$ "Self-inductance" of the loop C_1:

$$L_{11} = \frac{\Lambda_{11}}{I_1}$$

Mutual inductance

In the presence of another loop C_2, $\vec{B}_1$ will pass through C_2, $\Rightarrow$ mutual flux linkage: $\Lambda_{12} = N_2\Phi_{12}$

where $\Phi_{12} = \int_{S_2} \vec{B}_1 \cdot d\vec{s} \propto I_1$



$\Rightarrow$ "Mutual-inductance" between the 2 loops:

$$L_{12} = \frac{\Lambda_{12}}{I_1}$$

Depend on geometry & material.

Thank you