CHAPTER #28: Magnetic Fields

- Till now we have studied how an electric field can produce an electric force on a charged object.
- Now, a closely related goal is the study of how a magnetic field can produce a magnetic force on a (moving) charged particle.

Applications of Magnetic Fields & Magnetic Forces:

(i) Entertainment Industry; magnetic recording of music & images on audio tapes and videotapes, CD, DVD, hard drives, TV telephones etc.

(ii) Modern Cars; engine ignition, automatic window control, sunroof control, windshield wiper control.

(iii) Security Alarms; doorbells, automatic door latches.

You are Surrounded by Magnets.

Note: The science of Magnetic Fields is Physics. The application of Magnetic Fields is Engineering. Both ask: "What produces Magnetic Fields?"
What produces a Magnetic field?

(i) Because an E is produced by electric charge
\[ \bar{B} \leftrightarrow \text{magnetic charge} \]
Predicted by Somethono, but not found yet.

(ii) Moving electrically charged particles, such as a current in a wire. Current produces a magnetic field. \textit{Statement}

(iii) By means of elementary particles such as electrons because these have intrinsic magnetic field around them.

\[ \text{This characteristic makes permanent magnet a permanent.} \]

Note: Our job is to define the Magnetic Field $\bar{B}$.

\[ E = \frac{F_B}{q}. \]
\[ E = \frac{F_E}{q} \]

(Placing a test particle 'q' at rest at that point and measuring \( F_E \) acting on it.)

If magnetic monopoles were available, we could imagine defining \( \bar{B} \) in a similar way. But we can't do now because monopoles are not found.

\[ \bar{B} = \frac{F_M}{q} \]

\[ \Rightarrow \text{We must define } \bar{B} \text{ in another way, in terms of magnetic force } F_B \text{ exerting on a moving electrically charged test particle.} \]

In principle:

Finishing a charged particle through the point at which \( \bar{B} \) is to be defined, using various directions and speeds for the particle and determine \( F_B \) that acts on the particle at that point:

\[ B = \frac{F_B}{qv} \]

In vector form:

\[ F_B = qv \overrightarrow{\times} \bar{B} \]

\[ F_B = |qv|v \overrightarrow{BSin}\phi \]

\[ \Rightarrow \text{angle } \phi \text{ with the directions of } \overrightarrow{v} \text{ and } \overrightarrow{B} \]
Finding the Magnetic Force on a Particle

\[ \vec{F}_B = q \vec{v} \times \vec{B} = q \vec{v} \vec{B} \sin \phi \]

- \( \vec{v} = 0 \); \( \vec{F}_B = 0 \)
- \( \vec{v} \) and \( \vec{B} \) are parallel; \( \phi = 0 \); \( \vec{F}_B = 0 \)
- \( \vec{v} \) and \( \vec{B} \) are \( + \); \( \phi = 90^\circ \); \( \vec{F}_B \) is maximum.

**Direction:**

- Magnetic field direction:
  - \( \circ \) : Outward to you,
  - \( \times \) : Into the page/Away from you
- Particle is moving \( \text{out of page} \)

**Right-hand Rule**

- If a moving charged particle is \( + \),

**Index Figure:**

- Direction of velocity of charge
- Particle.

**Middle Figure:**

- Magnetic field towards your fingers away from thumb
- Shows the direction of \( \vec{F}_B \)

**Left-hand Rule**

- If the moving charged particle is \( - \),

Rest of the things are same.
Note: \( \vec{F}_B \) must be \( \perp \) to \( \vec{V} \) and \( \vec{B} \). But \( \vec{V} \) and \( \vec{B} \) may or may not be \( \perp \); perpendicular case is their max. orientation. \( \Phi \) varies the magnitude of \( \vec{F}_B \).

* **SI Unit:**

\[
B = \frac{E}{qv} \quad \text{(Magnitude)}
\]

1 tesla = 1T = \( \frac{1 \text{ N}}{(1 \text{ C})(1 \text{ m/s})} \)

\[
1 \text{ T} = 1 \text{ N A}^{-1} \text{ m}^{-1}
\]

Non-SI unit:

1 tesla = \( 10^4 \) gauss

* **Magnetic Field Lines**

Represent the magnetic field with field lines, as we did for electric fields.

**Rules:**

1. Direction of the tangent to a magnetic field line at any point gives the direction of \( \vec{B} \) at that point.
   
2. Spacing of the lines represent the magnitude of \( \vec{B} \); the magnetic field is stronger where the lines are closer together, and conversely.

Note: **Outside** magnetic: \( N \rightarrow S \)

**Inside** magnetic: \( S \rightarrow N \)
Both an electric field \( \mathbf{E} \) and a magnetic field \( \mathbf{B} \) can produce a force on a charged particle. When the two fields are perpendicular to each other, they are said to be crossed fields.

From previous knowledge, we know that a beam of electrons in a vacuum can be deflected by a magnetic field.

Q: Can the drifting conduction electrons in a copper wire also be deflected by a magnetic field?

In 1879, Edwin H. Hall (24-year-old graduate student at Johns Hopkins) showed that they can. This Hall effect allows us to find out whether the charge carriers in a conductor are positive or negative. Electric current is not conventional current.
A copper strip of width 'd' carrying a current 'i' whose conventional direction is from top to bottom.

- Charge carries ace electrons
- They drift in the opposite direction of conventional current (electric field); bottom to top.
- External magnetic field into the plane.

**Working:**

a) Turn on magnetic field, a magnetic deflecting force $F_B$ will act on each drifting electron.

b) By Fleming's left hand rule (because A -ve particle)
electrons pushing to right of the strip.

c) As time goes, -ve particles pile up on the right edge of strip which leads to the particles on left edge of strip.

d) $\mathcal{E}$ is produced from left to right.

e) This electric field exerts an electric force $F_E$ on each electron, tending to push it to the left.
f) At equilibrium:

\[ F_E = F_B \]

when this happens, the drifting electrons move along the strips without any deflection.

9) A Hall Potential difference \( V \) is associated with the electric field across strip width \( d \).

\[ V_H = Ed \]

we can measure this by voltmeter, and from that reading we can tell which edge is at higher potential. This tells us that the charge carriers are \((-ve)\) charged.

If you take the opposite assumption; the charge carriers then voltmeter reading contradict which implies that the charge carriers MUST be \(-ve\).

\[ F_E = F_B \]

\[ eE = eVdB \Rightarrow \frac{E}{Vd} = \frac{1}{B} \]

\[ J = neVd \Rightarrow Vd = \frac{J}{ne} \]

\[ J = \frac{i}{A} \Rightarrow Vd = \frac{i}{ne} \frac{A}{l \times d} \]
\[ V_H = E d \quad \Rightarrow \quad E = \frac{V_H}{d} \quad (3) \]

\[ E = V_0 B \quad (\text{From (1)}) \]

\[ E = \frac{i B}{\ln n e} \quad (4) \]

Equalizing (3) and (4):

\[ \frac{V_H}{d} = \frac{i B}{\ln n e} \quad \Rightarrow \quad V_H = \frac{i B}{\ln n e} \]

\[ n = \frac{B i}{V_H \ln e} \]

\( l \rightarrow \text{thickness of the strip} \)

\( d \rightarrow \text{width of the strip} \)