Applied Physics for Engineers **(PHY121)**

Magnetism (part-2)

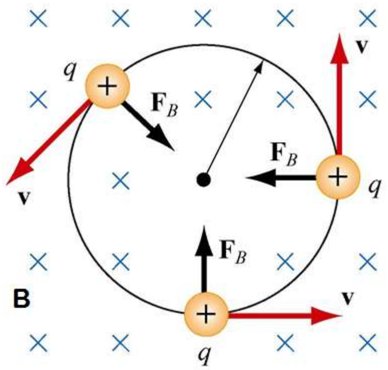
LECTURE # 14

Instructor
Muhammad Kaleem Ullah
Lecturer,
Department of Physics,
CUI, Lahore Campus.

What Kind of Motion in Uniform B Field?

Cyclotron Motion

(1) r : radius of the circle



$$qvB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB}$$

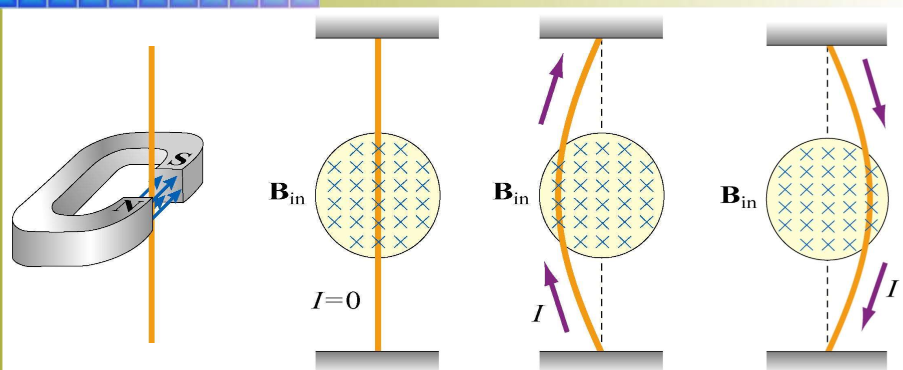
(2) T : period of the motion

$$T = \frac{2\pi r}{v} = \frac{2\pi m}{qB}$$

(3) ω : cyclotron frequency

$$\boxed{\omega = 2\pi f = \frac{2\pi}{T} = \frac{qB}{m}}$$

Magnetic Force on Current-Carrying Wire



Current is moving charges, and we know that moving charges **feel** a force in a magnetic field

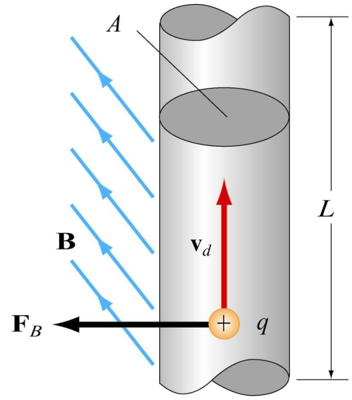
Magnetic Force on Current-Carrying Wire

$$\vec{\mathbf{F}}_B = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

$$= (\mathrm{C})\,\frac{\mathrm{m}}{\mathrm{s}} \times \vec{\mathbf{B}}$$

$$= \frac{(\mathrm{C})}{\mathrm{s}}\,\mathrm{m} \times \vec{\mathbf{B}}$$

$$\boxed{\vec{\mathbf{F}}_B = I\left(\vec{\mathbf{L}} \times \vec{\mathbf{B}}\right)}$$

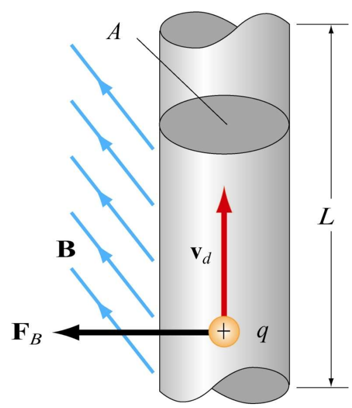


Summary Magnetic Force

$$\vec{\mathbf{F}}_B = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

$$d\vec{\mathbf{F}}_B = I d\vec{\mathbf{s}} \times \vec{\mathbf{B}}$$

$$\vec{\mathbf{F}}_B = I\left(\vec{\mathbf{L}} \times \vec{\mathbf{B}}\right)$$



Air Gap of a Magnet

- The air space between the poles of a magnet is its **air gap**.
- The shorter the air gap, the stronger the field in the gap for a given pole strength.

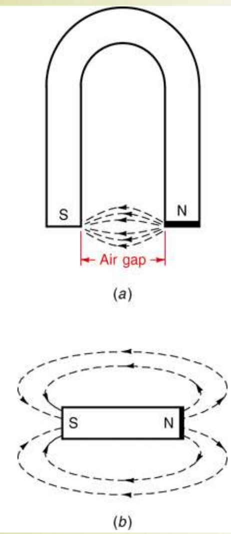


Fig. 1: The horseshoe magnet in *(a)* has a smaller air gap than the bar magnet in *(b)*.

Air Gap of a Magnet

- The shorter the air gap, the more intense the field. Eliminating the air gap eliminates the external field. This concentrates the lines within the field.
- Magnets are sometimes stored with “keepers” that eliminate the external field.

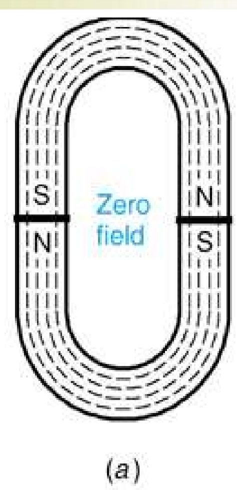


Fig. 2: Example of a closed magnetic ring without any air gap. (*a*) Two PM horseshoe magnets with opposite poles touching.

Air Gap of a Magnet

- A **toroid coil** has very little external field.
- Toroid cores (doughnut shaped) are used to greatly reduce unwanted magnetic induction.

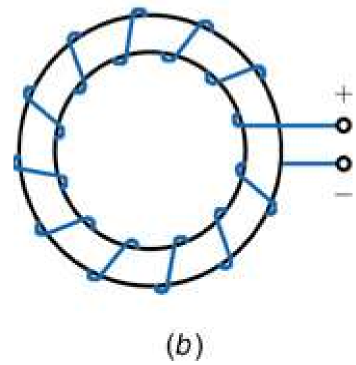


Fig. 3(b): Toroid magnet.

Types of Magnets

- There are two main classes of magnets:
  - An **electromagnet** is made up of coils of wire, and must have an external source of current to maintain a magnetic field.
    - Applications: buzzers, chimes, relays (switches whose contacts open or close by electromagnetism), tape recording.
  - A **permanent magnet** retains its magnetic field indefinitely.

Types of Magnets

- Classification of Magnetic and Nonmagnetic Materials
  - Magnetic materials:
    - **Ferromagnetic materials** include iron, steel, nickel, cobalt, and certain alloys. They become strongly magnetized in the same direction as the magnetizing field, with high values of permeability.
    - **Paramagnetic materials** include aluminum, platinum, manganese, and chromium. They become weakly magnetized in the same direction as the magnetizing field. The permeability is slightly more than 1.

Types of Magnets

- **Diamagnetic materials** include copper, zinc, mercury, gold, silver, and others. They become weakly magnetized in the opposite direction from the magnetizing field. The permeability is less than 1.

- Nonmagnetic materials:
  - air, paper, wood, and plastics

Ferrites

- **Ferrites** are nonmetallic materials that have the ferromagnetic properties of iron.
  - They have high permeability.
  - However, a ferrite is a non-conducting ceramic material.
  - Common applications include ferrite cores in the coils for RF transformers, and ferrite beads, which concentrate the magnetic field of the wire on which they are strung.

http://www.mag-inc.com/ferrites/ferrites.asp

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Magnetic Shielding

- **Shielding** is the act of preventing one component from affecting another through their common electric or magnetic fields.

- Examples:
  - The braided copper wire shield around the inner conductor of a coaxial cable
  - A shield of magnetic material enclosing a cathode-ray tube.

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How does Magnetic Shielding Work?

- When magnetic lines of flux encounter high permeability material, the magnetic forces are both absorbed by the material and redirected away from its target.
- The most effective shields are constructed as enclosures such as boxes or better yet, cylinders with end caps.

What is EMI?

- EMI is the abbreviation for Electro Magnetic Interference.
- EMI is an electrical or magnetic disturbance that causes unwanted interference.

P1

A proton is moving in a circular orbit of radius *14 cm* in a uniform magnetic field of magnitude *0.35 T*, directed perpendicular to the velocity of the proton. Find the orbital speed of the proton.

Solution: Because,

$$r = \frac{mv}{qB} \Rightarrow v = \frac{rqB}{m} = \frac{(0.14\ m)(1.60\times10^{-19}\ C)(0.35\ T)}{(1.67\times10^{-27}\ kg)}$$

$$= \frac{(0.14\ m)(1.60\times10^{-19}\ C)(0.35\ kg/C.s)}{(1.67\times10^{-27}\ kg)}$$

NOTE:
$T = N/A.m = N/(C.s^{-1}).m = N.s / C.m$
$= kg.ms^{-2}.s / C.m = kg.\ s^{-1} / C$
$= kg/C.s$

$$v = 4.7\text{x}10^{6}\ m/s$$

P2

A proton moves in a direction perpendicular to a uniform magnetic field *B* at *1.00×10⁷ m/s* and experiences an acceleration of *2.00×10¹³ m/s²* in the *+x direction when its velocity is in the +z* direction. Determine the magnitude and direction of the field.

Solution:

$$F = ma = (1.67\times10^{-27}\ kg)(2.00\times10^{13}\ m/s^2)$$
$$= 3.34\times10^{-14}\ N$$

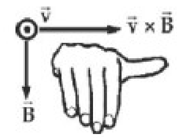
$$F = qvB\sin 90^0 \quad \Rightarrow \quad B = \frac{F}{qv} = \frac{(3.34\times10^{-14}\ N)}{(1.60\times10^{-19}\ C)(1.00\times10^{7}\ m/s)}$$

$$= 2.09\times10^{-2}\ N.s/C.m = 2.09\times10^{-2}\ N/A.m$$

$$= 2.09\times10^{-2}\ T = 20.9\times10^{-3}\ T$$
$$= 20.9\ mT$$

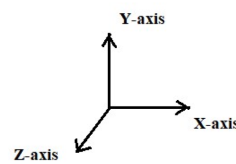
P2 (Continue…)

From FIGURE, the right-hand rule shows that B must be in the $-y$ direction to yield a force in the $+x$ direction when v is in the z direction. Therefore,



FIGURE

$$\boxed{\vec{\mathbf{B}} = -20.9\ \hat{\mathbf{j}}\ \mathrm{mT}}$$



•A proton moving at *4.00×10^{6} m/s* through a magnetic field of *1.70 T* experiences a magnetic force of magnitude *8.20×10^{-13} N*. What is the angle between the protons velocity and the field?

•An electron is accelerated from rest by a potential difference of *350 V*. It then enters a uniform magnetic field of magnitude *200 mT*, its velocity being at right angles to this field. Calculate *(a)* the speed of the electron and *(b)* the radius of its path in the magnetic field.

Hall Effect

- In 1879, Edwin H. Hall, a 24-year-old graduate student at the Johns Hopkins University, showed that the drifting conduction electrons in a copper wire can also be deflected by a magnetic field.
- This Hall effect allows to find out whether the charge carriers in a conductor are positively or negatively charged.
- The number of such carriers per unit volume of the conductor can also be measured.
- Fig.1.a shows a copper strip of width ***d***, carrying a current ***i*** whose conventional direction is from the top of the figure to the bottom.
- The charge carriers are electrons and, as we know they drift (with drift speed v_D) in the opposite direction, from bottom to top.

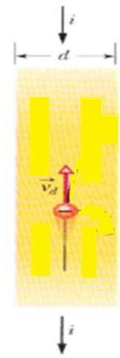


Fig.1.a

Hall Effect

- At the instant shown in Fig.1.a, an external magnetic field $\vec{B}$, pointing into the plane of the figure, has just been turned on.
  - From Eq. ($\vec{F_B} = q(\vec{v} \times \vec{B})$) we see that a magnetic deflecting force $\vec{F_B}$ will act on each drifting electron, pushing it toward the right edge of the strip.
  - As time goes on, electrons move to the right, mostly piling up on the right edge of the strip, leaving uncompensated positive charges in fixed positions at the left edge.
  - The separation of positive and negative charges produces an electric field E within the strip, pointing from left to right in Fig.1.b.
  - This field exerts an electric force $\vec{F_E}$ on each electron, tending to push it to the left.

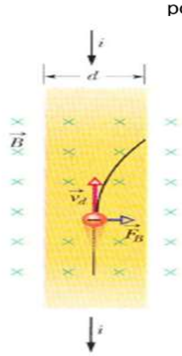


Fig.1.a

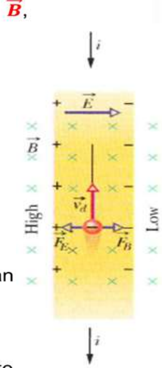
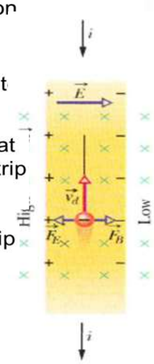


Fig.1.b

Hall Effect

- An equilibrium quickly develops in which the electric force on each electron builds up until it just cancels the magnetic force.
- When this happens, as Fig.1.b shows, the force due to $\vec{B}$ and the force due t $\vec{E}$ are in balance.
- The drifting electrons then move along the strip toward the top of the page at velocity $\overrightarrow{v_D}$, with no further collection of electrons on the right edge of the strip and thus no further increase in the electric field $\vec{E}$.
- A Hall potential difference **V** is associated with the electric field across strip width ***d***.
- From Eq. ($\boldsymbol{E = -\Delta V/\Delta s}$), the magnitude of that potential difference is



$$V = Ed \qquad \textbf{... (1)}$$

Fig.1.b

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Hall Effect

When the electric and magnetic forces are in balance, then

$$\boldsymbol{F_E = F_B}$$

$$\boldsymbol{eE = ev_D B} \qquad \textbf{... (2)}$$

As the drift speed $\boldsymbol{v_D}$ is

$$\boldsymbol{v_D} = \frac{J}{ne} = \frac{i}{neA} \qquad \textbf{... (3)}$$

in which ***J*** (**= *i*/A**) is the current density in the strip, ***A*** is the cross-sectional area of the strip, and ***n*** is the number density of charge carriers (their number per unit volume). In Eq.2, substituting for ***E*** with Eq.1 and substituting for $\boldsymbol{v_D}$ with Eq.3, we obtain

$$\boldsymbol{n = \frac{Bi}{Vle}} \qquad \textbf{... (4)}$$

in which ***l*** (**= *A/d***) is the thickness of the strip. With this equation we can find ***n*** from measurable quantities.

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END OF LECTURE