Magnetic field, Magnetic Force on Current, Hall Effect

Applied Physics

PH-122

Magnetic Field

- A magnetic field is a vector field that describes the magnetic influence of electric charges in relative motion and magnetized materials. A charge that is moving parallel to a current of other charges experiences a force perpendicular to its own velocity.

$$B = F_{B//}/q \times v$$

q is the charge of the particle.

$F_B = qv \times B$ (this shows direction of force by using right hand rule)

$F_B = qvB \sin\theta$ (this shows magnitude of force)

θ is the angle between direction of velocity and magnetic field.

Right hand rule

- $F_B = qv \times B$

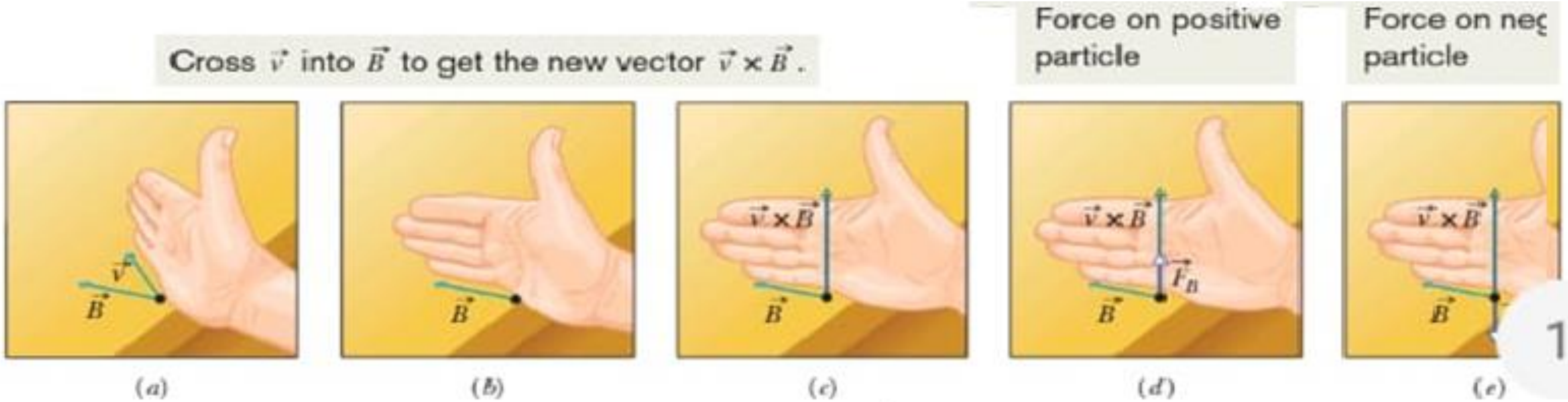


Figure (a)–(c) The right-hand rule (in which $\vec{v}$ is swept into $\vec{B}$ through the smaller angle ϕ between them) gives the direction of $\vec{v} \times \vec{B}$ as the direction of the thumb. (d) If q is positive, then the direction of $\vec{F}_B = q\vec{v} \times \vec{B}$ is in the direction of $\vec{v} \times \vec{B}$. (e) If q is negative, then the direction of $\vec{F}_B$ is opposite that of $\vec{v} \times \vec{B}$.

Unit

- $1\ tesla\ =\ 1\ T = 1 newton/(coulomb)\left(\frac{meter}{second}\right)$

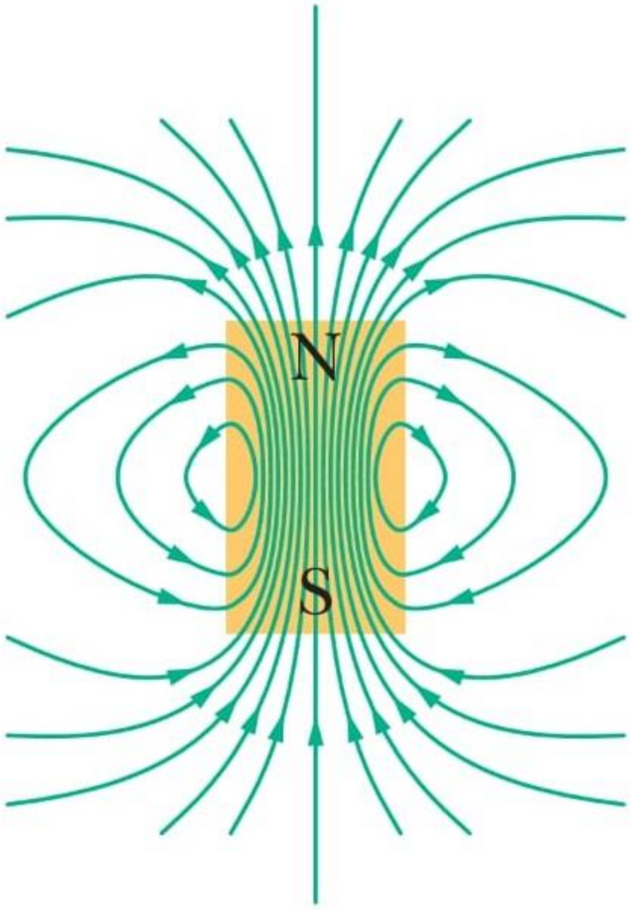
- Recalling that a coulomb per second is an ampere, we have

- 1 T =1newton/(coulomb/second)(meter)= 1N/A.m

Magnetic Field Lines

- We can represent magnetic fields with field lines as we did for electric fields. Similar rules apply

1. The direction of the tangent to magnetic field lines at any point gives the direction of **B** at that point
2. The spacing of the lines represent the magnitude of magnetic field **B** – The magnetic field is stronger where lines are closer together. Fig. shows how the magnetic field near a bar magnet can be represented by magnetic field lines



Problem:

- A uniform magnetic field , with magnitude 1.2 mT, is directed vertically upward throughout the volume of a laboratory chamber.A proton with kinetic energy 5.3 MeV enters the chamber, moving horizontally from south to north. What magnetic deflecting force acts on the proton as it enters the chamber? The proton mass is 1.67×10^{-27} kg. (Neglect Earth's magnetic field.)
- Solution:

  Magnetic field=B=1.2mT

  K.E = 5.3 MeV

  magnetic deflecting force =?

  mass of proton=m= 1.67×10^{-27} kg

Continued

$$F_B = qvB \sin \Theta$$

$$k = \frac{mv^2}{2}$$

$$v = \sqrt{\frac{2k}{m}}$$

$$v = \frac{\sqrt{((2 \times 5.3 \times 10^6 \times 1.6 \times 10^{-19})}}{\sqrt{(1.67 \times 10^{-27})}} = 3.2 \times 10^7 \text{m/s}$$

$$F = 1.6 \times 10^{-19} \times 3.2 \times 10^7 \text{m/s} 1.2mT$$

$$F = 6.1 \times 10^{-15} \text{ N.}$$

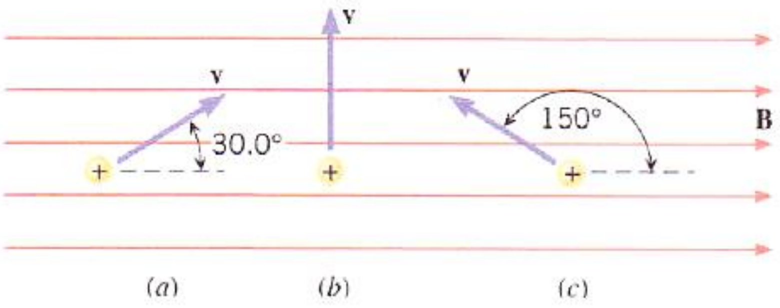
small force, but it acts on a particle of small mass, producing a large acceleration. a=F/m

$$a = 6.1 \times 10^{-15} / 1.67 \times 10^{-27} = 3.7 \times 10^{12} \text{ m/s}^2$$

Magnetic Forces and Magnetic Fields

Problem 1

A particle of charge +7.5 μC and a speed of 32.5 m/s enters a uniform magnetic field whose magnitude is 0.50 T. For each of the cases in the figure below, find the magnitude and direction of the magnetic force on the particle.



Note: the magnitude of the magnetic force is given by

$F = |q| v B \sin\theta$

Note: the direction of the magnetic force is given by right hand rule 1.

RHR #1 ⇒ With your right hand, point your fingers in the direction of $\vec{B}$ and your thumb in the direction of $\vec{V}$. Your palm points in the direction of $\vec{F}$ on a positive charge.

$q = 7.5 \times 10^{-6}\,C$

$v = 32.5\ m/s$

$B = 0.50\,T$

a) $F = (7.5 \times 10^{-6}\,C)(32.5\,m/s)(0.50\,T)\sin 30^\circ$

$$\boxed{\vec{F} = 6.1 \times 10^{-5}\ N \text{ into the page}}$$

b) $F = (7.5 \times 10^{-6}\,C)(32.5\,m/s)(0.50\,T)\sin 90^\circ$

$$\boxed{\vec{F} = 1.2 \times 10^{-4}\ N \text{ into the page}}$$

c) $F = (7.5 \times 10^{-6}\,C)(32.5\,m/s)(0.50\,T)\sin 150^\circ$

$$\boxed{\vec{F} = 6.1 \times 10^{-5}\ N \text{ into the page}}$$

Magnetic force on a current carrying wire

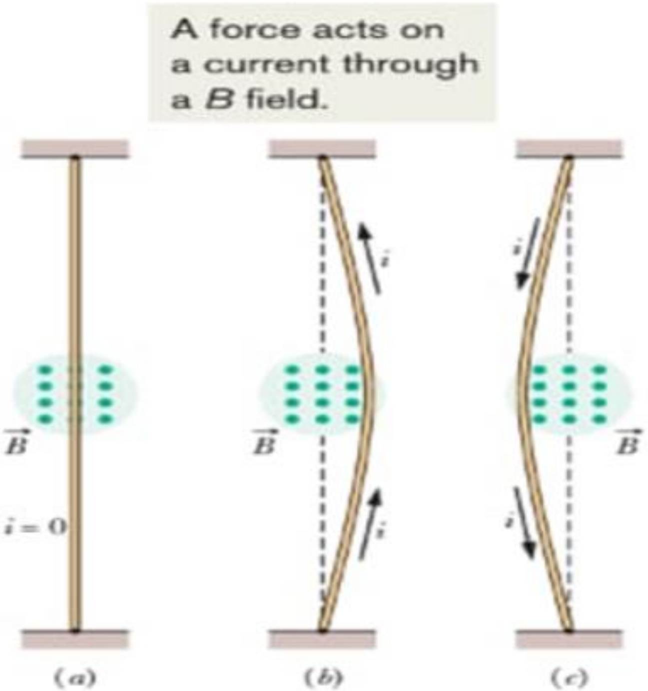


Figure A flexible wire passes between the pole faces of a magnet (only the farther pole face is shown). (*a*) Without current in the wire, the wire is straight. (*b*) With upward current, the wire is deflected rightward. (*c*) With downward current, the deflection is leftward. The connections for getting the current into the wire at one end and out of it at the other end are not shown.

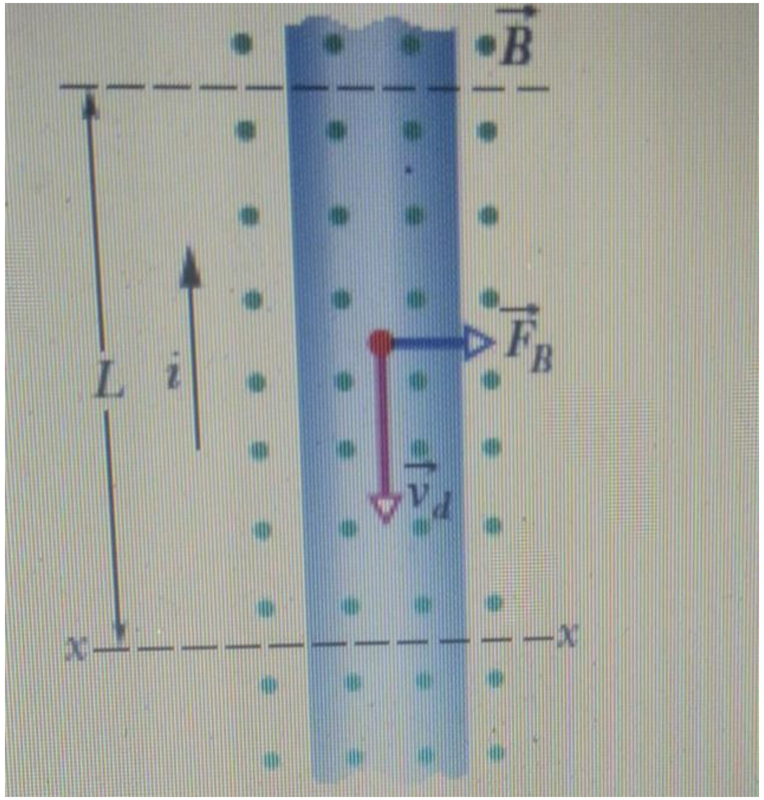
Continued

- A close-up view of a section of the wire of Fig. The current direction is upward, which means that electrons drift downward. A magnetic field that emerges from the plane of the page causes the electrons and the wire to be deflected to the right.
- Consider a length L of the wire.
- All the conduction electrons in this section

  of wire will drift past plane xx in Fig.

  in a time $t = L/v_d$

$$q = it = iL/v_d$$



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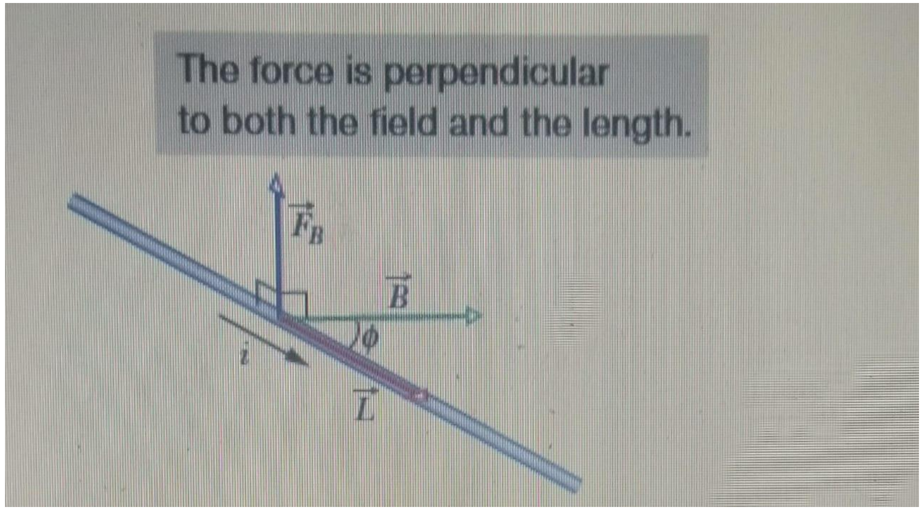


$$F_B = qv_d B \sin \Theta$$

Putting value of q in above equation

$$F_B = iLB\sin\Theta$$

this equation gives the magnetic force that acts on a length L of straight wire carrying a current i and immersed in a uniform magnetic field that is perpendicular to the wire.

- If the magnetic field is *not* perpendicular to the wire, as in Fig. the magnetic force is given by equation

$$F_B = iL \times B$$

Problem

- A straight, horizontal length of copper wire has a current i =28 A through it. What are the magnitude and direction of the minimum magnetic field needed to suspend the wire—that is, to balance the gravitational force on it? The linear density (mass per unit length) of the wire is 46.6 g/m.
- Solution:

Current=i=28A

linear density= 46.6g/m

$F_B = iL \times B$

continued

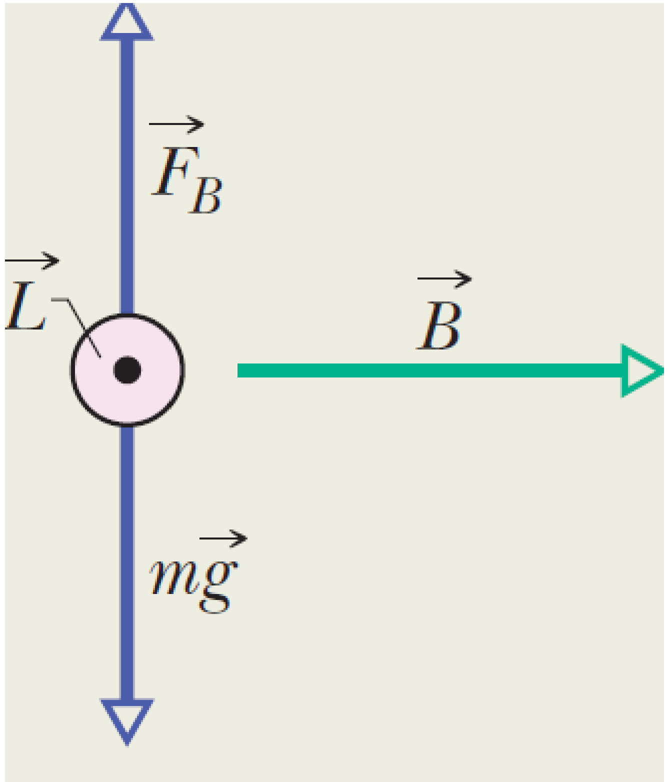
We need to maximize sinΘ in Eq. Θ=90.

The magnitude of is F=iLB sinΘ

$B = mg/iL \sin \Theta = (m/L)g/I$

$= ((46.6\ \text{g/m})(9.8\ \text{m/s}^2))/28\ \text{A}$

$= 1.6 \times 10^{-2} T$



This is about 160 times the strength of Earth's magnetic field

Hall effect

- The Hall effect was discovered in 1879 by Edwin Herbert Hall while working on his doctoral degree at the Johns Hopkins University in Baltimore, Maryland, USA.

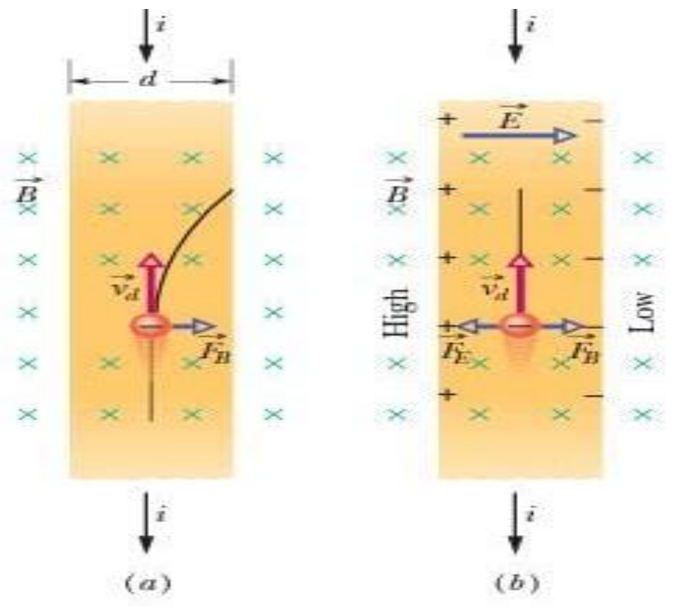
- Discovered 18 years before the electron.

Introduction

- Is a phenomenon that occurs when a conductor or semiconductor is placed in the magnetic field and a voltage is applied through the material perpendicular to the magnetic field.
- While this voltage induces current flow along the electric field direction, the charge carriers also experience a magnetic deflection from their path.
- This results a separation of positive and negative carriers, and thus the generation of an electric field perpendicular to the direction of current flow.
- Note that, at sufficient temperature, the net current in a semiconductor is made up of counteracting currents of p-type and n-type carriers.

Experimental Set Up

- 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 vd) in the opposite direction, from bottom to top.



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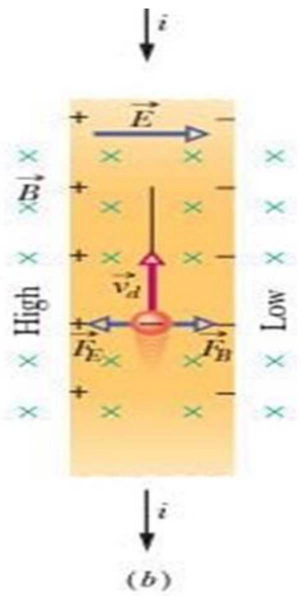
- An external magnetic field into the plane has been turned on.
- The magnetic deflecting force will act on each drifting electron putting it towards the right edge of strip and leaving positive charges on left edge of strip.
- The magnetic deflecting force is

$$F = qv \times B.$$

- The separation of positive and negative charges produces an electric field on the strip from left to right shown in figure.
- This electric force on the electrons, which opposes the magnetic force on them, begins to build up.



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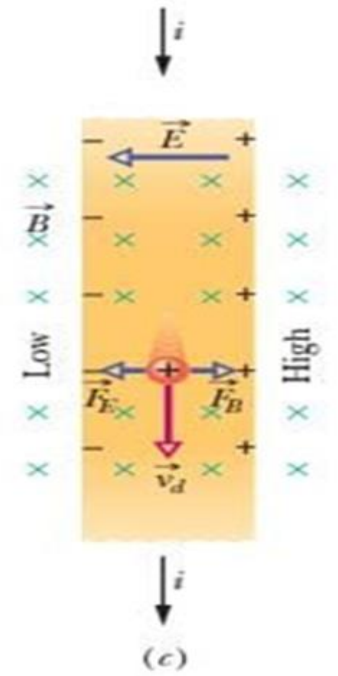
- An equilibrium quickly develops in which the electric force on each electron has increased enough to match the magnetic force.
- When this happens, as Figure shows, the force due to B and the force due to E are in balance.



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- A Hall potential difference V is associated with the electric field E across strip width d

$$V=Ed$$

- When the electric and magnetic forces are in balance

Electric force =magnetic force

$$eE= ev_dB \qquad (q=e)$$

- Drift velocity is

$$vd = J/ne \qquad \text{J= current density}$$

Continued

$$J = \frac{i}{A}$$

- Drift velocity is also written as

$$vd = J/ne = i/neA$$

- A is the cross-sectional area of the strip,and n is the number density of charge carriers (number per unit volume).

eE= ev_dB (*As v=Ed so E=v/d)*

$$\frac{ev}{d} = ev_dB \qquad \text{............}(a)$$

- Now putting value of v_d *in (a)*

Continued

- We get

$$\frac{v}{d} = \frac{\mathbf{iB}}{\mathbf{neA}}$$

$$\mathbf{n} = \frac{\mathbf{iBd}}{\mathbf{eAv}}$$

n=iB/vle **(l = A/d)**

Applications

- Magnetometers, i.e. to measure magnetic field.
- Hall effect sensor is also used as Current Sensor.
- Magnetic Position Sensing in Brushless DC Electric Motors
- Automotive fuel level indicator.
- Spacecraft propulsion.
- And many more.

If you have any questions regarding this lecture, please ask in the live session

Thank you