Level UGI- Semester 2

Magnetism Theory

PHY-1209-C-7 ECTS

Prerequisite Module Code (PHY-1102)

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Chapter One- Magnetic Field

Magnetism

Permanent magnets: exert forces on each other as well as on unmagnetized Fe pieces.

- The needle of a compass is a piece of magnetized Fe.

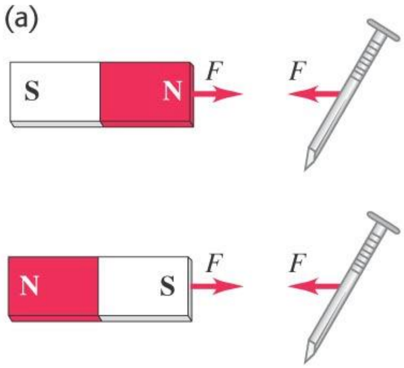
- If a bar-shaped permanent magnet is free to rotate, one end points north (north pole of magnet). - An object that contains Fe is not by itself magnetized, it can be attracted by either the north or South Pole of permanent magnet.

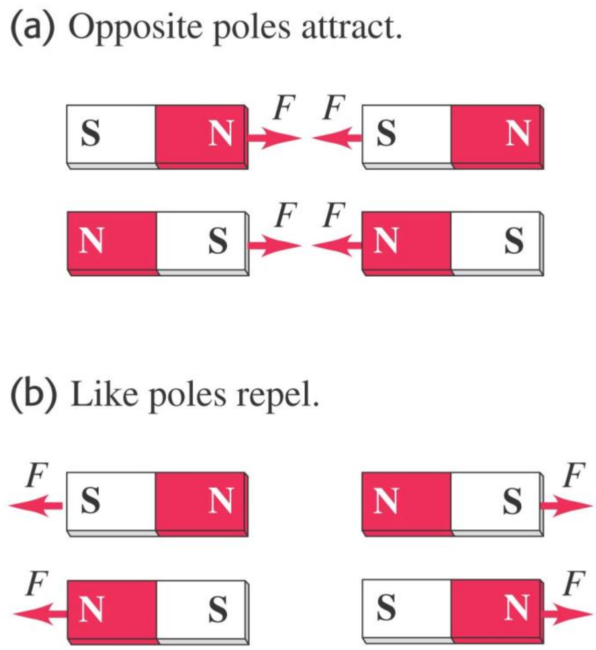
- A bar magnet sets up a magnetic field in the space around it and a second body responds to that field. A compass needle tends to align with the magnetic field at the needle's position.

- Magnets exert forces on each other just like charges. You can draw magnetic field lines just like you drew electric field lines.

- Magnetic north and south pole's behavior is not unlike electric charges. For magnets, like poles repel and opposite poles attract.

- A permanent magnet will attract a metal like iron with either the north or South Pole.





To introduce the concept of magnetic field properly, we introduced the concept of electric field. We represented electric interactions in two steps:-

Electric field

1. A distribution of electric charge at rest creates electric field E in the surrounding space.
2. The electric field exert a force F=q.E or any other charge q that is present in field.

We Can describe magnetic interactions in a similar way:-

Magnetic field

1. A moving charge or a Current Creates a magnetic field in the surrounding space (in addition its electric field).
2. The magnetic field exerts a force F on any other moving charge or Current that is present in the field.

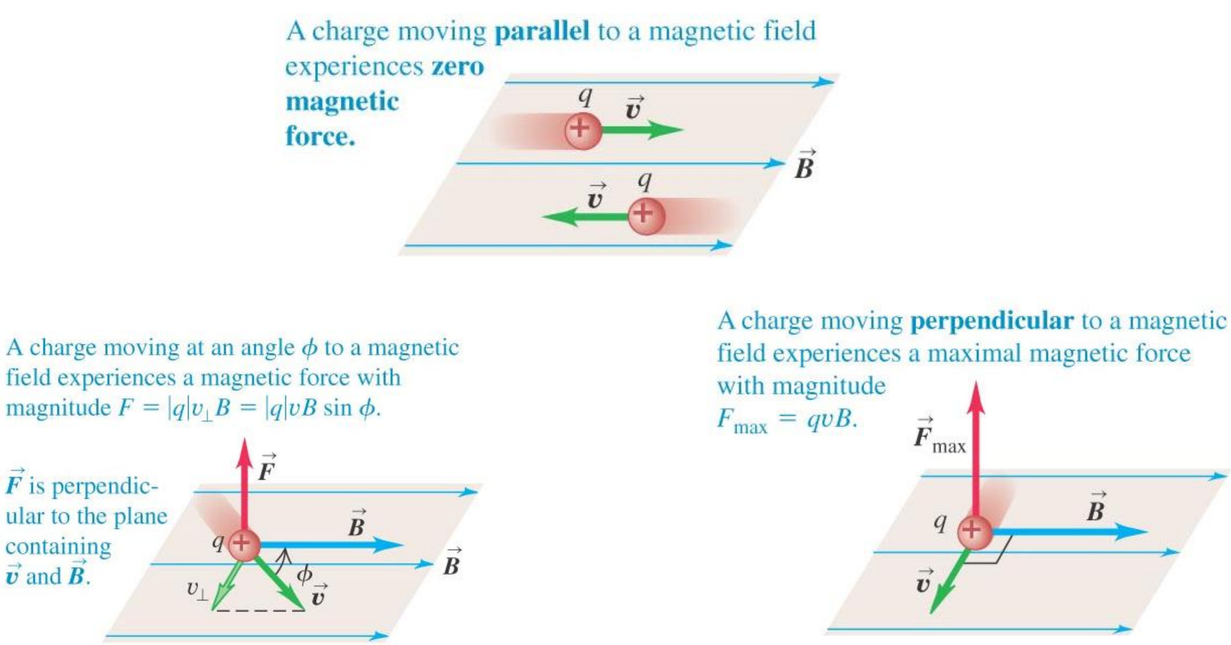
- The magnetic field is a vector field → vector quantity associated with each point in space.

$$F_m = |q| v_{\perp} B = |q| v \; B \sin\varphi \qquad \boxed{\vec{F}_m = q\vec{v}\times\vec{B}}$$

- $\vec{F}_m$ is always perpendicular to $\vec{B}$ and $\vec{v}$.

- The moving charge interacts with the fixed magnet. The force between them is at a maximum when the velocity of the charge is perpendicular to the magnetic field.

Interaction of magnetic force and charge



Magnetic force on Moving charges

There are four characteristics of the magnetic force on moving charge: -

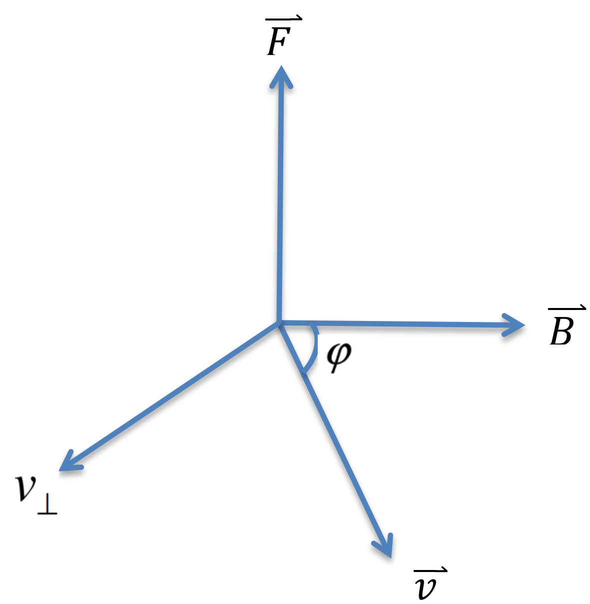
1- Its magnitude is proportional to the magnitude of the charge.
2. The magnitude of the force is also proportional magnitude to the magnitude, or strength of the field
3- The magnetic force depends on the particle's velocity
4. The magnetic force $\overrightarrow{F}$ doesn't has the same direction as the magnetic field $\overrightarrow{B}$ but instead is always perpendicular to both $\overrightarrow{B}$ and velocity $\overrightarrow{V}$.

The direction of $\overrightarrow{F}$ is always perpendicular to the plane containing $\overrightarrow{V}$ and $\overrightarrow{B}$. Its magnitude is given by: -

$$F_m = |q| v_\perp B = |q| v \ B \sin\varphi$$

Where $|q|$ is the charge; $\emptyset$ is the angle measured from the direction of $\overrightarrow{V}$ to the directional of $\overrightarrow{B}$, as shown in the Figure:

$$\vec{F}_m = q\vec{v} \times \vec{B}$$



The unit of $\overrightarrow{B}$ is [1 N.s/C.m] or [1 N/A.m]

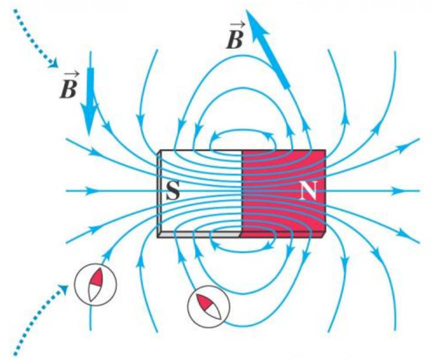
This unit is called the Tesla (T)

$$[1 \text{ T} = 10^4 \text{ G}]$$

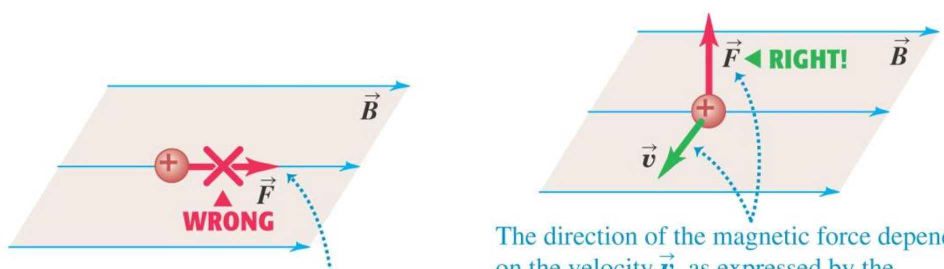
When a charged particle moves through a region of space where both electric and magnetic fields are present, both fields exert forces on the particle. The total forces $\overrightarrow{F}$ are the vector sum of the electric and magnetic forces:-

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

Magnetic Field Lines

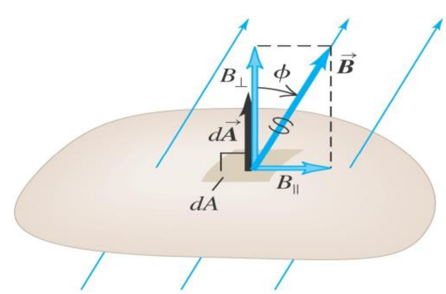


- Magnetic field lines may be traced from N toward S (analogous to the electric field lines).
- At each point they are tangent to magnetic field vector.
- The more densely packed the field lines, the stronger the field at a point.
- Field lines never intersect.
- The field lines point in the same direction as a compass (from N toward S).
- Magnetic field lines are not "lines of force".
- Magnetic field lines have no ends → they continue through the interior of the magnet.



The direction of the magnetic force depends on the velocity $\vec{v}$, as expressed by the magnetic force law $\vec{F} = q\vec{v} \times \vec{B}$.

Magnetic Flux and Gauss's Law for Magnetism



We define the magnetic flux $\emptyset_B$ through a surface just as we define electric flux $\emptyset_E$ is connection with Gauss's law. Can divide any surface into elements of area dA. From this Figure:-

$$B_{\perp} = B\cos\emptyset$$

$Where\ \emptyset$ is the angle between the direction of $\overrightarrow{B}$ and a line perpendicular to the surface.

We define the magnetic flux $d\emptyset_B$ through this area as:-

$$d\emptyset_B = B_{\perp}\, dA = B\cos\emptyset\; dA$$
$$= \overrightarrow{B}\,.\,d\vec{A}$$

The total magnetic flux through the surface is sum of the contribution from the individual area elements

$$\Phi_B = \int B_{\perp} dA = \int B\cos\varphi \cdot dA = \int \vec{B}\cdot d\vec{A}$$

If $\overrightarrow{B}$ is uniform over a plane surface with total area A, then

$$\Phi_B = B_{\perp} A = BA\cos\varphi$$

If $\overrightarrow{B}$ happens to be perpendicular to the surface, then [Cos $\emptyset = 1$] and the equation reduced to:-

$$\emptyset_B = B\ A$$

The SI unit of magnetic flux is equal to the unit of magnetic field (1T) times the unit of area ($1m^2$).
This unit is called the weber (1Wb).

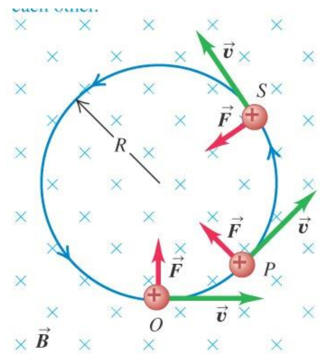
1 Weber (1 Wb = 1 T m^2 = 1 N m / A)

- The total magnetic flux through a closed surface always Zero, then

$$\Phi_B = \oint \vec{B}\cdot d\vec{A} = 0 \qquad\qquad B = \frac{d\Phi_B}{dA_{\perp}}$$

- This is called Gauss's law for magnetism.
- The magnetic field is equal to the flux per unit area across an area at right angles to the magnetic field = magnetic flux density.

Motion of Charged Particles in a Magnetic Field



- Motion of a changed particle, under the action of a magnetic field a lone is always motion with constant Speed.
- The centripetal acceleration is $[\frac{v^2}{R}]$, and only the magnetic force acts, so from. Newton's Second law:-

$$F = ma \implies F = m\frac{v^2}{R}$$

$$[F = |q|\, v\, B = m\frac{v^2}{R}]$$

Where m is the mass of the Particle, solving this eq. for the radius R of the circular path, we find:-

$$R = \frac{mv}{|q|B}$$

We can also write this as:

$$R = \frac{P}{|q|B}$$

Where $P = mv$ is magnitude of the Particles momentum.

Angular speed (w) of the particle can be found

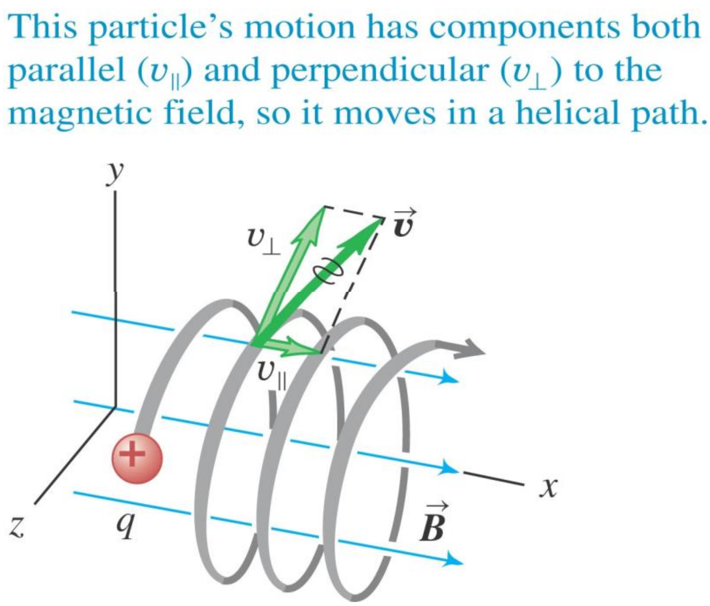
$$v = Rw \implies w \; \frac{v}{R}$$

We get:-

$$w = \frac{v}{R} = v\,\frac{|q|B}{mv}$$

$$w = \frac{|q|B}{m} \Leftarrow \text{angular speed}$$

- If v is not perpendicular to B ⇒ $v \parallel$ (parallel to B) constant because $[F \parallel = 0]$⇒ particle moves in a helix. (R same as before, with $v = v\perp$)



A charged particle will move in a plane perpendicular to the magnetic field.

Applications of Motion of Charged Particles

Thomson's $^{e}/_{m}$ Experiment

Thomson used the idea just described to measure the ratio of charge to mass for the electron.
The speed $\vec{v}$ of electrons is determined by the accelerating potential V.
The gained Kinetic energy:-

$$K.E = (\tfrac{1}{2} mv^2).$$

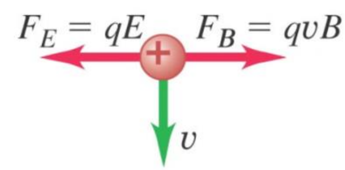
Equal the lost electric potential energy (eV); where (e) is the magnitude of electron charger then:

$$\frac{1}{2}mv^2 = eV$$

$$v^2 = \frac{2ev}{m} \qquad \therefore v = \sqrt{\frac{2eV}{m}}$$

Particles of a specific speed can be selected from the beam using an arrangement of E and B fields.

- F_m (magnetic) for + charge towards right (q v B).
- F_E (electric) for + charge to left (q E).
- $F_{net} = 0$ if $F_m = F_E \Rightarrow -qE + q\,v\,B = 0 \Rightarrow v = E/B$
- Only particles with speed E/B can pass through without being deflected by the fields.



v = E/B ; we get:-

$$\frac{E}{B} = \sqrt{\frac{2eV}{m}} \qquad So\ \frac{e}{m} = \frac{E^2}{2VB^2}$$