PHY121: Applied Physics for Enginners

Magnetism (part-1)

LECTURE # 15

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Outlines

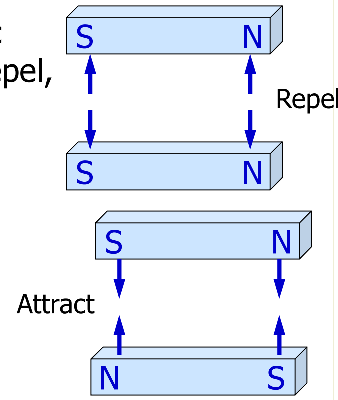
- The Magnetic Field
- Magnetic Flux Φ
- Flux Density *B*
- Induction by the Magnetic Field

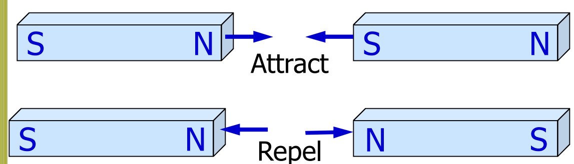
Magnetism

It is caused by the movement of charge

Recall how there are two kinds of electrical charge (+ and -), and likes repel, opposites attract.

Similarly, there are two kinds of magnetic poles (north and south), and like poles repel, opposites attract.



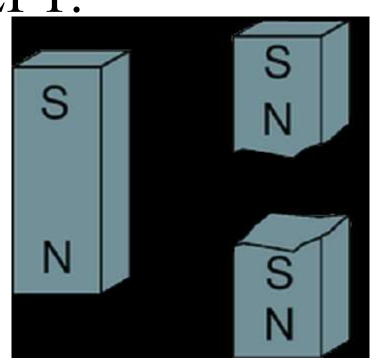


Magnetic Poles

- Magnetic poles behave similarly to electric charges EXCEPT:

Electric charges can be isolated

Magnetic poles cannot



Magnetic Fields

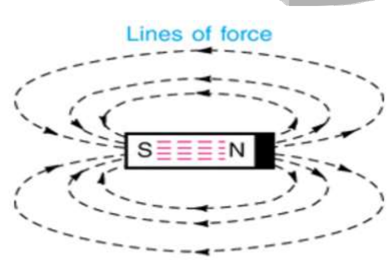
Magnetic fields are caused by the motion of electric charges

Magnets at rest consist of charges in motion

- Every spinning electron is a tiny magnet
- Electrons spinning in the same direction produce a stronger magnet

Magnetic Fields

- Magnetic Field Lines
  - Every magnets has two poles (north and south)
  - The magnetic field or the strength of the magnet, is concentrated at the poles.
  - The field exists in all directions but decreases in strength as distance from poles increases



(b)

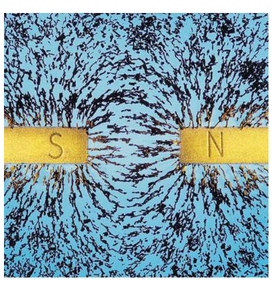
Fig. 13-2b: Field indicated by lines of force.

Magnetic Fields

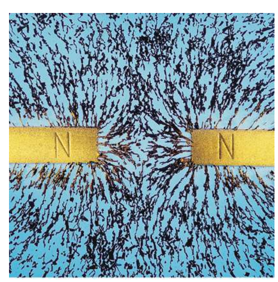
- Field Lines
  - Magnets have an invisible field (made up of lines of force).
  - These lines of force are from the north to the south pole of the magnet (external field).
  - Field lines are unaffected by nonmagnetic materials, but become more concentrated when a magnetic substance (like iron) is placed in the field.

Magnetic Fields

- Like magnetic poles repel one another.
- Unlike poles attract one another.



(a)



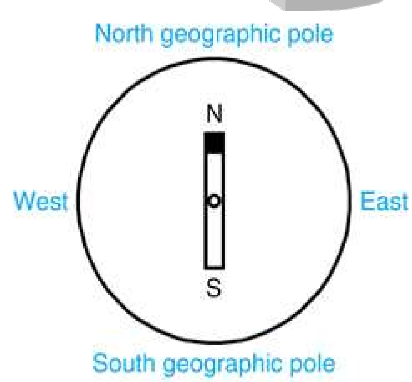
(b)

Magnetic Fields

- North and South Magnetic Poles
  - Earth is a huge natural magnet.
  - The **north pole** of a magnet is the one that seeks the earth's magnetic north pole.
  - The **south pole** is the one that is opposite the north pole.

Magnetic Fields

- North and South Magnetic Poles
  - If a bar magnet is free to rotate, it will align itself with the earth's field.
  - North-seeking pole of the bar is simply called the **north pole.**



(*a*)

Definition of $\vec{B}$

As we define the electric field $\vec{E}$ $\quad \vec{E} = \dfrac{\vec{F}_E}{q}.$

But the magnitude of magnetic field $\vec{B}$ is defined as in terms of force magnitude:

$$B = \frac{F_B}{|q|v},$$

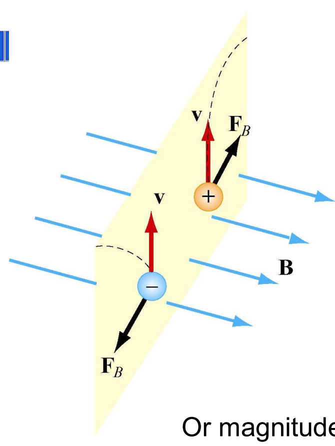
where q is the charge of the particle

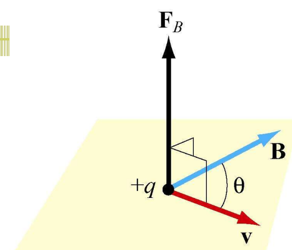
$$\text{B Units} = \frac{\text{newton}}{(\text{coulomb})(\text{meter/second})} = 1\frac{\text{N}}{\text{C}\cdot\text{m/s}} = 1\frac{\text{N}}{\text{A}\cdot\text{m}}$$

This is called 1 Tesla (T)

$$1\ \text{T} = 10^4\ \text{Gauss (G)}$$

Moving Charges Feel Magnetic Force





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

Or magnitude $\quad$ **$F_B = |q|vB\sin\theta$**

Magnetic force perpendicular both to Velocity ***v*** of charge and magnetic field **B** and θ is the angle between the directions of velocity $\vec{v}$ and magnetic field $\vec{E}$.

Right hand Rule

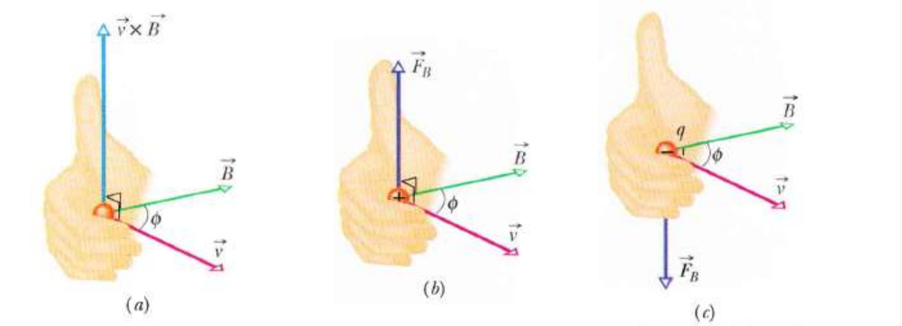


FIG. (a) The right-hand rule (in which $\vec{v}$ is swept into $\vec{B}$ through the smaller angle ϕ between them) gives the direction of $\vec{v}\times\vec{B}$ as the direction of the thumb. (b) If q is positive, then the direction of $\vec{F}_B = q\vec{v}\times\vec{B}$ is in the direction of $\vec{v}\times\vec{B}$.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

Putting it Together: Lorentz Force

Charges Feel…

$$\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$$

Electric Fields

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

Magnetic Fields

$$\boxed{\vec{\mathbf{F}} = q\left(\vec{\mathbf{E}}+\vec{\mathbf{v}}\times\vec{\mathbf{B}}\right)}$$

This is the final word on the force on a charge

Example1

A uniform magnetic field $\vec{B}$, 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:

To find the magnitude of $\vec{F}_B$, we can use ($F_B = |q|vB \sin \phi$) provided we first find the proton's speed v. We can find v from the given kinetic energy because $K = \frac{1}{2}mv^2$. Solving for v, we obtain

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

$$= \sqrt{\frac{(2)(5.3\ \text{MeV})(1.60 \times 10^{-13}\ \text{J/MeV})}{1.67 \times 10^{-27}\ \text{kg}}}$$

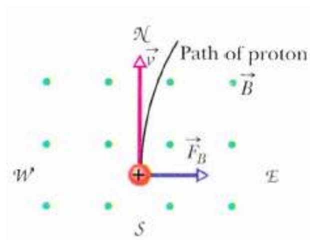
$$= 3.2 \times 10^{7}\ \text{m/s}.$$

Example1 (continue…)

$$F_B = |q|vB \sin \phi$$

$$= (1.60 \times 10^{-19}\ \text{C})(3.2 \times 10^{7}\ \text{m/s}) \times (1.2 \times 10^{-3}\ \text{T})(\sin 90°)$$

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



This may seem like a small force, but it acts on a particle of small mass, producing a large acceleration; namely,

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

Magnetic Flux Φ

- **Magnetic flux** is defined as the number of lines of force flowing outward from a magnet’s north pole.
- Symbol: Φ
- Units:
  - **maxwell** (**Mx**) equals one field line
  - **weber (Wb)** One weber (Wb) = 1 x 10^8 lines or Mx

Magnetic Flux Φ

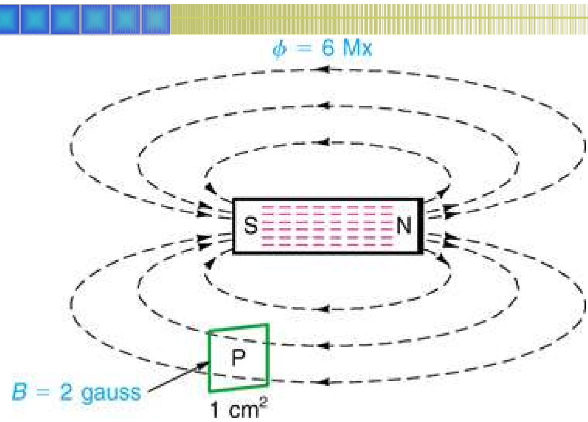


Fig.: Total flux Φ is 6 lines or 6 Mx. Flux density *B* at point P is 2 lines per square centimeter or 2 G.

Magnetic Flux Φ

- Systems of Magnetic Units
  - **CGS system**: Centimeter-Gram-Second. This system defines small units.
    - Mx and μWb (100 Mx) are cgs units.
  - **MKS system:** meter-kilogram-second. This system defines larger units of a more practical size.
    - Wb (1×10^8 Mx) is an MKS unit.
  - **SI:** Systeme Internationale. Basically another name for the metric system. SI units provide a worldwide standard in mks dimensions; values are based on one ampere of current.

Flux Density B

- **Flux density** is the number of lines per unit area of a section perpendicular to the direction of flux.
  - Symbol: B
  - Equation: $B = \Phi$ / area
- Flux Density Units
  - Gauss (G) = 1 Mx/cm^2 (cgs unit)
  - Tesla (T) = 1 Wb/meter^2 (SI unit)

Induction by the Magnetic Field

- **Induction** is the electric or magnetic effect of one body on another without any contact between them.
- When an iron bar is placed in the field of a magnet, poles are **induced** in the iron bar.
- The induced poles in the iron have polarity opposite from the poles of the magnet.

Induction by the Magnetic Field

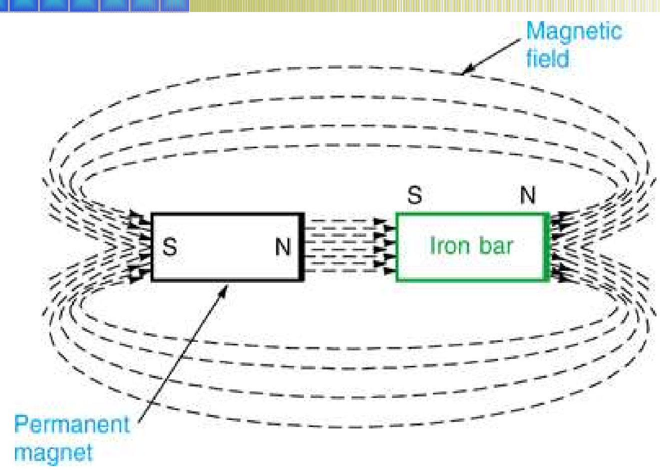


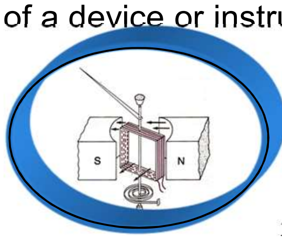
Fig. 13-7: Magnetizing an iron bar by induction.

Induction by the Magnetic Field

- Magnetic Permeability
  - **Magnetic permeability** is the ability to concentrate lines of magnetic force.
  - **Ferromagnetic materials** have high permeability.
  - **Magnetic shields** are made of materials having high permeability.
  - Symbol: μ_r (no units; μ_r is a comparison of two densities)

Induction by the Magnetic Field

- **Permeability (μ)** is the ability of a material to support magnetic flux.
- **Relative permeability** (μ_r) compares a material with air. Ferromagnetic values range from 100 to 9000.
- Magnetic shields use highly permeable materials to prevent external fields from interfering with the operation of a device or instrument.



Magnetic shield around a meter movement.

END OF LECTURE