PHYS102
Effects
of
Magnetic Fields

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March 12, 2007

0.1 Definition

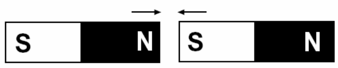
Magnetic Fields

- All of us have interacted with magnets.
  - Motors (convert electrical to mechanical energy).
  - Computers (hard drives used for data storage).
- Do magnets exert forces on each other?
  - ANSWER: Yes!
- A great example of a magnet is a bar magnet which has “poles” typically called “North” and “South”.
  - The terms north and south are arbitrary.
  - Like poles - repel
  - Unlike poles - attract
  - See a resemblance to the electric field generated by point particles?

Behavior of Poles

- Two north poles repel each other as shown.
- A north pole attracts a south pole as shown.
- Describe the interaction of magnets in terms of a magnetic field ($\vec{B}$)
- We can envision a field in much the same way we view an $\vec{E}$-field, but there is a very distinct difference.
  - $\vec{E}$-fields can be generated by a single stationary charged particle.
  - $\vec{B}$-fields are not generated **not generated** by any such “monopole” “**monopole**”

Like poles repel one another.



Unlike poles attract one another.

What is Magnetism?

- SO WHAT IS MAGNETISM?
  - MAGNETISM IS ABOUT MOVING ELECTRIC CHARGES!
- What do we know about moving charges?
- That's correct, the same moving electric charge we discussed when analyzing electric currents and circuits.
- We can calculate the force a charged particle experiences whilst in a magnetic field.

PHYS102 Magnetic Fields - Effects – slide 4

Magnetic Force slide 5

0.2 Qualitative

Magnetic Force - Qualitative

- Let's try to determine properties of the force by considering the following demonstration!
  - A high-voltage discharge initiated in the tube "creates" a beam of electrons.
  - The path of the beam is made visible when it strikes a tilted fluorescent screen.
  - A magnetic field (bar magnet) is placed near this beam.

PHYS102 Magnetic Fields - Effects – slide 5

Magnetic Force - Qualitative II

- Conclusions - from experimenting.
  1. If charge is stationary in $\vec{B}$-field, then particle experiences no magnetic force.
  2. The magnetic force is always at right angles $\perp$ both to the velocity ($\vec{v}$) of the particle and to the $\vec{B}$-field.
  3. Magnetic force is greatest (MAX) if $\vec{v} \perp \vec{B}$ and is ZERO if $\vec{v} \parallel \vec{B}$
  4. The magnitude of the magnetic force is proportional to the charge q.
- Summarizing the four main conclusions in one mathematical statement:

$$\vec{F}_B = q\left(\vec{v} \times \vec{B}\right)$$

- UNITS: $[F]$ = N, $[q]$ = C, $[v]$ = m/s, $[B] = \frac{N\,s}{C\,m} \equiv 1$ Tesla (T).

PHYS102 Magnetic Fields - Effects – slide 6

Magnetic Force - Quantitative

$$\vec{F}_B = q\left(\vec{v} \times \vec{B}\right)$$

- IMPORTANT NOTE: Magnetic fields do NO Work.IMPORTANT NOTE: Magnetic fields do NO Work.

$$W = \int \vec{F}_B \cdot d\vec{l} = 0 \quad \text{Since } (\vec{v} \times \vec{B}) \perp d\vec{l}$$

  - The magnetic force magnetic force is always perpendicular perpendicular to a charged particles displacement displacement !!

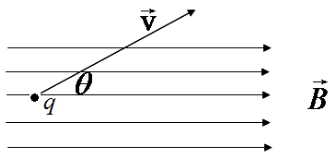
Magnetic Force - Quantitative II

$$\vec{F}_B = q\left(\vec{v} \times \vec{B}\right)$$

- The magnitude magnitude of the magnetic force is then

$$|\vec{F}_B||\vec{F}_B| = q\,v\,B\,\sin\theta$$

  - Where θ is the angle between the vectors $\vec{v}$ and $\vec{B}$.



The Lorentz Force

- What if a charged particle is moving in an electric field and and a magnetic field? How do we describe the force acting the charged particle? Once the force acting on the charge is known, then we can use our knowledge of mechanics to solve problems!
- We use the superposition principle superposition principle and sum all forces acting on the charged particle.

$$\vec{F}_B = q\left(\vec{v} \times \vec{B}\right)$$
$$\vec{F}_E = q\,\vec{E}$$
$$\vec{F}_{\text{TOTAL}} = \vec{F}_E + \vec{F}_B$$
$$\vec{F}_{\text{TOTAL}} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

(This is known as the "Lorentz Force")(This is known as the "Lorentz Force")

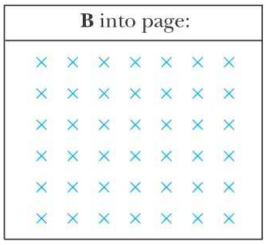
The Lorentz Force II

$$\vec{F}_{\text{TOTAL}} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

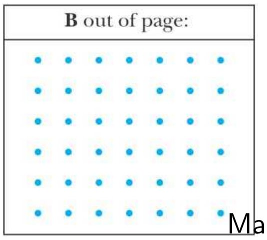
- It may be wise to use unit vectors use unit vectors in the above equation.
- The Lorentz force will deal with 3 dimensions quite regularly , but we draw in 2 dimensions.
  - We need to define a notation that is consistent.

3D World Drawn in 2D

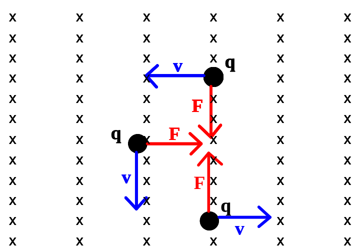
- For the figure on the right, the magnetic field is perpendicular to the screen and is going into the screen.



- For the figure on the right, the magnetic field is perpendicular to the screen and is coming out of the screen.

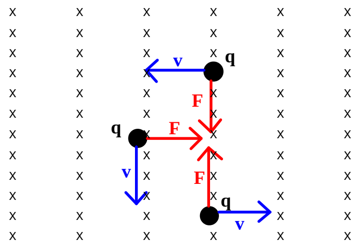


Charged Particle Motion in B-Field



- A positive charged particle entering a uniform magnetic field experiences a force perpendicular to its displacement.

Charged Particle Motion in B-Field



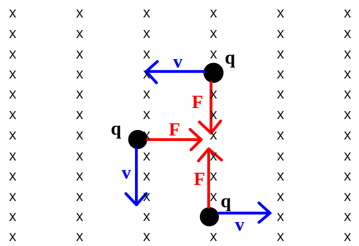
- We could calculate the radius of curvature, go back to mechanics!

$$\sum \vec{F} = m\,\vec{a}$$

$$\Rightarrow q\,v\,B = \frac{m\,v^2}{r} \quad \text{(Magnetic force responsible for centripetal force.)}$$

$$\Rightarrow r = \frac{m\,v}{q\,B}$$

Charged Particle Motion in B-Field II



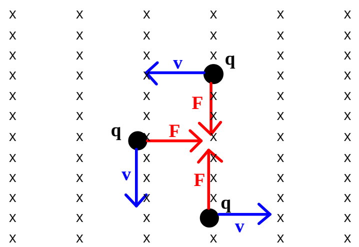
- We could also calculate the time it takes the particle to complete one revolution.

$$r = \frac{m\,v}{q\,B}$$

$$T = \frac{2\,\pi\,r}{v}$$

$$\Rightarrow T = \frac{2\,\pi\,m}{q\,B}$$ (Called the cyclotron period.)(Called the cyclotron period.)

Charged Particle Motion in B-Field III



- From period, we could discuss frequency.

$$T = \frac{2\,\pi\,m}{q\,B}$$

$$f = \frac{1}{T} = \frac{q\,B}{2\,\pi\,m}$$

$$\omega = 2\,\pi\,f = \frac{q\,B}{m}$$ (Called the cyclotron frequency.)(Called the cyclotron frequency.)

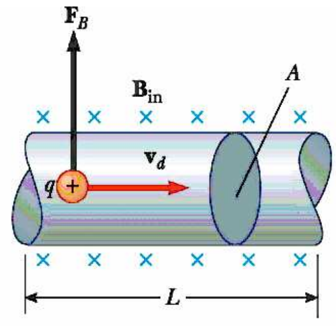
Force on Wires Carrying Current

- If we place a current carrying wire in an external magnetic field, should the wire experience a force?
- We already determined an expression for the force experienced by a single charged particle moving in a magnetic field.
- Let's begin there:

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

- We don't have a single charged particle instead we have a current (I).

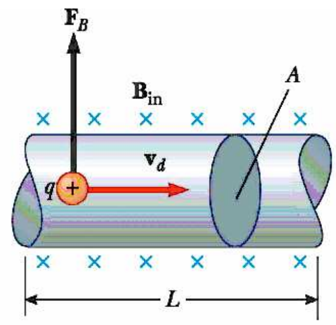
Force on Wires Carrying Current II



- The magnetic force is experienced by each moving charge in the current.
- The total force is the product of the force on one charge with the number of charges

$$\vec{F}_B = (q\,\vec{v} \times \vec{B})\,n\,A\,L = I\,\vec{L} \times \vec{B}$$

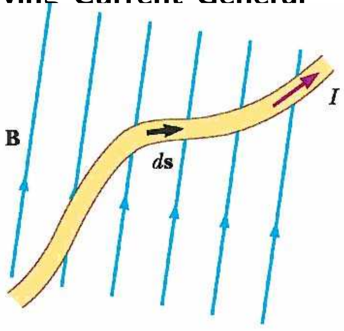
Force on Wires Carrying Current III



$$\vec{F}_B = I\,\vec{L} \times \vec{B}$$

- The vector $\vec{L}$ has magnitude L and is in the direction of current direction of current.
- What happens if the wire is not straight? (THINK OF 17^{th}-CENTURY MATHEMATICS)

Force on Wires Carrying Current General



- We begin by breaking up the wire into very small pieces (so that the length of wire is approximately straight).

$$d\vec{F}_B = I\, d\vec{s} \times \vec{B}$$
$$\Rightarrow \vec{F}_B = I \int (d\vec{s} \times \vec{B})$$