Magnetism

Physics 122

Concepts

• Magnetic field
• Magnetic force

Skills

• Determine the direction of magnetic field created by electric current
• Determine the direction of magnetic force on electric current
• Two right hand rules
Magnets

- Magnets have magnetic poles – north and south
  - Like poles repel
  - Unlike poles attract
- Similarity to electric interaction

Magnetic field

- Introduce magnetic field:
  - Field lines go from north pole to south
  - Mnemonic rule – birds fly from north to south

Magnetic field of the Earth

- Earth has a magnetic field \( B \sim 5 \times 10^{-5} \text{T} \)
- Compass - a small magnet in a form of an arrow - is used to determine the direction of the magnetic field
- South magnetic pole is located close to the north geographic pole, that is why north end of the compass is pole is pointing there (unlike poles attract)
Magnetic field

- Magnetic field is labeled by $B$
- It is measured in Tesla and Gauss
  
  \[ 1T = 10 \text{ kG} \]
  \[ 1T = 1 \text{N/A m} \]

Magnets

- North and south poles do not exist separately!!!
  - Two halves of a broken magnet still have south and north pole each
- Different from electric charges – positive and negative charges can exist separately

Magnetic field created by currents

- Electric currents – moving electric charges – create magnetic field
- Stationary electric charges do not create magnetic field
- First right hand rule
  - Thumb along the current
  - Wrap your fingers around the wire
  - Fingers show the direction of the magnetic field
Magnetic field created by current

- Magnetic field \( B \) created by current \( I \) at a distance \( r \) from the conductor is:
  \[
  B = \frac{\mu_0 I}{2\pi r}
  \]
- \( \mu_0 = 4\pi \times 10^{-7} \text{Tm/A} \) - magnetic permeability of free space

Magnetic field of loop current

- Magnetic field is in ~ same direction inside a current loop
- Several loops create stronger magnetic field - solenoid

Magnetic field of a solenoid

- Magnetic field inside solenoid
  - Is parallel to its axis
  - Depends on the current \( I \)
  - Depends on the number of loops per unit length \( n=N/l \):
    \[
    B = \mu_0 n I
    \]
  - Does not depend on diameter
  - Does not depend on the total length
Magnetic force on electric currents
- Magnetic field exert a magnetic force on electric currents—
moving electric charges
\[ F = IlB \sin \theta \]
\( \theta \)– angle between \( B \) and \( I \)
\( F \) is max when \( B \) is perpendicular to \( I \) and zero when \( B \) is parallel to \( I \)

Direction of the magnetic force
- Second right hand rule:
  - Fingers along the current
  - Bend to show the direction of the magnetic field
  - Thumb shows the direction of the force

Magnetic force on moving charge
- Magnetic force \( F \) is perpendicular to the velocity \( v \) of a particle with charge \( q \)
\[ F = qvB \sin \theta \]
- Charged particles move in circles in magnetic fields
Magnetic fields are used to separate matter from antimatter
And measure particle velocity

Torque

\[ \tau = r \vec{F} = Fr \sin \theta \]

\[ \tau = r \vec{F} = rF \sin \theta \]

Current loop in magnetic field

\[ \tau = \tau_1 + \tau_2 = IaB \frac{b}{2} + IaB \frac{b}{2} = Iab = IAB \]

- \( A = ab \) – area of the loop
- Magnetic field exerts a torque on a loop parallel to the magnetic field:

\[ \tau = IAB \]
Current loop in magnetic field

- \( \theta \) – angle between magnetic field and a perpendicular to the loop!!!
- Magnetic field orients a loop current perpendicular to \( B \).
- \( N \) loops:

\[
\tau = NIAB \sin \theta
\]

Force between two currents

- Parallel currents attract
- Anti-parallel repel

\[
B_1 = \frac{\mu_0 I_1}{2\pi L}
\]
\[
F_{21} = I_2 B_1
\]
\[
F_{21} = \frac{\mu_0 I_1 I_2}{2\pi L}
\]