BRAIN MAP

MAGNETIC EFFECTS OF CURRENT AND MAGNETISM

Magnetic resonance imaging (MRI), a medical imaging technique used in radiology to investigate the anatomy and physiology of the body, use magnetic fields and radio waves to form images of the body. It is used for diagnosis, staging of disease and for follow-up without exposure to ionizing radiation.

Magnetic Force

- Magnetic force on a moving charge,
  $\vec{F}_m = q(\vec{v} \times \vec{B})$
  $F_m = qvB \sin\theta$
  θ is the angle between $\vec{v}$ and $\vec{B}$.
- Lorentz force, $\vec{F} = q(\vec{v} \times \vec{B} + \vec{E})$
- Force on a current carrying conductor in a uniform magnetic field (B).
  $\vec{F} = I\,\vec{l} \times \vec{B} = I\,l\,B \sin\theta\,\hat{n}$
  This force acts on the COM of rod.

Charged Particle in Uniform Magnetic Field

- If $\theta = 0°$ or $180°$, path is a straight line.
- If $\theta = 90°$, path is circle.
  Radius of circle,
  $r = \dfrac{mv}{qB} = \dfrac{\sqrt{2Km}}{qB} = \dfrac{\sqrt{2qVm}}{qB}$
  Time period,
  $T = \dfrac{2\pi m}{qB}, \omega = \dfrac{qB}{m}, \upsilon = \dfrac{qB}{2\pi m}$
- For any other angle path is helix.
  Radius, $r = \dfrac{mv\sin\theta}{qB}$
  Time period, $T = \dfrac{2\pi m}{qB} = \dfrac{1}{\upsilon}$
  Pitch of helical path $p = (v\cos\theta)T = \dfrac{2\pi mv\cos\theta}{qB}$

Cyclotron

- It is machine to accelerate charged particles or ions to high energies.
- Cyclotron frequency,
  $\upsilon_c = \dfrac{qB}{2\pi m}$

Biot-Savart Law

- Magnetic field due to a current carrying element,
  $d\vec{B} = \dfrac{\mu_0}{4\pi}\dfrac{I(d\vec{l} \times \vec{r})}{r^3}$

Applications of Biot-Savart Law

- Magnetic field due to a straight wire of finite length,
  $B = \dfrac{\mu_0}{4\pi}\dfrac{I}{R}(\sin\alpha + \sin\beta)$
- Magnetic field due to a straight wire of infinite length,
  $B = \dfrac{\mu_0}{2\pi}\dfrac{I}{R}$
- Magnetic field on the axis of a circular loop
  $B = \dfrac{\mu_0 NIR^2}{2(R^2 + x^2)^{3/2}}$
- Magnetic field at the centre of a circular loop
  $B = \dfrac{\mu_0 NI}{2R}$
- Magnetic field at the centre due to arc of circle
  $B = \left(\dfrac{\theta}{2\pi}\right)\left(\dfrac{\mu_0 NI}{2R}\right)$
- Magnetic field on the axis of a solenoid,
  $B = \dfrac{\mu_0 nI}{2}(\cos\theta_1 - \cos\theta_2)$
- Magnetic field at centre (on the axis) of a long solenoid
  $B = \mu_0 nI$
- Magnetic field at ends of a long solenoid,
  $B = \dfrac{\mu_0 nI}{2}$

Magnetic Dipole

- Every current carrying loop is a magnetic dipole.
- Magnetic dipole moment of magnetic dipole is given by $m = NIA$.
- Direction of $\vec{m}$ is perpendicular to the plane of the loop and given by right hand screw law.

Magnetic Moment of a Revolving Electron

- $\mu_l = \dfrac{evr}{2} = \dfrac{e}{2m_e}(L)$; L = orbital angular momentum
  Vectorially, $\vec{\mu}_l = -\dfrac{e}{2m_e}\vec{L}$
- Gyromagnetic ratio, $\dfrac{\mu_l}{L} = \dfrac{e}{2m_e} = 8.8 \times 10^{10}\,\text{C kg}^{-1}$
- Bohr magneton, $\mu_B = \dfrac{eh}{4\pi m_e} = 9.27 \times 10^{-24}\,\text{A m}^2$
  It is the smallest value of magnetic moment.

Magnetic Dipole in Uniform Magnetic Field

- Net force, $\vec{F} = 0$
- Torque, $\vec{\tau} = \vec{m} \times \vec{B}$ or $\tau = mB\sin\theta$
- Potential energy, $U = -\vec{m}\cdot\vec{B} = -mB\cos\theta$
- Work done in moving a dipole from its angular position θ_1 to θ_2
  $W_{\theta_1 \to \theta_2} = U_{\theta_2} - U_{\theta_1} = mB(\cos\theta_1 - \cos\theta_2)$
- $\theta = 0°$ is stable equilibrium position of the dipole. Here, $F = 0, \tau = 0$ and $U = -mB$ = minimum.
- $\theta = 180°$ is unstable equilibrium position of the dipole. Here, $F = 0, \tau = 0$ and $U = mB$ = maximum.
- Time period of vibration of a freely suspended magnet in a uniform magnetic field
  $T = 2\pi\sqrt{\dfrac{I}{mB}}$

Magnetic Field Due to a Bar Magnet

- End-on position, $B = \dfrac{\mu_0}{4\pi}\dfrac{2mr}{(r^2 - l^2)^2}$
  For short magnet $r >> l$, $B = \dfrac{\mu_0}{4\pi}\dfrac{2m}{r^3}$
- Broadside-on position, $B = \dfrac{\mu_0}{4\pi}\dfrac{m}{(r^2 + l^2)^{3/2}}$
  For short magnet $r >> l$, $B = \dfrac{\mu_0}{4\pi}\dfrac{m}{r^3}$

Gauss's Law in Magnetism

$\oint \vec{B}\cdot d\vec{s} = 0$

- It shows magnetic monopole does not exist.
- Magnetic fields are always in closed loop.

Earth's Magnetism

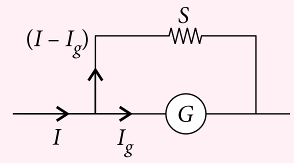
- Net magnetic field, $B = \sqrt{B_H^2 + B_V^2}$
  Here, $B_H = B\cos\delta, B_V = B\sin\delta$
  δ is the dip angle at the place.
- At equator, $B_H = B$ so, $\delta = 0°$ and $B_V = 0$.
- At poles, $B_V = B$ so, $\delta = 90°$ and $B_H = 0$
- The lines drawn through different places having same declination are called isogonic lines. A line which passes through places having zero declination is called agonic line.
- The lines which pass through different places having same dip are called isoclinic lines. A line which passes through places having zero dip is called aclinic line.
- The lines drawn through places having the same value of B_H are called isodynamic lines.

Ampere's Circuital Law

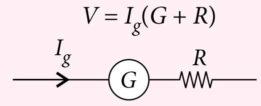
- Ampere's circuital law
  $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{en}$
- Force per unit length between two parallel current carrying wires,
  $\dfrac{F}{l} = \dfrac{\mu_0}{2\pi}\dfrac{I_1 I_2}{r}$
- Parallel currents attract and antiparallel currents repel.

Moving Coil Galvanometer

- Deflection, $\phi = \left(\dfrac{NAB}{\kappa}\right)I$
- Current sensitivity, $\dfrac{\phi}{I} = \dfrac{NAB}{\kappa}$
- Voltage sensitivity, $\dfrac{\phi}{V} = \left(\dfrac{NAB}{\kappa}\right)\dfrac{I}{V} = \left(\dfrac{NAB}{\kappa}\right)\dfrac{1}{R}$
- Conversion of galvanometer into ammeter
  $\dfrac{S}{G} = \dfrac{I_g}{I - I_g}$
  Shunt, $S = \dfrac{I_g G}{I - I_g}$



- An ammeter is connected in series to the wire in which current is to be found.
- Conversion of galvanometer into ammeter
  $V = I_g(G + R)$



  High resistance required in series,
  $R = \dfrac{V}{I_g} - G$
- A voltmeter is connected in parallel across the two points between which potential difference is to be found.

Magnetic Properties of Materials

- Magnetisation of material, $\vec{M} = \dfrac{\vec{m}_{net}}{V}$
- Magnetic induction due to current carrying solenoid having a core
  $B = B_0 + B_M = \mu_0 n(I + I_M)$
- Magnetic field intensity $\vec{H} = \dfrac{\vec{B}}{\mu_0} - \vec{M}$
- Magnetic susceptibility, $\chi = \dfrac{M}{H}$
- Magnetic permeability, $\mu = \mu_0(1 + \chi)$
- Relative permeability $\mu_r = 1 + \chi$
- Curie law, $\chi = \dfrac{C}{T}$
- Curie-Weiss law, $\chi = \dfrac{C}{T - T_C}$ $(T > T_C)$

Classification of Magnetic material

- Diamagnetic substances, where the total magnetic moment of all the particles is zero.
- Paramagnetic substances, where the total magnetic moment of all the particles constituting a substance is not zero and has a small value.
- Ferromagnetic substances, where the total magnetic moment of all the particles has a large value.
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Diamagnetic	Paramagnetic	Ferromagnetic
$-1 \le \chi < 0$	$0 < \chi < \varepsilon$	$\chi >> 1$
$0 \le \mu_r < 1$	$1 \le \mu_r < 1 + \varepsilon$	$\mu_r >> 1$
$\mu < \mu_0$	$\mu > \mu_0$	$\mu >> \mu_0$