CHAPTER 13

ELECTROMAGNETISM

* $1T = NA^{-1}m^{-1}$ or Wbm^{-2}
* $Wb = NmA^{-1}$
* $1G = 10^{-4}T$

FORMULA SHEET

* $F = BIL \sin\theta$

* $\phi = BA\cos\theta$ ϕ: Magnetic Flux

* $B = \frac{\mu_0 I}{2\pi r}$ $\mu_0 = 4\pi \times 10^{-7}\ Wb\,A^{-1}m^{-1}$

* $\Sigma B.\Delta l = \mu_0 I$ → Ampere's Law

* Magnetic Field due to current carrying solenoid:

  $BL = N\mu_0 I$

  $B = n\mu_0 I$ $n = N/L$

* $F = qvB\sin\theta$

* $f = \frac{qB}{2\pi m}$ f: cyclotron frequency

* e/m in terms of Velocity:

  $\frac{e}{m} = \frac{v}{Br}$

* e/m in terms of voltage:

  $\frac{e}{m} = \frac{2V}{B^2r^2}$

* Torque on current carrying loop / coil:

  $\tau = NIAB\cos\theta$

* For Galvanometer:

$$I = \frac{C\theta}{NAB}$$

* For Ammeter:

$$R_s = \frac{R_g I_g}{I - I_g}$$

* For Voltmeter:

$$R_h = \frac{V}{I_g} - R_g$$

* Lorentz Force $= q[E + (v \times B)]$

* $\varepsilon = 2\pi r E$

* RIGHT HAND RULE

When a steady current passes through a conducting wire, it creates a magnetic field around the wire. The direction of such field is determined by Right Hand Rule.

Curl your fingers in direction of magnetic field, thumb indicates direction of current.

* FLEMING'S LEFT HAND RULE

Whenever a current carrying conductor comes under a magnetic field, there will be a force acting on the conductor. The direction of this force can be found using Fleming's Left Hand Rule.

F: Force → Thumb
B: Magnetic Field → First Finger
I: Current → Middle Finger

* FLEMING'S RIGHT HAND RULE

If a conductor is forcefully brought under a magnetic field, there will be induced current in the conductor. The direction of this force can be found using Fleming's Right Hand Rule.

F: Force / Motion → Thumb
B: Magnetic Field → Fore Finger
I: Current → Middle Finger

* Fleming's Left Hand Rule is mainly applicable to electric motors and Fleming's Right Hand Rule is mainly applicable to electric generators.

MAGNETIC FLUX

→ Magnetic Flux represents the magnetic field lines passing through the vector area element ΔA placed perpendicular to the field.

$$\Delta\phi = B \cdot \Delta A$$
$$= B\Delta A \cos\theta$$

→ Direction of vector area element ΔA is normal to surface area

→ The flux ϕ through area A will be maximum if the surface is perpendicular to the field, bcz in this case normal to the surface will be parallel to B.

→ Unit of Magnetic Flux : Weber

$1 Wb = 1 NmA^{-1}$

AMPERE'S LAW

→ Relates the integrated magnetic field in a loop around a current carrying wire to the current passing through the wire.

$$\Sigma B.\Delta l = \mu_0 I$$

μ_0 = Permeability of free space $(4\pi \times 10^{-7}\ Wb A^{-1} m^{-1})$

$\Delta l = 2\pi r$

MCQ: Two long parallel wires 6cm apart carry current of 8A and 2A. What is magnitude of magnetic field midway between them?

Sol:

$I_1 = 8A$

$I_2 = 2A$

The midway between wires is $= r_1 = r_2 = 3cm = 3\times10^{-2}m$

$$B_{net} = B_1 + B_2$$

$$= \frac{\mu_0 I_1}{2\pi r_1} - \frac{\mu_0 I_2}{2\pi r_2}$$

Negative sign is there as fields are opposite in middle

$$B = (4\pi \times 10^{-7})\left(\frac{8-2}{2\pi \times 3 \times 10^{-2}}\right)$$

$$B = 4\times10^{-5}T$$

CHARACTERISTICS OF A MAGNET

1. It has two poles
2. Magnetism at poles is greater than at middle
3. Magnet can be demagnetized by:
   a) Passing A.C
   b) Heating strongly
   c) Striking a magnet again and again ~~by~~ with a surface like that of earth e.g by hammering with hammer.

MAGNETIC FIELD DUE TO A CURRENT CARRYING SOLENOID

→ A cylindrical coil made of a conducting wire is called solenoid.

→ The magnetic field of a solenoid is strong along its axis and weaker, rather negligible outside. i.e magnetic field is strong inside a solenoid while it is weak outside the solenoid.

→ To Find direction of magnetic field in a current carrying solenoid, we use Right Hand Rule:
"Hold the solenoid in your right hand in such a way that the curved fingers must indicate the direction of current through the turns, then the thumb represents direction of magnetic field inside solenoid"

→ The end from where magnetic field enters acts as south pole while the end where it leaves acts as north pole.

⊗ current enters
⊙ current leaves

For solenoid:

$$BL = N\mu_0 I$$

or

$$B = n\mu_0 I \qquad \because n = N/L$$

MCQ: A solenoid is 10 m long and is wound with two layers of wire. The inner layer has 50 turns and the outer layer has 40 turns. A current of 3A flows in both layers in the same direction. What is the magnitude of magnetic flux density along the axis of solenoid?

Sol:

If 10cm then convert cm into m

$L = 10\,m$

$N_1 = 50$ turns

$N_2 = 40$ turns

$I = 3A$

$B = ?$

$n_1 = 50/10 = 5$

$n_2 = 40/10 = 4$

$$B = n_1\mu_0 I_1 + n_2 \mu_0 I_2$$

$$= \mu_0 I(n_1 + n_2)$$

$$= (4\pi \times 10^{-7})(3)(5+4)$$

$$= (4\pi \times 10^{-7})(27)$$

$$\doteq 339 \times 10^{-7} = 3.4 \times 10^{-5}$$

NOTE: Had these solenoids been carrying currents in the opposite directions then the fields would have been in opposite directions and would have been subtracted.

* MAGNETIC STRENGTH OF AN ELECTROMAGNET DEPENDS ON:

1. Number of turns of wire along electromagnet's core
2. Current through the wire
3. Size of the iron core

Increasing these factors can result in an electromagnet that is much larger and stronger than a natural magnet.

* MOTION OF A CHARGED PARTICLE IN UNIFORM MAGNETIC FIELD

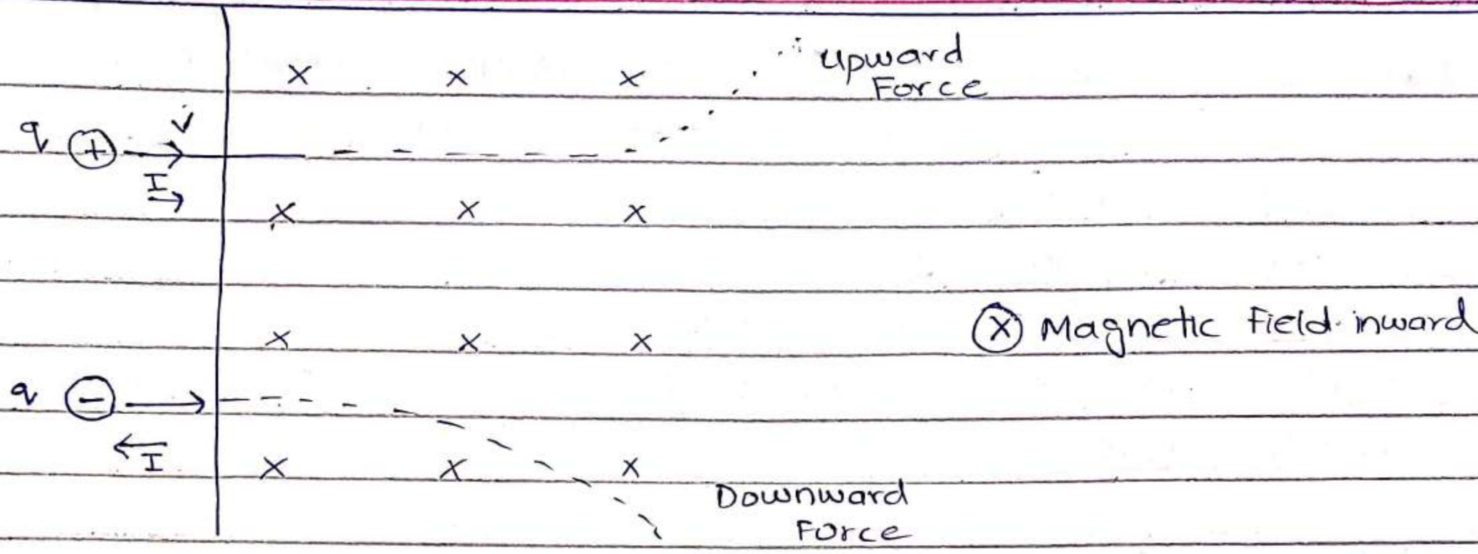
→ A moving charged particle in a magnetic field experience a force.

→ The force acting on the charged particle results from the interaction of the external magnetic field and the magnetic field created by the moving charg

$F = qvB \sin\theta$

→ This force is maximum when charged particle moves perpendicularly to the magnetic field and minir when the charge moves parallel to the field.

→ The direction of this force is determined by Fleming's Left Hand Rule.



For +ve charge, I in direction of positive charge
For -ve charge, I opposite to direction of -ve charge

* A charged particle in a uniform magnetic field follows uniform circular motion.

* $\omega = \frac{qB}{m}$

* $f = \frac{qB}{2\pi m}$ f: cyclotron frequency

LORENTZ FORCE:

The net force acting on a charge due to the combine effect of electric field and magnetic field is called Lorentz Force.

VELOCITY SELECTOR:

Velocity Selector is a device which is used to fire electrons of specific velocity.

Velocity selector consist of cross electric and magnetic field. Only those electrons will pass straight through it for which $F_e = F_m$

MAGNETIC RESONANCE IMAGING (MRI)

→ MRI uses a combination of a strong magnetic field and radio waves to produce detailed high resolution images of the inside of the body.

GALVANOMETER

→ A moving coil galvanometer is an instrument used for detection and measurement of small electric currents.

→ Measure 1mA or less

Principle of Galvanometer: Current carrying loop placed in a magnetic field experiences a torque.

→ Most modern galvanometers are of moving coil type and are called d' Arsonval galvanometers.

→ A cylinder of soft iron is placed at the centre of the coil which intensifies the magnetic field and makes it radial by concentrating the magnetic field lines due to its high permeability (and gives more inertia to the coil)

→ Galvanometer is always connected in series with the circuit component through which we need to detect current

* For Galvanometer:

$$I = \frac{C\theta}{NAB}$$

$C\theta$ is restoring torque

* Galvanometer constant is given by:

$$k = \frac{C}{BAN}$$

→ A Galvanometer can be made sensitive by making k small

→ C is made small by increasing the length and decreasing diameter of suspension wire

→ A, B, N are made large

→ C : Restoring torque per unit twist

* Galvanometer Types:
  1. Lamp Scale Method
  2. Pivoted Coil Galvanometer

AMMETER

→ measure current in Amperes

→ Low resistance wire (shunt Resistance) connected in parallel to Galvanometer

→ The internal resistance of a galvanometer is more than ammeter.

→ An ideal ammeter has a zero resistance.

→ Ammeter is connected in series with the device to measure its current.

→ Equivalent Resistance For Ammeter

$$\frac{1}{R_e} = \frac{1}{R_s} + \frac{1}{R_g}$$

→ For Shunt Resistance:

$$R_s = \frac{R_g I_g}{I - I_g}$$

VOLTMETER

- A galvanometer can be converted into a voltmeter by connecting a high resistance in series with a galvanometer
- Voltmeter measures potential difference between two points
- An ideal voltmeter have infinite resistance.
- Voltmeter is connected in parallel with the device to measure the potential difference.

- Equivalent Resistance for Voltmeter:

$$R_e = R_s + R_g$$

- For Voltmeter:

$$R_h = \frac{V}{I_g} - R_g$$

AVOMETER- MULTIMETER

- An instrument to measure current, voltage and resistance
- Amperemeter, Voltmeter, Ohmmeter (AVO)
- can measure DC as well as AC current and voltage

* FORCE EXPERIENCED BY TWO CURRENT CARRYING PARALLEL WIRES

If current flows in same direction then both wires attract each other (Right Hand Rule) and apply equal force on eachother. If x experience 5×10^{-5} N force to right, then force experienced by y will be 5×10^{-5} N to left

POINTS:

→ Electric force on charged particle is collinear with field

→ Magnetic force on charged particle is always perpendicular to field

→ Electric force does work

→ Magnetic force does no work

→ The force on a charged particle moving parallel to magnetic field is zero.

* A moving charge is surrounded by 3 fields:
    1. Electric Field
    2. Magnetic Field
    3. Gravitational Field

* If the current in two parallel conductors be flowing in opposite direction, then two conductors will repel eachother.

* If the current in two parallel conductors be flowing in same direction, then the two conductors will attract each other.

* If a stream of proton move parallel to each other in the same direction, then they attract eachother.

* Terminal potential difference of a battery is greater than its emf when battery is charged.

* Insulations around wires are damaged due to high voltage

* Silver is the best conductor of electricity

* The energy of a charged particle moving through a magnetic field remain unchanged.

* If stationary particle is subjected to uniform magnetic field, it will be unaffected.

$$F = qvB \sin\theta$$

$$v = 0 \quad \text{so} \quad F = 0$$

* The dimention of the ratio of electric field with magnetic field is same as speed.

Reason: $v = \frac{E}{B}$

MCQ: When a charged particle enters a uniform magnetic field, there is a change in:

a) K.E
b) Magnitude of velocity
✓c) Direction of velocity

MCQ: Keeping magnetic field 'B' and velocity of the particles constant, which particle will show the most deflection when passed through magnetic field:

a) Neutrons (c) β-particles
✓b) α-Particles (d) γ-particles

Reason:

$$F = qvB$$
$$F \propto q$$

MCQ: The expression for magnetic field due to a current carrying solenoid with iron core placed inside it is:

$$B = n\mu_0\mu_r I$$

* An electron cannot be accelerated in cyclotron. For electron, betatron is used.

* In a magnetic field, beta particles are deflected much more than the heavier alpha particles.

* If a current is passed in a spring, it gets compressed.