UNIT	ELECTROMAGNETISM

The branch of physics, which deals with the study of magnetic field produced by the moving charges or current, is called electromagnetism.

MAGNETISM

The branch of physics which deals with the properties of magnetic field produced by the permanent magnetic (bar magnet) is called magnetism.

Q.1 – 1. Explain, briefly, the concept of magnetic field (induction). How are its direction and magnitude specified? Define the unit of magnetic induction.

MAGNETIC FIELD

The region or space around a magnet or a current, where a test magnet feels the magnetic influence of the source is called magnetic field.

SI Unit of Magnetic Field

The SI unit for magnetic field B is **tesla** (T) in the honour of physicist Nikola Tesla.

$$1\,T = 1\,N\,A^{-1}\,m^{-1}$$

In C.G.S System the unit of magnetic field is gauss (G) in the honour of German mathematician and physicist's Karl Friedrich Gauss.

$$1\,G = 10^{-4}\,T$$

Q.1 – 2. State the right hand rule for specifying the direction of magnetic field due an electric current? Illustrate with example.

RIGHT HAND RULE FOR MAGNETIC FIELD

Fig.(1.1)

The direction of $\vec{B}$ due to a current in a wire is found by the right-hand rule. This rule states that if the current-carrying wire is grasped by the right hand with the thumb in the direction of the current, the fingers encircle the wire in the direction of the field.

In this case, the lines of magnetic field are circles concentric with the wire.

Q.1 – 3. Describe the existence, magnitude and direction of the magnetic force on electric current placed in a magnetic field. Obtain the equation for the force.

FORCE ON A CURRENT CARRYING CONDUCTOR IN A UNIFORM MAGNETIC FIELD

Consider a current carrying wire in a region of uniform magnetic field as shown in the fig (1.2 a). It is observed that the wire experiences a magnetic force ($\vec{F}$) that is always perpendicular to the magnetic field ($\vec{B}$) and also the current (I). The direction of magnetic force is given by the right hand rule as

When the right hand is held so that the fingers can be curled from the direction of the current into the direction of the magnetic field, the magnetic force points in the direction of the thumb.

It is experimentally observed that the magnitude of the magnetic force on a current carrying conductor depends on the following factors :

(1) The magnetic force on a current carrying conductor increases with increase in current and decreases in current through the conductor i.e. the magnetic force is directly proportional to current in the conductor.

$F \propto I$ ------------ (1)

(2) The magnetic force increases with the increase in length of the conductor.

$F \propto L$ ------------ (2)

(3) The magnetic force on a current carrying conductor increases with the increase in the intensity of magnetic field and vice versa.

$F \propto B$ ------------ (3)

(4) If the conductor makes an angle (θ) with the direction of magnetic field then the magnetic force on it is proportional to $\sin\theta$.

$F \propto \sin\theta$ ------------ (4)

Combine equations (1), (2), (3) and (4) we get

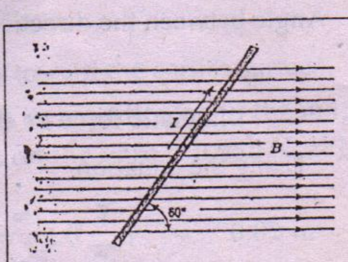

Fig 1.2

$F \propto I L B \sin\theta$

$F = \text{constant}\ I L B \sin\theta$

$F = k\ I L B \sin\theta$

Where (k) is constant of proportionality.

In SI units, the value of k is unity. Therefore put k = 1

$F = (1)\ I L B \sin\theta$

$F = I L B \sin\theta$ ---------- (5)

If the wire is perpendicular to the field ($\theta = 90°$), then the force is maximum and

$F_{max} = I L B \quad [I \perp B]$

If the wire is parallel to the field ($\theta = 0°$), then the force is zero.

In vector notations, the above Eq. (5) can be written as:

$$\vec{F} = I\vec{L} \times \vec{B} = I L B \sin\theta\ \hat{n}$$

Where $\vec{L}$ is a vector whose magnitude is the length of the wire and whose direction is along the wire (assumed straight) in the direction of the current. The unit vector $\hat{n}$ is along the direction of $\vec{F}$ and is perpendicular the plane defined by $\vec{L}$ and $\vec{B}$.

NUMERICAL PROBLEMS

1. A wire carrying current of 30 A current has a length L = 12 cm between th pole pieces of a magnet at an angle $\theta = 60^0$. The magnetic field is approximatel uniform and is 0.90 T. Ignore the field beyond the pole pieces. Find the force o the wire.

Solution

Length of the conducting wire , $L = 12\text{ cm} = 0.12\text{ m}$

Current flowing through the wire , $I = 30\text{ A}$

Strength of the uniform magnetic field , $B = 0.90\text{ T}$

Angle between the direction of the current and the direction of the magnetic field,

$$\theta = 60^\circ$$

Magnetic force on the wire , $F_m = ?$

Using the equation

$$\vec{F}_m = I\vec{L}\times\vec{B} = ILB\sin\theta\,\hat{n}$$

$$\vec{F}_m = (30\text{ A})(0.12\text{ m})(0.90\text{ T})(0.866)\,\hat{n}$$

$$\vec{F}_m = 2.8\text{ N}\,\hat{n}$$

2. What is the force per metre of length on a wire carrying a 0.50 A current in a 0.50 T magnetic field?

Solution **Current flowing through the wire , $I = 0.50\text{ A}$**

Strength of the magnetic field , $B = 0.50\text{ T}$

Force per meter length , $\frac{F}{L} = ?$

The magnetic force on a wire of length L carrying current I and placed in a magnetic induction field B is given by:

$$\vec{F} = I\vec{L}\times\vec{B} = ILB\sin\theta\,\hat{n}$$

where θ is the angle between L and B and $\hat{n}$ is a unit vector perpendicular to the plane determined by $\vec{L}$ and $\vec{B}$.. When the wire is perpendicular to the B-field, then $\theta = 90^\circ$ and $\sin 90^\circ = 1$.

The magnitude of the force per unit metre is:

$$\frac{F}{L} = IB$$

$$\frac{F}{L} = 0.5\text{ A}\times 0.5\text{ T} = 0.25\text{ A N A}^{-1}\text{m}^{-1} = 0.25\text{ N m}^{-1}$$

$$\frac{F}{L} = 0.25\ \frac{\text{N}}{\text{m}}$$

3. A power line parallel to the earth's surface carries current of 20.0A straight west. At that point the earth's magnetic field is 0.80 gauss parallel to the earth's surface and directed straight north.

Find the force due to the field on a 15 m length of the wire.

What is the direction of the force?

Solution

Length of the conducting wire , $L = 15\text{ m}$

Current flowing through the wire , $I = 20.0\text{ A}$

Direction of the current, $\vec{L} = 15\ m\ \hat{w}$

Earth's magnetic field (magnetic induction), $\vec{B} = (0.80\ G)\ \hat{N} = 0.80 \times 10^{-4}\ T\hat{N}$

Angle between the direction of the current and the direction of the earth magnetic field,

$\theta = 90°$ ($1\ Gauss = 10^{-4}$ tesla)

Using the equation

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

$$\vec{F} = (20.0\ A)(15\ m\ \hat{w}) \times (0.80 \times 10^{-4}\ T\ \hat{N})$$

$$\vec{F} = (20.0\ A)(15\ m)(0.80 \times 10^{-4}\ T)\ \hat{w} \times \hat{N}$$

$$\vec{F} = 0.024\ N\ \hat{w} \times \hat{N}$$

$$\vec{F} = 0.024\ N\ \hat{D}$$

$\vec{F} = 0.024$ N, vertically downward toward the earth's surface.

4. A 2.0 cm length of a wire carries a current of 5.0A perpendicular to the magnetic field between the pole pieces of a magnet. The force on the wire is 0.080 N. What is the magnitude of the magnetic field?

Solution **Length of the conducting wire, L = 2.0 c m = 0.02 m**

Current flowing through the wire, $I = 5.0\ A$

Magnetic force on the wire, $F_m = 0.080\ N$

Angle between the direction of the current and the direction of the earth magnetic field,

$\theta = 90°$

Magnitude of the magnetic field (magnetic induction), $B = ?$

Using the equation

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

$$\vec{F} = I\ L\ B\sin\theta\ \hat{n}$$

In magnitude form,

$$F = I L B$$

$$\Rightarrow \quad B = \frac{F}{IL} = \frac{0.080\ N}{5.0\ A \times 0.02\ m} = 0.80T$$