APPLIED PHYSICS II - MODULE III – Part II

ELECTROMAGNETISM

CO3 : Convert galvanometer into ammeter and voltmeter.

Magnetic field:

We all are familiar with magnets. Magnets have a wide range of applications from use in loud speakers, electric fans, refrigerator doors to high end devices like MRI machines. In the previous section we studied the electric field produced by charges. Similarly, magnets produce magnetic fields around it, The magnetic field by a magnet has its origin in the intrinsic magnetic property of its electrons. In addition to magnets, moving charges or currents also produce magnetic field around it.

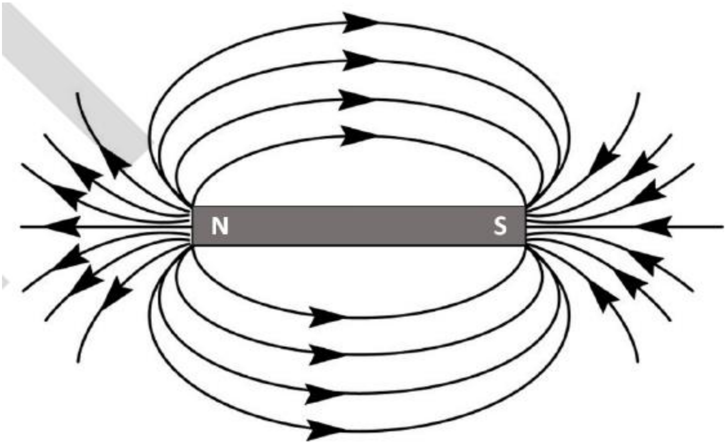

Fig. 3.13 Magnetic field of a bar magnet

The region around a magnet or a moving charge within which another magnetic material or a moving charge experiences a magnetic force is called a magnetic field. Magnetic fields are represented using field lines. The number of field lines through a particular area represents the magnitude of the magnetic field. The SI unit of magnetic field is newton/ampere. metre. It is usually written as Tesla and abbreviated as T.

Magnetic Flux:

It is the measure of total magnetic field passing through a given area. The magnetic flux through an area A in a magnetic field is given by the expression

$$\Phi = BA\cos\theta$$

where θ is the angle between the direction of magnetic field and the perpendicular drawn to the area A. The SI unit of magnetic flux is weber (Wb).

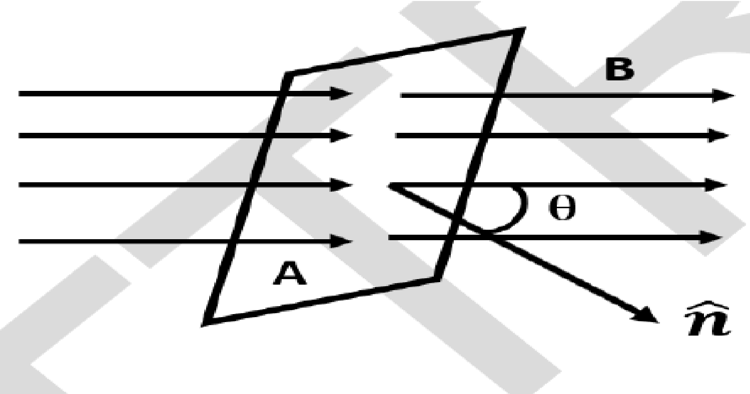

Fig. 3.14 Magnetic flux through an area

Conceptual Learning 1:
Two types of magnets are used in various devices – permanent magnet and electromagnets (in electromagnets, magnetic field is produced by passing current through a wire coil wound around an iron core). List some applications for each type of magnets.

Electromagnetic Induction:

We know that moving charges or currents produces magnetic field around it . The reverse of this process is also possible. A varying magnetic field can induce electric current in a circuit.

The phenomenon in which electric current is generated in a circuit by varying magnetic fields is called electromagnetic induction.

Fig. 3.14 shows a closed circuit with a galvanometer. When the magnet is moved towards or away from the circuit an emf is induced in the circuit. Due to this emf an induced current flows through the circuit and the galvanometer deflects.

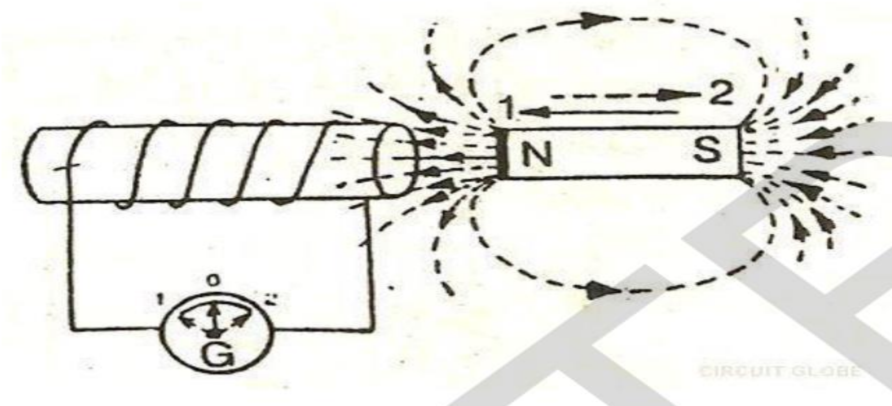

Fig. 3.15 Circuit to illustrate electromagnetic induction

Michael Faraday studied electromagnetic induction in detail by preforming a number of experiments and formulated the following laws.

1. Faraday's first law of electromagnetic induction: Faraday's first law states that whenever the magnetic flux associated with a circuit changes, an emf is induced in the circuit and it persist only as long as the flux change persists.

2. Faraday's second law of electromagnetic induction: Faraday's second law states that the magnitude of the induced emf produced in the circuit is equal to the rate of change of magnetic flux linked with the circuit. Induced emf is given by,

$$\boldsymbol{e = \frac{d\phi}{dt}}$$

where ϕ is the magnetic flux through the circuit.

Lenz's law:

The direction of the induced emf is such as to oppose the change that causes it. Lenz's law help us to determine the polarity of the induced emf. Combining Faraday's law and Lenz's law, the induced emf can be expressed in mathematical as

$$\boldsymbol{e = -\frac{d\phi}{dt}}$$

The negative sign indicates the opposing nature of the induced emf.

Conceptual Learning 2:

Induction cooker used in kitchen is a device which works on the principle of electromagnetic induction. Explain its working.

Lorentz Force:

An electric charge placed in an electric field experiences a force of magnitude qE in the direction of the field. In a magnetic field a charge experiences a force only when it is moving. The magnitude of this magnetic force is $qvBsin\theta$, where v is the velocity of the charge, B is the magnetic field and θ is the angle between the direction of magnetic field and direction of velocity.

In the presence of both electric and magnetic fields, a moving charge experience both electric and magnetic force. The total force on the charge is the sum of these two forces.

$$F = F_{electric} + F_{magnetic}$$

$$F = qE + qvBsin\theta$$

This force is called Lorentz force. The force acting on the charge q due to electric and magnetic field is called Lorentz force.

Force on a current carrying conductor placed in a magnetic field:

Motion of charges constitutes electric current. A charge moving in a magnetic field experiences a force. Thus a current carrying conductor placed in a magnetic field experiences a force.

The magnitude of the force acting on a current carrying conductor placed in an external magnetic field is given by the expression

$$F = BiLsin\theta$$

where B is the magnetic field, i is the current through the magnetic field, L is the length of the conductor, and θ is the angle between direction of current and direction of magnetic field. This force is perpendicular to both the direction of current and direction of magnetic field. The force maximum when the conductor is held perpendicular to the magnetic field. In that case the force, $F = BiL$.

Fleming's Left hand rule:

Fleming's left hand rule gives the direction of the force acting on a current carrying conductor placed in a magnetic field, when the magnetic field is perpendicular to the direction of current flow ($\theta = 90^0$). The magnitude of the force when $\theta = 90^0$ is F = BiL.

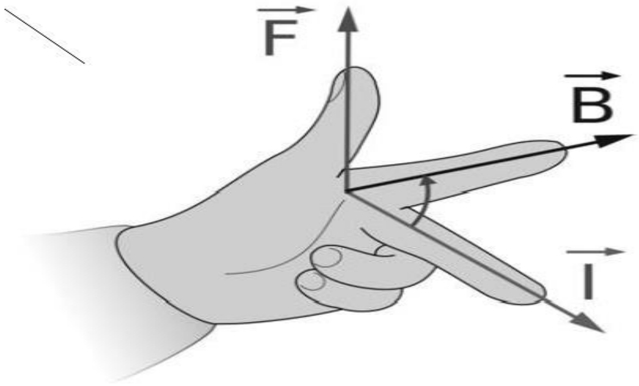

Fig. 3.16 Fleming's left hand rule

Fleming's left hand rule states that *if the thumb, forefinger and middle finger of the left hand are placed mutually at right angles, with the forefinger pointing* *in the direction of magnetic field and middle finger pointing in the direction of electric current, then the thumb gives the direction of the force acting on the conductor.*

Moving Coil Galvanometer:

A moving coil galvanometer is very sensitive instrument used for the detection and measurement of small electric current in a circuit.

Principle:

The moving coil galvanometer works on the principle that a current carrying conductor placed in a magnetic field experiences a force. The magnitude of this force acting on a conductor of length L, carrying a current i placed in a magnetic field B is given by the expression $F = BiL\sin\theta$, where θ is the angle between the direction of current and the direction of magnetic field. The direction of the force is given by Fleming's left hand rule.

Construction:

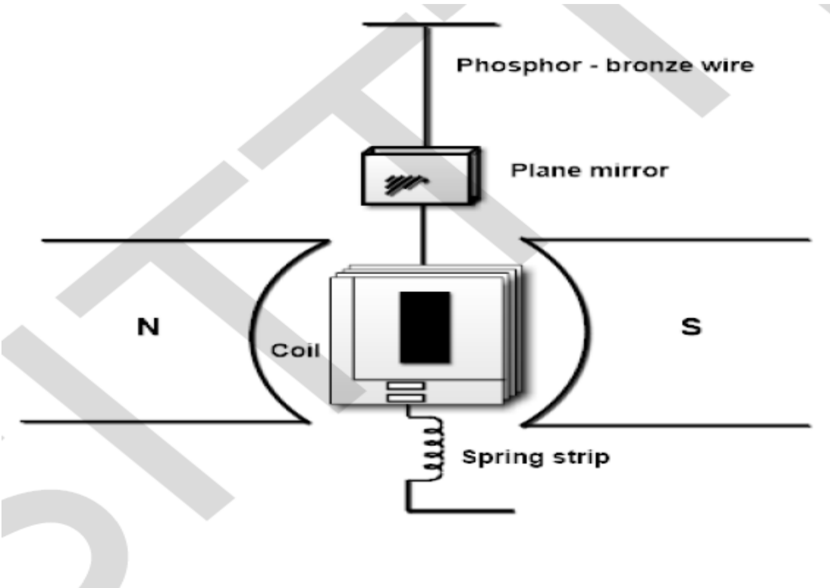

Fig. 3.17 Schematic diagram of a moving coil galvanomter

The galvanometer consists of a rectangular coil of copper wire wound on an aluminium frame with many turns. It is suspended between the pole pieces of a powerful magnet using a phosphor bronze wire. The magnet is provided with concave pole pieces. The pole pieces create a uniform radial magnetic field which is always parallel to the plane of the coil for all positions. A small mirror is attached to the suspension wire to measure the deflection of the coil. The current to be measured enters the coil through the suspension wire and leaves through the spring strip.

Theory:

Let l be the length and b the breadth of the coil . When current flow through the coil, forces act on all the four sides of the coil. The net force and net moment due to the forces acting on the horizontal sides of the coil is zero. The force on each vertical side of the coil, $F=Bil$ since the field is perpendicular to current.

The Fleming's left hand rule gives the direction of the forces. The forces acting on the two vertical sides are equal in magnitude but opposite in direction and is separated by a distance b. These two equal and opposite forces constitutes a couple. The moment of the couple (C) is given by

$$C = Bil \times b = BiA$$

where $A=l \times b$ is the area of the coil. If there are ' n ' turns in the coil, then

$$C = nBiA$$

Due to this moment of the couple, the coil rotates. As the coil rotates, the suspension wire gets twisted and an opposing couple (restoring couple) develops inside the wire. When the moments of the two couples balance each other, the rotation stops.

Let ' θ ' be the angle of through which the coil is rotated , the opposing moment is ' αθ ' , where α is the opposing moment developed inside the wire when it is rotated through unit angle.

When the two moments balance , we can write

$$\alpha\theta = nBiA$$

$$\boldsymbol{\theta = \left(\frac{nBA}{\alpha}\right) i}$$

The quantity given in the bracket is constant for a given galvanometer. Thus angle of deflection θ is proportional to current i. The angle of deflection is measured using a lamp and scale arrangement.

Conversion of galvanometer into an ammeter and a voltmeter:

A galvanometer is basically used to detect electric current in a circuit. To measure values of current or voltage in a circuit, the galvanometer can be used with some modifications. The galvanometer is modified such a way that when it is connected, the values of current and voltage in the circuit are not varied much due to its presence.

1. Conversion of galvanometer into an ammeter:

An ammeter is used to measure the value of current in a circuit. It is always connected in series in a circuit. Directly connecting a galvanometer in series in a circuit will change the value of current in the circuit and also might damage the galvanometer due to large current. *A galvanometer can be converted into an ammeter for measuring large current by connecting a suitable shunt in parallel with the galvanometer. Shunt is a low resistance connected in parallel with a sensitive galvanometer to reduce the sensitiveness and to protect the instrument from heavy currents.* Majority of current flows through the shunt resistance.

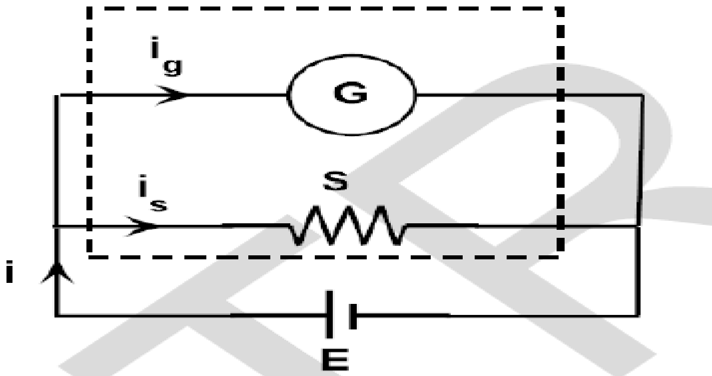

Fig. 3.18 Galvanomter converted to an ammeter

Here i is the current to be measured. A part i_g of the current flows through the galvanometer and the remaining current $(i - i_g) = i_S$ flows through the shunt.

$$i = i_g + i_S$$

Since, voltage across the shunt = voltage across the galvanometer

$$i_S S = i_g G$$

$$(i - i_g)\, S = i_g\, G$$

Or $$i_g = \frac{iS}{G+S} \quad \text{..................(1)}$$

Since S and G are constants,

$$i_g \propto i$$

Thus the current through the galvanometer is directly proportional to the main current to be measured.

If i is the current to be measured and i_g the maximum current that can be sent through a galvanometer of resistance G, the value of the shunt to be connected parallel to the galvanometer can be calculated from the relation(1).

That is , the value of shunt resistance is given by

$$S = \frac{i_g G}{(i - i_g)}$$

2. Conversion of galvanometer to voltmeter:

A voltmeter is an instrument used to measure the potential difference across two points in an electrical circuit. For this, it is connected in parallel with the section of the circuit. *A galvanometer is converted into a voltmeter by a connecting a suitable high resistance in series with the galvanometer.* The current flowing through the galvanometer is reduced due to the large resistance connected to it. The value of R is so chosen that the current through the instrument should not be greater than the maximum for which the galvanometer is designed.

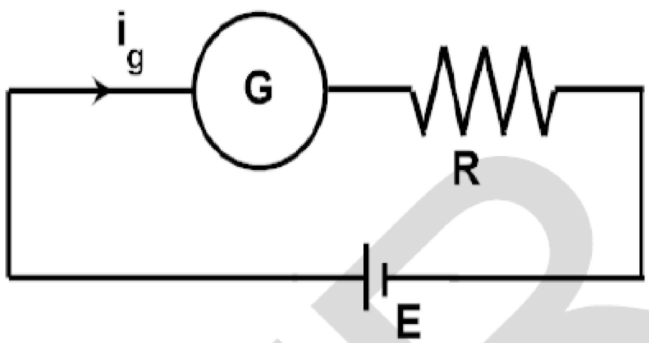

Fig. 3.19 Galvanomter converted to a voltmeter

A galvanometer of resistance G connected with a large resistance R is shown in fig.3.18. The voltage to be measured is E. Here the current through the galvanometer is i_g. Applying Kirchhoff's second law in the circuit,

$$i_g G + i_g \mathrm{R} = E$$

$$i_g (G+R) = E$$

Since R and G are constants for a given instrument, E is directly proportional to i_g . Thus, the value of high resistance to be connected is

$$R = \frac{E}{i_g} - G$$

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