APPLIED PHYSICS -II

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UNIT-II ELECTROMAGNETISM

1) State Coulomb's law

Coulomb's law states that the force of interaction between two electric charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between the two charges.

According to Coulombs law, the electrostatic force F between two charges q_1 and q_2 separated by a distance r is given by:

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

Where ϵ_0 is the permittivity of free space

2) Define electric field and intensity of electric field

The region around a charged particle within which another charge experiences an electric force is called electric field. The intensity of electric field at a point is defined as the force experienced by a unit positive charge placed at that point. The SI unit of electric field is N/C.

3) Define electric potential

The electric potential at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point

4) What is a Capacitor

Capacitor is a system of two conductors placed close to each other with an insulating medium in between them. One of the conductor is given a positive charge (+Q) and the other conductor is given an equal negative charge (-Q).

For a given capacitor, the charge Q on the capacitor is proportional to the potential difference V between the two conductors. That is

$$Q \propto V$$
$$\text{or } Q = CV$$

The proportionality constant C is called the capacitance of the capacitor. The SI unit of capacitance is farad (F).

5) Define electric current

The rate of flow of charges is called electric current. If q is the quantity of charge flows across an area in t seconds, then electric current (I) is given by

$$I = \frac{q}{t}$$

The SI unit of electric current is Ampere (A)

6) Differentiate between direct current and alternating current

The current whose direction and magnitude remains constant is called direct current or DC. Example current from a battery is DC

If the current in a circuit changes its direction alternately, the current is called alternating current or AC.

7) State Ohms law. Explain an experimental method to verify Ohms law.

Ohms law states that the current flowing through a conductor is directly proportional to the potential difference across its ends, provided the temperature is constant.

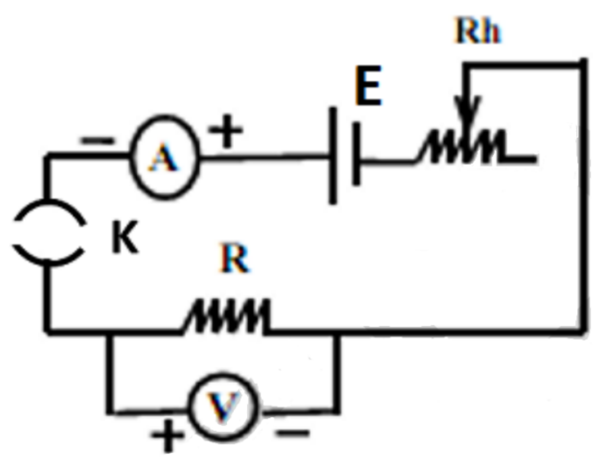
$$I \propto V$$
$$\text{or } \frac{V}{I} = R \text{ , a constant}$$

The constant R is called the resistance of the conductor.

Verification of Ohm's law

Ohms law can be verified using the circuit shown below . A conducting wire of resistance R is connected to a cell of emf E through a key K and rheostat Rh. The ammeter A measures the current through the circuit and the voltmeter V measures the potential difference across the resistance R.

When the key K is closed, current flows through the circuit. The rheostat is adjusted to get a particular value of potential difference across the resistance. The corresponding ammeter reading is also noted. The rheostat is adjusted for different value of potential differences and the corresponding value of current through the resistance is obtained from the ammeter. In each case the ratio of V/I is calculated and found to be constant. This constant value gives the resistance R of the conductor.



8) Describe the terms specific resistance and specific conductance.

Specific resistance (ρ)

The resistance of a conductor is directly proportional to the length of the conductor and inversely proportional to the area of cross section of the conductor. If L is the length and A is the area of cross section of a conductor, then its resistance

$$R \propto \frac{L}{A}$$

$$R = \rho \frac{L}{A}$$

The proportionality constant ρ is called the specific resistance or resistivity of the material of the conductor. It the measure of the opposition to the flow of current through a material. The unit of resistivity is ohm m (Ωm).

Specific conductance (σ)

The reciprocal of specific resistance is called the specific conductance (σ) or conductivity of a material.

$$\sigma = \frac{1}{\rho}$$

$$\sigma = \frac{L}{RA}$$

The unit of specific conductance is $ohm^{-1}m^{-1}$ ($\Omega^{-1}m^{-1}$).

9) Briefly describe the factors affecting the resistance of a conducting wire

The resistance of a conducting wire depends on four factors.

1. Material of the wire

The resistance of a wire depends on the material of the wire, the resistivity or specific resistance is different for different materials. Because of their low specific resistance the conductors made of silver, copper and aluminium has low resistance compared to other materials.

2. Length of the wire

The resistance of a conductor is proportional to its length. That is resistance increases with the length of the conductor.

3. Area of cross section of the wire

The resistance of a conductor is inversely proportional to its area of cross section. That is resistance decreases with the increase in thickness or area of cross section of the conductor.

4. Temperature

Resistance of a conductor increases with the increase in temperature.

10) State and explain Kirchoffs laws.

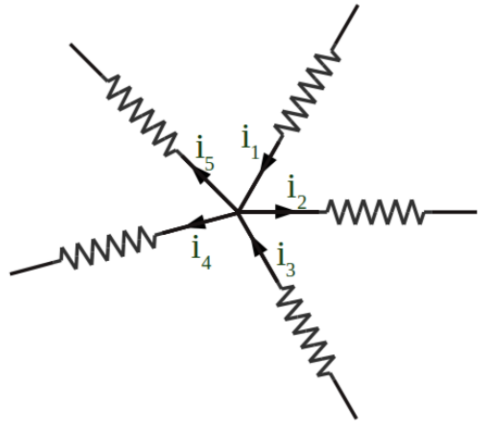
1) Kirchoffs first law (Junction rule):

Kirchoff's first law states that the algebraic sum of the currents meeting at a junction is zero.

The current flowing towards the junction is taken as positive and current flowing away from the junction is taken as negative, then

$$i_1 - i_2 + i_3 - i_4 - i_5 = 0$$
$$\text{or } i_1 + i_3 = i_2 + i_4 + i_5$$

Total current coming to the junction = Total current going out of the junction



2) Kirchoffs second law (loop rule)

Kirchoff s second law states that the algebraic sum of the potential differences around any closed loop in a circuit is zero.

In applying the rule, one starts from a and goes along a loop, The potential difference across a resistance is taken positive when traversed in the direction of the current and potential difference across a cell is taken positive when traversed from the positive terminal to negative terminal. For example, applying Kirchoffs law, in the circuit shown below,

For the loop PQRSTUP,

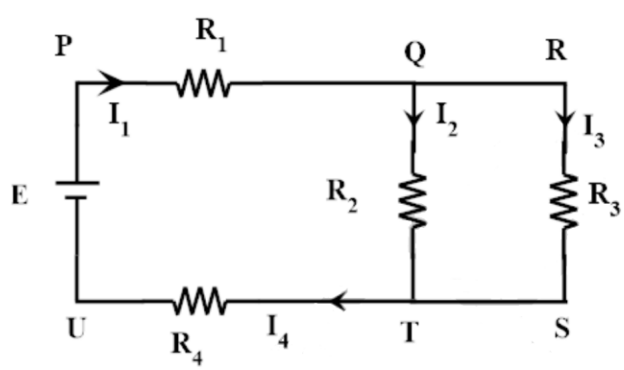
$$I_1R_1 + I_3R_3 + I_4R_4 - E = 0$$

For the loop PQTUP

$$I_1R_1 + I_2R_2 + I_4R_4 - E = 0$$

For the loop QRSTQ

$$I_3R_3 - I_2R_2 = 0$$



11) Applying Kirchoffs laws, derive the balancing condition of Wheatstones bridge.

Wheatstones bridge is a network of four resistances which can be used for the measurement of resistance. In the diagram shown P, R and S are the known resistances whose value can be varied and X is the unknown resistance. A cell is connected between the opposite points A and C. To detect the flow of current along the path BD a galvanometer of resistance G is connected as shown. The current through various branches is shown in the figure.

Applying junction rule at the junctions, B and D gives

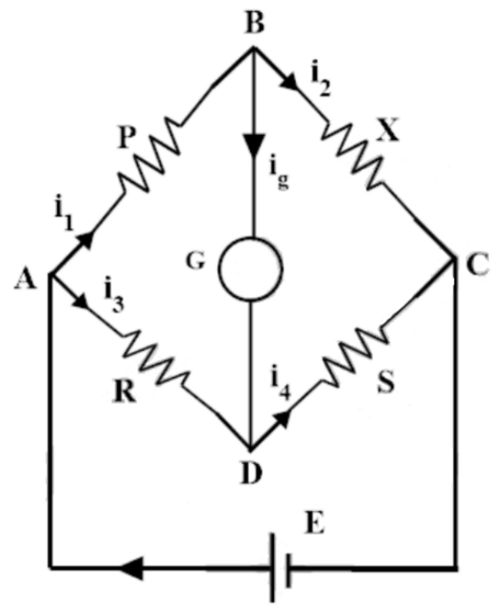
At junction B: $i_1 = i_2 + i_g$ —— (1)
At junction D: $i_4 = i_3 + i_g$ —— (2)

Applying Kirchoffs second law (loop rule) in the closed loop ABDA

$$i_1 P + i_g G - i_3 R = 0 \quad \text{—— (3)}$$

Similarly in the closed loop BCDB

$$i_2 X - i_4 S - i_g G = 0 \quad \text{—— (4)}$$



By varying the values of the resistances of the galvanometer can be made zero , $i_g = 0$. This condition is called the balanced condition of the bridge.
Using this condition $i_g = 0$ in equation (1) and (2)

$$i_1 = i_2 \quad \text{—— (5)}$$
$$i_4 = i_3 \quad \text{—— (6)}$$

Similarly substituting $i_g = 0$ in equation (3) and (4)

$$i_1 P = i_3 R \quad \text{—— (7)}$$
$$i_2 X = i_4 S \quad \text{—— (8)}$$

Dividing Eqn. (7) by Eqn. (8) gives.

$$\frac{i_1 P}{i_2 X} = \frac{i_3 R}{i_4 S}$$

Using Equations (5) and (6)

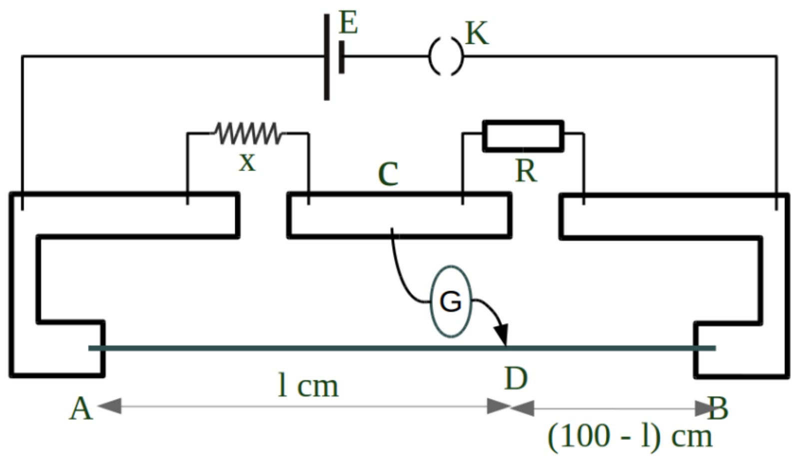
$$\frac{\boldsymbol{P}}{\boldsymbol{X}} = \frac{\boldsymbol{R}}{\boldsymbol{S}}$$

This is the balancing condition of Wheatstones bridge.Using the balancing condition, we can calculate the value of the unknown resistance X

12)Explain the principle and working of a Meter bridge.

Meter bridge is a practical arrangement of Wheatstones bridge used to measure unknown resistance. It consists of a wire AB of length 1m connected between two L-shaped copper strips. The unknown resistance X and the resistance box R are connected between the

L-shaped strips and a straight copper strip as shown in the diagram. A galvanometer is connected between the point C and jockey J. The jockey J can be moved along the wire AB. The whole arrangement is fixed on a wooden base. A cell of emf E is also connected as shown. Current flows through the circuit and the galvanometer shows deflection. The jockey J is moved along the wire and its position is adjusted such that galvanometer shows zero deflection. Now the bridge is balanced. Let l be the balancing length in centimeter as measured from the point A.



The four resistances of the bridge are (1) resistance X , (2) resistance box R , (3) resistance of length AD of the wire, and (4) resistance of wire DB of the wire

Using the balancing condition of Wheatstone s bridge

$$\frac{X}{R} = \frac{\text{Resistance of length AD (l cm)}}{\text{Resistance of length DB (100 - l cm)}}$$

Let r be the resistance per unit length of the wire AB then

$$\frac{X}{R} = \frac{lr}{(100 - l)r}$$

The unknown resistance is then

$$X = \frac{lR}{(100 - l)}$$

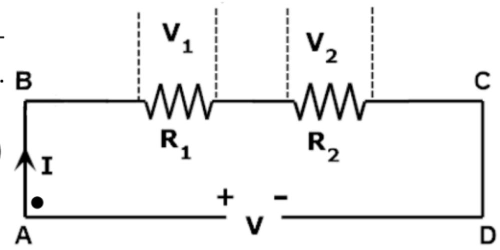
13) What is meant by the effective resistance of a combination of resistances

The effective resistance or equivalent of a combination of resistors is that singe resistance which produces the same effect of the combination of the resistances. The effective resistance draws the same current as drawn by the resistor combination from the power source.

14) Obtain expression for the effective resistance of a series combination and parallel combination of resistors.

1) Series combination

A combination of resistors is said to be series combination if same current (I) flows through all the resistors. The effective resistance (R_s) of a series combination is that single resistance which draws the same current (I) from the source of potential difference (V)
That is



$$R_s = \frac{V}{I} \qquad \text{—— (1)}$$

Applying Kirchoffs second law (loop rule) in the closed circuit ABCDA

$$\begin{aligned} IR_1 + IR_2 &= V \\ V &= I(R_1 + R_2) \\ \frac{V}{I} &= R_1 + R_2 \qquad \text{—— (2)} \end{aligned}$$

Comparing equation (1) and (2)

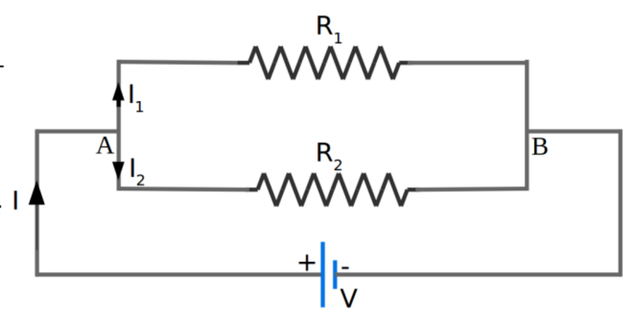
$$\boldsymbol{R_s = R_1 + R_2}$$

If there are $'n'$ number of resistors connected in series, then the effective resistance is

$$R_s = R_1 + R_2 + R_3 + - - - - - + R_n$$

2) Parallel combination

The combination of resistors is said to be a parallel combination if same potential difference exists across all the resistors. The equivalent resistance (R_p) of a parallel combination also draws the same current (I) from the source of potential difference (V)



That is

$$R_p = \frac{V}{I} \qquad \text{—— (1)}$$

Applying Kirchoffs first law at the junction A, we get

$$I = I_1 + I_2$$

Since the voltage across each resistance is V, therefore using Ohm's law

$$\begin{aligned}
I &= \frac{V}{R_1} + \frac{V}{R_2} \\
I &= V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \\
\frac{I}{V} &= \frac{1}{R_1} + \frac{1}{R_2} \qquad \text{—— (2)}
\end{aligned}$$

From equation (1)

$$\frac{I}{V} = \frac{1}{R_p}$$

Comparing equation (1) and (2) we get

$$\boldsymbol{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}}$$

If there are n number of resistors in parallel, the effective resistance is given by

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + - - - + \frac{1}{R_n}$$

15) Define magnetic field

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. The SI unit of magnetic field is newton/(ampere.metre) or Tesla (T)

16) Define magnetic Flux

Magnetic flux is the measure of total magnetic field passing through a given area. The magnetic flux (Φ) 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 (B) and the perpendicular drawn to the area (A).
The SI unit of magnetic flux is weber (Wb).

17) What is meant by electromagnetic induction?

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

18) State Faradays law of electromagnetic induction.

1. Faradays first law of electromagnetic induction:

Faradays first law states that whenever the magnetic flux associated with a circuit changes, an emf is induced in the circuit.

2. Faradays second law of electromagnetic induction:

Faradays second law states that the induced emf produced in the circuit is equal to the rate of change of magnetic flux through it. Induced emf (E) is given by

$$E = \frac{d\Phi}{dt}$$

where Φ is the magnetic flux through the circuit.

19)Explain Lorentz force.

The force experienced by a charged particle in an electromagnetic field is known as Lorentz force. It is the sum of electric force and magnetic force acting on the charged particle.

The electric force acting on a particle of charge q in an electric field E is qE in the direction of the electric field. That is

$$F_{electric} = qE$$

In a magnetic field a charge experiences a force only when it is moving. The magnitude of this magnetic force is,

$$F_{magnetic} = qvB\sin\theta$$

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.

$$F = F_{electric} + F_{magnetic}$$
$$F = qE + qvB\sin\theta$$

This is the expression for Lorentz force on a charged particle moving in an electromagnetic field

20) Write a note on the force acting on a current carrying conductor placed in a magnetic field

A charge moving in a magnetic field experiences a force. Since electric current is the motion of charges 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

$$F = BiL\sin\theta$$

Where B is the magnetic field, i is the current through the conductor, 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

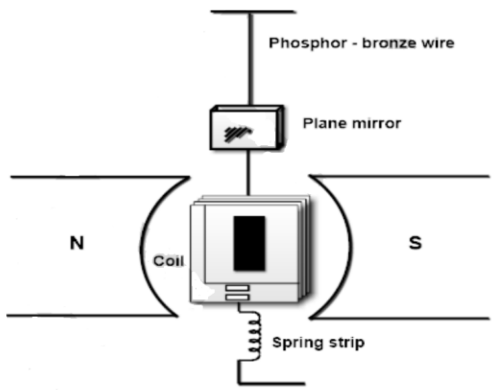
21) State Flemings left hand rule.

Flemings 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

22) Explain the construction and working of a moving coil galvanometer.

A moving coil galvanometer is an instrument used to detect electric current in a circuit. The moving coil galvanometer works on the principle that a current carrying conductor placed in a magnetic field experiences a force. The 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 magnetic field.

The galvanometer consists of a rectangular coil with many turns, suspended between the pole pieces of a magnet using a phosphor bronze wire. The pole pieces create a uniform radial magnetic field which is always parallel to the plane of the coil. A small mirror is attached to the suspension wire to measure the deflection of the coil. The current enters the coil through the suspension wire and leaves through the spring strip.



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 forces acting on the two vertical sides are equal in magnitude, opposite in direction and is separated by a distance b. The two forces constitutes a couple. The moment of the couple (C) is given by

$$\begin{aligned} C &= Bil \times b \\ &= BiA \end{aligned}$$

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 develops inside the wire. When the moments of the two couples balance each other , the rotation stops.

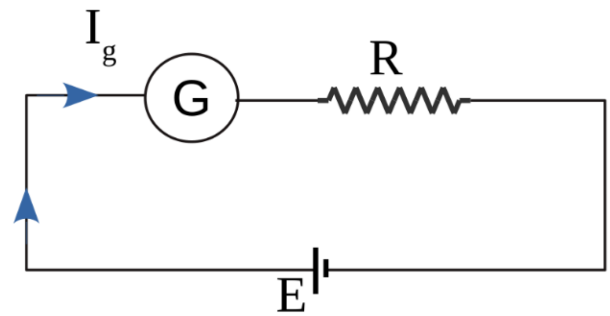
Let θ be the angle of through which the coil is rotated , the opposing moment is $\alpha\theta$, where α is the opposing moment developed inside the wire when it is rotated through unit angle. When the two moments balance , we can write

$$\alpha\theta = nBiA$$
$$\theta = (\frac{nBA}{\alpha})i$$

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

23) Explain how a galvanometer can be converted into a voltmeter.

Voltmeter is an instrument used to measure potential difference between to points in an electrical circuit. A galvanometer can be converted into a voltmeter by connecting a high resistance (R) in series with the galvanometer.



The voltage to be measured is E. Here the current through the galvanometer is i_g . Applying Kirchoffs second law in the circuit,

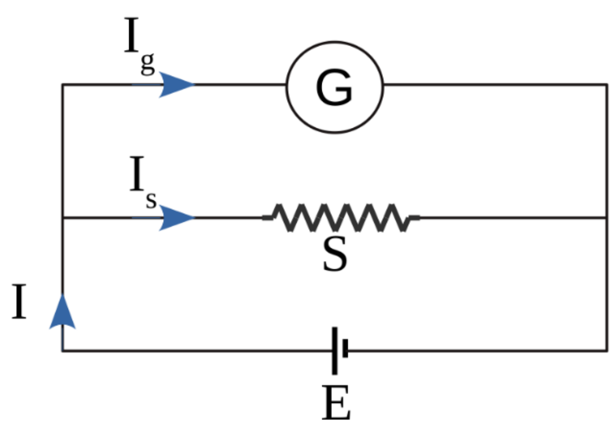
$$i_gG + i_gR = E$$
$$i_g(G + R) = E$$

Thus the value of high resistance to be connected in series is

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

24) Using a circuit diagram, explain how a galvanometer can be converted into an ammeter

Ammeter is a device used for measuring electric current. A galvanometer can be converted into an ammeter by connecting a small shunt resistance (S) in parallel to the galvanometer. Such that the majority of current flows through the shunt resistance.



Here I the current to be measured. A part I_g of the current flows through the galvanometer and the remaining current $(I - I_g)$ flows through the shunt.

Since,

$$\text{voltage across the shunt} = \text{voltage across the galvanometer}$$
$$(I - I_g)S = I_g G$$

Hence the value of shunt resistance is given by

$$\boldsymbol{S = \frac{I_g G}{I - I_g}}$$