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QUARTERLY EXAMINATION ANSWER KEY-2024

GRADE: XI **PHYSICS** **MARKS: 70**

PART – I

1.	a	8.80X10^{-7} J
2.	c	C remains same, Q is doubled
3.	d	Zero
4.	d	820^0C
5.	a	Staright line
6	b	12 Ohm in parallel
7.	b	1.2 Am^2
8.	b	45^0
9.	a	Dia magnetiuc material
10.	d	Zero
11.	c	$Q/\sqrt{2}$
12.	c	Longitudinal
13.	b	Micro waves
14.	c	Refraction
15.	b	Its wavelength

PART-II

II) ANSWER ANY SIX OF THE FOLLOWING QUESTIONS: 6X2=12

Q.NO 24 IS COMPULSORY

16. What are the properties of an equipotential surface?

(i) The work done to move a charge q between any two points A and B, W = q (V_B – V_A). If the points A and B lie on the same equipotential surface, work done is zero because V_A = V_B.

(ii) The electric field is normal to an equipotential surface. If it is not normal, then there is a component of the field parallel to the surface. Then work must be done to move a charge between two points on the same surface.

17. Consider a point charge +q placed at the origin and another point charge -2q placed at a distance of 9 m from the charge +q. Determine the point between the two charges at which electric potential is zero.

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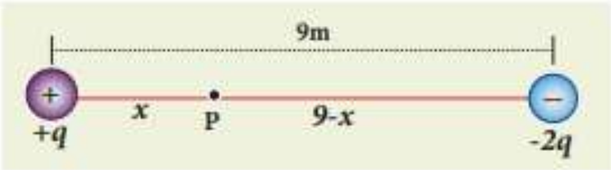

Since the total electric potential at P is zero,

$$V_{tot} = \frac{1}{4\pi\epsilon_o}\left(\frac{q}{x} - \frac{2q}{(9-x)}\right) = 0 \text{ (or)}$$

$$\frac{q}{x} = \frac{2q}{(9-x)} \text{ (or)}$$

$$\frac{1}{x} = \frac{2}{(9-x)}$$

Hence, $x = 3$ m

18. What is Peltier effect?

When an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at the other junction. This is known as Peltier effect.

19. Define electrical resistivity.

Electrical resistivity of a material is defined as the resistance offered to current flow by a conductor of unit length having unit area of cross section.

20. Define Ampere.

One ampere is defined as that constant current which when passed through each of the two infinitely long parallel straight conductors kept side by side parallelly at a distance of one metre apart in air or vacuum causes each conductor to experience a force of 2 × 10−7 newton per metre length of conductor.

21. State Lenz's law

Lenz's law states that the direction of the induced current is such that it always opposes the cause responsible for its production.

22. Define displacement current.

Displacement current can be defined as the current which comes into play in the region in which the electric field (or the electric flux) is changing with time.

23. Compute the speed of the electromagnetic wave in a medium if the amplitude of electric and magnetic fields are 3 × 104 N C–1 and 2 × 10–4 T, respectively.

Solution

The amplitude of the electric field, Eo = 3 × 104 N C–1

The amplitude of the magnetic field, Bo = 2 × 10–4 T.

Therefore, speed of the electromagnetic wave in that medium is

$$v = \frac{3\times10^4}{2\times10^{-4}} = 1.5\times10^8 ms^{-1}$$

24. The angle of minimum deviation for an equilateral prism is 37o . Find the refractive index of the material of the prism.

Given, A = 60°; D = 37°

Equation for refractive index is,

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$n = \frac{\sin\left(\frac{60^0+37^0}{2}\right)}{\sin\left(\frac{60^0}{2}\right)} = \frac{\sin(48.5^0)}{\sin(30^0)} = \frac{0.75}{0.5} = 1.5$$

The refractive index of the material of the prism is, $n = 1.5$

PART-III

ANSWER ANY SIX OF THE FOLLOWING QUESTIONS: 6X3=18

Q.NO 33 IS COMPULSORY

25. Obtain the expression for energy stored in the parallel plate capacitor.

Capacitor not only stores the charge but also it stores energy. When a battery is connected to the capacitor, electrons of total charge $-Q$ are transferred from one plate to the other plate. To transfer the charge, work is done by the battery. This work done is stored as electrostatic potential energy in the capacitor.

To transfer an infinitesimal charge dQ for a potential difference V, the work done is given by

$$dW = V\,dQ \qquad (1.85)$$

where $V = \frac{Q}{C}$

The total work done to charge a capacitor is

$$W = \int_0^Q \frac{Q}{C} dQ = \frac{Q^2}{2C} \qquad (1.86)$$

This work done is stored as electrostatic potential energy (U_E) in the capacitor.

$$U_E = \frac{Q^2}{2C} = \frac{1}{2}CV^2 \quad (\because Q = CV) \qquad (1.87)$$

where $Q = CV$ is used. This stored energy is thus directly proportional to the capacitance of the capacitor and the square of the voltage between the plates of the capacitor.

But where is this energy stored in the capacitor? To understand this question, the equation (1.87) is rewritten as follows using the results $C = \frac{\epsilon_0 A}{d}$ and $V = Ed$

$$U_E = \frac{1}{2}\left(\frac{\epsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\epsilon_0 (Ad)E^2 \qquad (1.88)$$

where Ad = volume of the space between the capacitor plates. **The energy stored per**

density $u_E = \frac{U}{Volume}$. From equation (1.88), we get

$$u_E = \frac{1}{2}\epsilon_0 E^2 \qquad (1.89)$$

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26. The resistance of a wire is 20 Ω. What will be new resistance, if it is stretched uniformly 8 times its original length?

$R_1 = 20\ \Omega$, $R_2 = ?$

Let the original length of the wire (l_1) be l.

New length, $l_2 = 8l_1$ (i.,e) $l_2 = 8l$

Original resistance, $R_1 = \rho \frac{l_1}{A_1}$

New resistance $R_2 = \rho \frac{l_2}{A_2} = \frac{\rho(8l)}{A_2}$

Though the wire is stretched, its volume remains unchanged.

Initial volume = Final volume

$A_1 l_1 = A_2 l_2$, $\quad A_1 l = A_2(8l)$

$$\frac{A_1}{A_2} = \frac{8l}{l} = 8$$

By dividing equation for R_2 by equation for R_1, we get

$$\frac{R_2}{R_1} = \frac{\rho(8l)}{A_2} \times \frac{A_1}{\rho l}$$

$$\frac{R_2}{R_1} = \frac{A_1}{A_2} \times 8$$

Substituting the value of $\frac{A_1}{A_2}$, we get

$$\frac{R_2}{R_1} = 8 \times 8 = 64$$

$$R_2 = 64 \times 20 = 1280\ \Omega$$

27. Derive the expression for effective resistance when resistors are connected in series.

Resistors in series:

When two or more resistors are connected end to end, they are said to be in series. The resistors could be simple resistors or bulbs or heating elements or other devices. Three resistors R1 , R2 and R3 connected in series. The amount of charge passing through resistor R1 must also pass through resistors R2 and R3 since the charges cannot accumulate anywhere in the circuit.

Due to this reason, the current I passing through all the three resistors is the same. According to Ohm's law, if same current pass through different resistors of different values, then the potential difference across each resistor must be different. If V1, V2 and V3 be the potential differences (voltage) across each of the resistors R_1, R_2 and R_3 respectively, then we can write V1 = IR_1, V2 = IR_2 and V3 = IR_3. But the supply voltage V must be equal to the sum of voltages (potential differences) across each resistor.

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \quad (2.21)$$

$$V = I(R_1 + R_2 + R_3)$$

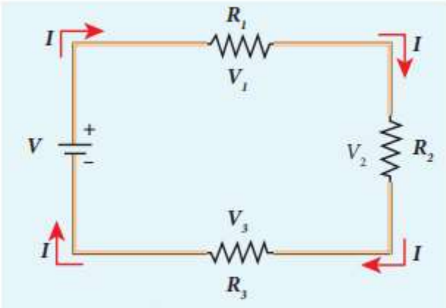
$$V = IR_S \quad (2.22)$$

where R_S is the equivalent resistance.

$$R_S = R_1 + R_2 + R_3 \quad (2.23)$$

When several resistors are connected in series, the total or equivalent resistance is the sum of the individual resistances as shown in the Figure 2.9 (b).

Note: The value of equivalent resistance in series connection will be greater than each individual resistance.



(a) Three resistors in series

(b) Equivalent resistance (R_S) has the same current

28. Compute the intensity of magnetisation of the bar magnet whose mass, magnetic moment and density are 200g, 2Am2 and 8g/cm3 respectively.

Solution

Density of the magnet is

$$Density = \frac{Mass}{Volume} \Rightarrow Volume = \frac{Mass}{Density}$$

$$Volume = \frac{200\times10^{-3}\,\text{kg}}{\left(8\times10^{-3}\,\text{kg}\right)\times10^{6}\,\text{m}^{-3}}$$

$$= 25\times10^{-6}\,\text{m}^3$$

Magnitude of magnetic moment $p_m = 2\,\text{A m}^2$

Intensity of magnetization,

$$M = \frac{Magnetic\ moment}{Volume} = \frac{2}{25\times10^{-6}}$$

$$M = 0.8\times10^{5}\,\text{A m}^{-1}$$

29. Describe the various losses in transformer.

i) Core loss or Iron loss

This loss takes place in transformer core. Hysteresis loss and eddy current loss are known as core loss or Iron loss. When transformer core is magnetized and demagnetized repeatedly by the alternating voltage applied across primary coil, hysteresis takes place due to which some energy is lost in the form of heat. Hysteresis loss is minimized by using steel of high silicon content in making transformer core. Alternating magnetic flux in the core induces eddy currents in it.

Therefore there is energy loss due to the flow of eddy current, called eddy current loss which is minimized by using very thin laminations of transformer core.

ii) Copper loss Transformer windings have electrical resistance. When an electric current flows through them, some amount of energy is dissipated due to Joule heating. This energy loss is called copper loss which is minimized by using wires of larger diameter.

iii) Flux leakage Flux leakage happens when the magnetic lines of primary coil are not completely linked with secondary coil. Energy loss due to this flux leakage is minimized by winding coils one over the other.

30. List out any six properties of Electro Magnetic waves.

* Electromagnetic waves are produced by any accelerated charge.

* Electromagnetic waves do not require any medium for propagation. So electromagnetic wave is a non-mechanical wave.

* Electromagnetic waves are transverse in nature.

* Electromagnetic waves are not deflected by electric field or magnetic field.

* Electromagnetic waves can exhibit interference, diffraction and polarization.

*Like other waves, electromagnetic waves also carry energy, linear momentum and angular momentum.

* If the electromagnetic wave incident on a material surface is completely absorbed, then the energy delivered is U and momentum imparted on the surface is P = U/ c

31. Write a note on microwaves.

It is produced by special vacuum tubes such as klystron, magnetron and gun diode.

The frequency range of microwaves is 109 Hz to 1011 Hz.

These waves undergo reflection and can be polarised.

It is used in radar system for aircraft navigation, speed of the vehicle, microwave oven for cooking and very long distance wireless communication through satellites.

32. What is critical angle? Mention the conditions for total internal reflection of light?

The angle of incidence in the denser medium for which the angle of refraction is 90° (or) the refracted ray graces the boundary between the two media is called critical angle ic .

The two conditions for total internal reflection to take place are, (i) light must travel from denser to rarer medium, (ii) angle of incidence in the denser medium must be greater than critical angle (i>ic).

33.

The magnetic flux passing through a coil perpendicular to its plane is a function of time and is given by OB = $(2t^3 + 4t^2 + 8t + 8)$ Wb. If the resistance of the coil is 5 Ω, determine the induced current through the coil at a time t = 3 second.

Solution:

Magnetic flux $(\Phi_B) = (2t^3 + 8t^2 + 8t + 8)$Wb

Resistance of the coil (R) = 5 Ω

time (t) = 3 second

Induced current through the coil, $I = \frac{e}{R}$

Induced emf, $e = \frac{d\Phi_B}{dt} = \frac{d}{dt}((2t^3 + 4t^2 + 8t + 8) = 6t^2 + 8t + 8$

Here time (t) = 3 second

$e = 6(3)^2 + 8 \times 3 + 8 = 54 + 24 + 8 = 86$ V

∴ Induced current through the coil, $I = \frac{e}{R} = \frac{86}{5} = 17.2$ A

PART- IV

IV.ANSWER ALL THE QUESTIONS 5X5=25

34. a) Explain in detail, the principle construction and working of a van de Graaff generator.

* In the year 1929, Robert Van de Graaff designed a machine which produces a large amount of electrostatic potential difference, up to several million volts (107 V).

* This Van de Graff generator works on the principle of electrostatic induction and action at points. A large hollow spherical conductor is fixed on the insulating stand. A pulley B is mounted at the centre of the hollow sphere and another pulley C is fixed at the bottom.

* A belt made up of insulating materials like silk or rubber runs over both pulleys. The pulley C is driven continuously by the electric motor. Two comb shaped metallic conductors E and D are fixed near the pulleys. The comb D is maintained at a positive potential of 10^4 V by a power supply.

* The upper comb E is connected to the inner side of the hollow metal sphere. Due to the high electric field near comb D, air between the belt and comb D gets ionized by the action of points. The positive charges are pushed towards the belt and negative charges are attracted towards the comb D.

* The positive charges stick to the belt and move up. When the positive charges on the belt reach the point near the comb E, the comb E acquires negative charge and the sphere acquires positive charge due to electrostatic induction.

* As a result, the positive charges are pushed away from the comb E and they reach the outer surface of the sphere. Since the sphere is a conductor the positive charges are distributed uniformly on the outer surface of the hollow sphere.

* At the same time, the negative charges nullify the positive charges in the belt due to corona discharge before it passes over the pulley. When the belt descends, it has almost no net charge.

* At the bottom, it again gains a large positive charge. The belt goes up and delivers the positive charges to the outer surface of the sphere.

* This process continues until the outer surface produces the potential difference of the order of 10^7 which is the limiting value. We cannot store charges beyond this limit since the extra charge starts leaking to the surroundings due to ionization of air. The

leakage of charges can be reduced by enclosing the machine in a gas filled steel chamber at very high pressure.

* The high voltage produced in this Van de Graaff generator is used to accelerate positive ions (protons and deuterons) for nuclear disintegrations and other applications.

b) Derive the expression for the force on a current carrying conductor in a magnetic field.

When a current carrying conductor is placed in a magnetic field, the force experienced by the conductor is equal to the sum of Lorentz forces on the individual charge carriers in the conductor.

Consider a small segment of conductor of length dl, with cross-sectional area A and current I. The free electrons drift opposite to the direction of current. So the relation between current I and magnitude of drift velocity v_d is

$I = neAv_d$

If the conductor is kept in a magnetic field B, then average force experienced by the charge (electron) in the conductor is

$$\vec{f} = -e(\vec{v}_d \times \vec{B})$$

If n is the number of free electrons present in unit volume, then

$$n = \frac{N}{V}$$

where N is the number of free electrons in the small element of volume $V = Adl$.

Hence Lorentz force on the elementary section of length dl is the product of the number of the electrons ($N = nAdl$) and the force acting on each electron.

$$d\vec{F} = -enAdl(\vec{v}_d \times \vec{B})$$

The current element in the conductor is $Id\vec{l} = -enA\vec{v}_d dl$. Therefore the force on the small elemental section of the current-carrying conductor is

$$d\vec{F} = (I\,d\vec{l} \times \vec{B}) \qquad (3.66)$$

Thus the force on a straight current carrying conductor of length l placed in a uniform magnetic field is

$$\vec{F}_{total} = (I\vec{l} \times \vec{B}) \qquad (3.67)$$

In magnitude,

$$F_{total} = BIl\sin\theta$$

(a) If the conductor is placed along the direction of the magnetic field, the angle then $\theta = 0^\circ$. Hence, the force experienced by the conductor is zero.

(b) If the conductor is placed perpendicular to the magnetic field, then the angle $\theta = 90^\circ$ Hence, the force experienced by the conductor is maximum, which is $F_{total} = BIl$.

35. a) Give the properties of dia, para, ferro magnetic materials.

The properties of diamagnetic materials are

i) Magnetic susceptibility is negative.

ii) Relative permeability is slightly less than unity.

iii) The magnetic field lines are repelled or expelled by diamagnetic materials when placed in a magnetic field.

iv) Susceptibility is nearly temperature independent.

The properties of paramagnetic materials are:

i) Magnetic susceptibility is positive and small.

ii) Relative permeability is greater than unity.

iii) The magnetic field lines are attracted into the paramagnetic materials when placed in a magnetic field.

iv) Susceptibility is inversely proportional to temperature.

The properties of ferro magnetic materials are

i) Magnetic susceptibility is positive and large.

ii) Relative permeability is large.

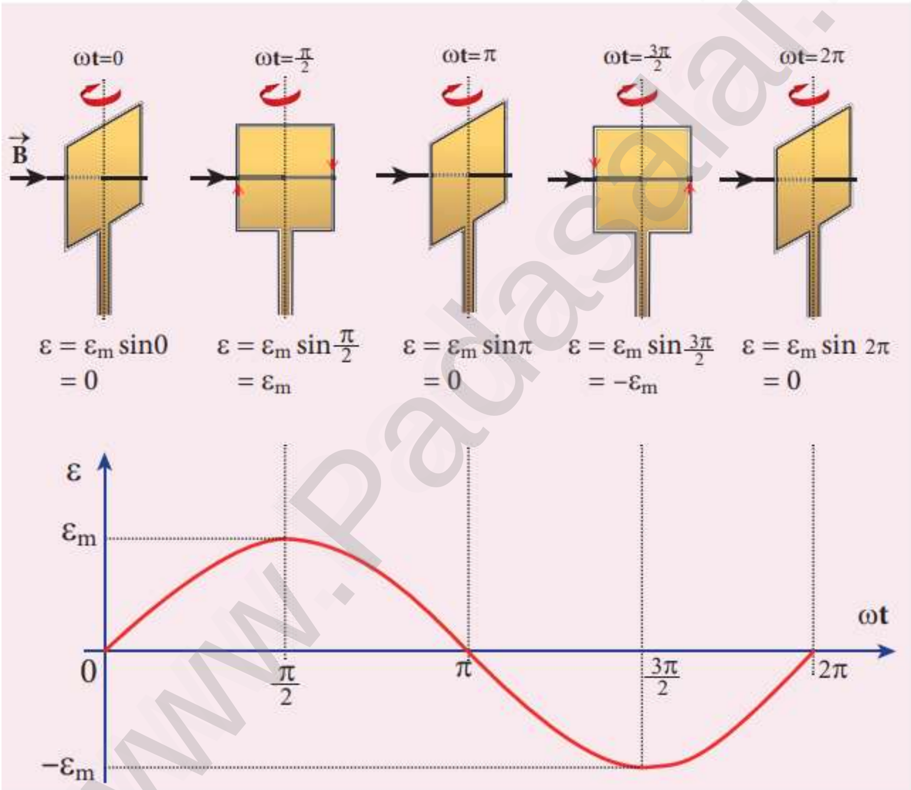
iii) The magnetic field lines are strongly attracted into the ferromagnetic materials when placed in a magnetic field.

iv) Susceptibility is inversely proportional to temperature.

b) Show mathematically that the rotation of a coil in a magnetic field in a magnetic field over one rotation induces on alternating emf of one cycle.

Consider a rectangular coil of N turns kept in a uniform magnetic field B. The coil rotates in anti-clockwise direction with an angular velocity ω about an axis, perpendicular to the field and to the plane of the paper.

At time t = 0, the plane of the coil is perpendicular to the field and the flux linked with the coil has its maximum value Φm = NBA



In a time t seconds, the coil is rotated through an angle θ (= ωt) in anti–clockwise direction. In this position, the flux linked NBAcosωt is due to the component of ρ B normal to the plane of the coil. The component (B sinωt) parallel to the plane has no role in electromagnetic induction. Therefore, the flux linkage with the coil at this deflected position is

$$N\Phi_B = NBA\cos\theta = NBA\cos\omega t$$

According to Faraday's law, the emf induced at that instant is

$$\varepsilon = -\frac{d}{dt}(N\Phi_B) = -\frac{d}{dt}(NBA\cos\omega t)$$
$$= -NBA(-\sin\omega t)\omega$$
$$= NBA\omega\sin\omega t$$

When the coil is rotated through 90° from initial position, $\sin\omega t = 1$. Then the maximum value of induced emf is

$$\varepsilon_m = NBA\omega$$

Therefore, the value of induced emf at any instant is then given by

$$\varepsilon = \varepsilon_m \sin\omega t \quad (4.22)$$

It is seen that the induced emf varies as sine function of the time angle ωt. The graph between induced emf and time angle for one rotation of the coil will be a sine curve (Figure 4.25) and the emf varying in this manner is called **sinusoidal emf** or **alternating emf**.

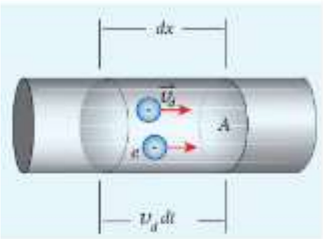
If this alternating voltage is given to a closed circuit, a sinusoidally varying current flows in it. This current is called **alternating current** and is given by

$$i = I_m \sin\omega t \quad (4.23)$$

where I_m is the maximum value of induced current.

36) a. Describe the microscopic model of current and obtain microscopic form of Ohm's law.

Consider a conductor with area of cross section A and let an electric field ρ E be applied to it from right to left. Suppose there are n electrons per unit volume in the conductor and assume that all the electrons move with the same drift velocity v_d



The drift velocity of the electrons = v_d

If the electrons move through a distance dx within a small interval of dt, then

$$v_d = \frac{dx}{dt}; \quad dx = v_d\, dt \quad (2.7)$$

Since A is the area of cross section of the conductor, the electrons available in the volume of length dx is

= volume × number of electrons per unit volume

$$= A\,dx \times n \quad (2.8)$$

Substituting for dx from equation (2.7) in (2.8)

$$= (A\, v_d\, dt)\, n$$

Total charge in the volume element dQ = (charge) × (number of electrons in the volume element)

$$dQ = (e)(Av_d dt)n$$

Hence the current $I = \frac{dQ}{dt}$

$$I = neAv_d \quad (2.9)$$

Current density (J)

The current density (J) is defined as the current per unit area of cross section of the conductor.

$$J = \frac{I}{A}$$

The S.I unit of current density is $\frac{A}{m^2}$ (or) A m^{-2}

$$J = \frac{neAv_d}{A} \text{ (from equation 2.9)}$$

$$J = nev_d \quad (2.10)$$

The above expression is valid only when the direction of the current is perpendicular to the area A. In general, the current density is a vector quantity and it is given by

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$$\vec{J} = ne\vec{v}_d$$

Substituting $\vec{v}_d$ from equation (2.4)

$$\vec{J} = -\frac{n \cdot e^2 \tau}{m}\vec{E} \quad (2.11)$$

$$\vec{J} = -\sigma\vec{E}$$

But conventionally, we take the direction of (conventional) current density as the direction of electric field. So the above equation becomes

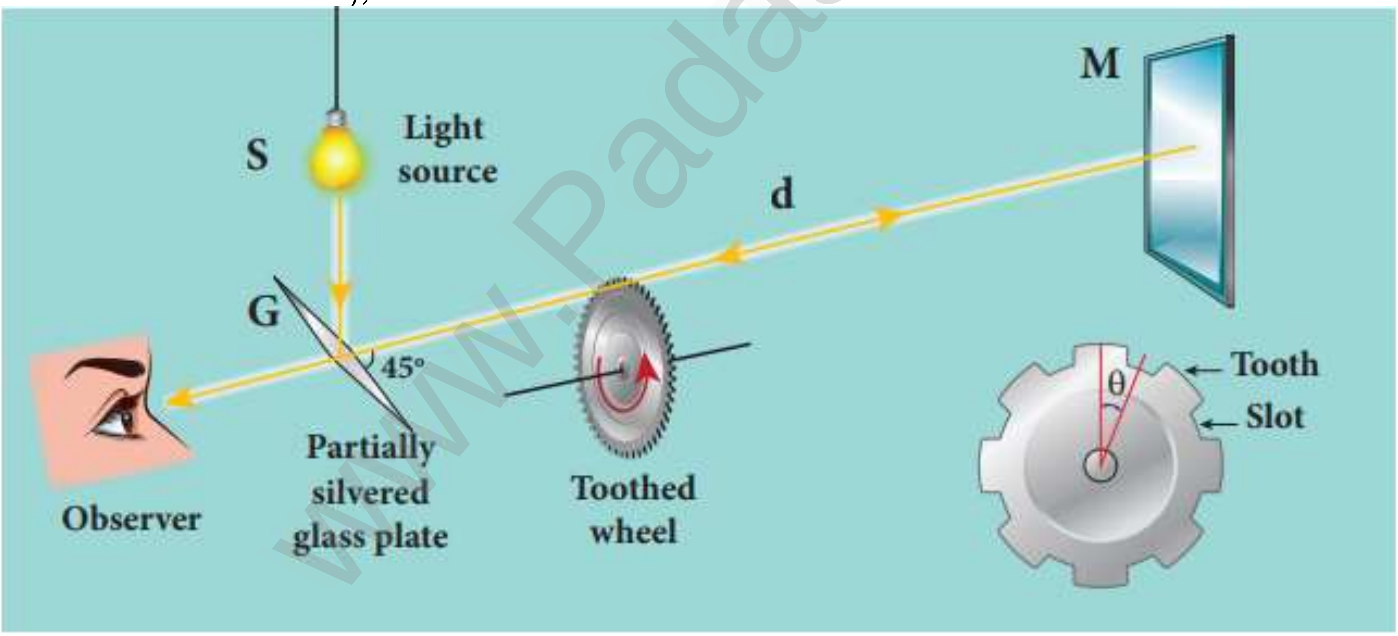
$$\vec{J} = \sigma\vec{E} \quad (2.12)$$

where $\sigma = \frac{ne^2\tau}{m}$ is called conductivity.

The equation (2.12) is called microscopic form of ohm's law.

36) b. Describe the Fizeau's method to determine the speed of light.

The angular speed of rotation of the toothed-wheel was increased from zero to a value ω until the light passing through one cut would completely be blocked by the adjacent tooth. This is ensured by the disappearance of the light while looking through the partially silvered glass plate. Expression for speed of light: The speed v of light in air is equal to the ratio of the distance 2d (the distance light travelled from the toothed-wheel to the mirror and back), to the time taken t.



Here, θ is the angle between one tooth and the next slot which is turned within that time t.

$$\theta = \frac{\text{total angle of the circle in radian}}{\text{number of teeth+number of cuts}}$$

$$\theta = \frac{2\pi}{2N} = \frac{\pi}{N}$$

Substituting θ in equation (6.13),

$$\omega = \frac{\pi / N}{t} = \frac{\pi}{Nt}$$

Rewriting the above equation for t,

$$t = \frac{\pi}{N\omega} \quad (6.14)$$

Substituting this in equation (6.12),

$$v = \frac{2d}{\pi / N\omega}$$

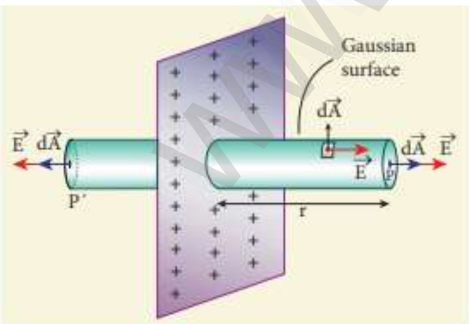
After rearranging,

$$v = \frac{2dN\omega}{\pi} \quad (6.15)$$

37) a) Obtain the expression for electric field due to an changed infinite plane sheet.

Electric field due to charged infinite plane sheet Consider an infinite plane sheet of charges with uniform surface charge density σ (charge present per unit area). Let P be a point at a distance of r from the sheet.

Since the plane is infinitely large, the electric field should be same at all points equidistant from the plane and radially directed outward at all points. A cylindrical Gaussian surface of length 2r and two flats surfaces each of area A is chosen such that the infinite plane sheet passes perpendicularly through the middle part of the Gaussian surface.



Total electric flux linked with the cylindrical surface,

$$\Phi_E = \oint \vec{E}\cdot d\vec{A}$$
$$= \int_{\substack{Curved\\surface}} \vec{E}\cdot d\vec{A} + \int_P \vec{E}\cdot d\vec{A} + \int_{P'} \vec{E}\cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0} \quad (1.68)$$

The electric field is perpendicular to the area element at all points on the curved surface and is parallel to the surface areas at P and P' (Figure 1.38). Then, applying Gauss' law,

$$\Phi_E = \int_P EdA + \int_{P'} EdA = \frac{Q_{encl}}{\epsilon_0} \quad (1.69)$$

Since the magnitude of the electric field at these two equal flat surfaces is uniform, E is taken out of the integration and Q_{encl} is given by $Q_{encl} = \sigma A$, we get

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$$2E\int_P dA = \frac{\sigma A}{\epsilon_0}$$

The total area of surface either at P or P′

$$\int_P dA = A$$

Hence $2EA = \frac{\sigma A}{\epsilon_0}$ or $E = \frac{\sigma}{2\epsilon_0}$ (1.70)

In vector form, $\vec{E} = \frac{\sigma}{2\epsilon_0}\hat{n}$ (1.71)

b) Emission spectra

When the spectrum of Self Luminous source is taken, we get emission spectrum. Each source has its own characteristic emission spectrum. The emission spectrum can be divided into three types:

(i) Continuous emission spectrum (or continuous spectrum) If the light from incandescent lamp (filament bulb) is allowed to pass through prism (simplest spectroscope), it splits up into seven colours. Thus, it consists of wavelengths containing all the visible colours ranging from violet to red Examples: spectrum obtained from carbon arc and incandescent solids.

(ii) Line emission spectrum (or line spectrum): Suppose light from hot gas is allowed to pass through prism, line spectrum is observed. Line spectra are also known as discontinuous spectra. The line spectra consists of sharp lines of definite wavelengths or frequencies. Such spectra arise due to excited atoms of elements. These lines are the characteristics of the element and are different for different elements. Examples: spectra of atomic hydrogen, helium, etc.

(iii) Band emission spectrum (or band spectrum) Band spectrum consists of several number of very closely spaced spectral lines which overlap together forming specific bands which are separated by dark spaces. This spectrum has a sharp edge at one end and fades out at the other end. Such spectra arise when the molecules are excited. Band spectrum is the characteristic of the molecule and hence the structure of the molecules can be studied using their band spectra. Example: spectra of ammonia gas in the discharge tube etc.

38) a. Find out the phase relationship between voltage and current in a pure capacitive circuit.

Consider a circuit containing a capacitor of capacitance C connected across an alternating voltage source (Figure 4.44). The instantaneous value of the alternating voltage is given by

$$v = V_m \sin\omega t \qquad (4.43)$$

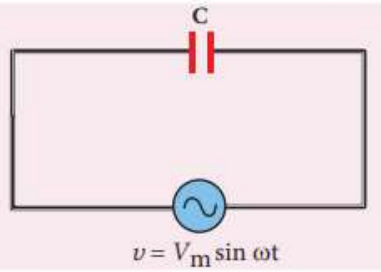

Figure 4.44 AC circuit with capacitor

Let q be the instantaneous charge on the capacitor. The emf across the capacitor at that instant is $\frac{q}{C}$. According to Kirchoff's loop rule,

$$v - \frac{q}{C} = 0$$

$$q = CV_m \sin\omega t$$

By the definition of current,

$$i = \frac{dq}{dt} = \frac{d}{dt}\left(CV_m \sin\omega t\right)$$

$$= CV_m \frac{d}{dt}\left(\sin\omega t\right)$$

$$= CV_m \omega \cos\omega t \qquad \text{(or)}$$

$$i = \frac{V_m}{1/C\omega}\sin\left(\omega t + \pi/2\right)$$

Instantaneous value of current,

$$i = I_m \sin\left(\omega t + \pi/2\right) \qquad (4.44)$$

where $\frac{V_m}{1/C\omega} = I_m$, the peak value of the alternating current. From equations (4.43) and (4.44), it is clear that current leads the applied voltage by $\pi/2$ in a capacitive circuit. This is shown pictorially in Figure 4.45. The wave diagram for a capacitive circuit also shows that the current leads the applied voltage by 90°.

Capacitive reactance X_C

The peak value of current I_m is given by $I_m = \frac{V_m}{1/C\omega}$. Let us compare this equation with $I_m = \frac{V_m}{R}$ for a resistive circuit. The quantity $1/C\omega$ plays the same role as the resistance R in resistive circuit. This is the resistance offered by the capacitor, called capacitive reactance (X_C). It measured in ohm.

$$X_c = \frac{1}{\omega C} \qquad (4.45)$$

The capacitive reactance (X_C) varies inversely as the frequency. For a steady current, $f = 0$.

$$\therefore X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{1}{0} = \infty$$

Thus a capacitive circuit offers infinite resistance to the steady current. So that steady current cannot flow through the capacitor.

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b) Explain the determination of the internal resistance of a cell using voltmeter

The emf of cell ε is measured by connecting a high resistance voltmeter across it without connecting the external resistance R as shown in Figure 2.20(a). Since the voltmeter draws very little current for deflection, the circuit may be considered as open. Hence the voltmeter reading gives the emf of the cell. Then, external resistance R is included in the circuit and current I is established in the circuit. The potential difference across R is equal to the potential difference across the cell (V). The potential drop across the resistor R is

$V = IR$

Due to internal resistance r of the cell, the voltmeter reads a value V, which is less than the emf of cell ε.

It is because, certain amount of voltage (Ir) has dropped across the internal resistance r.

Then $V = \varepsilon - Ir$

$Ir = \varepsilon - V$

Dividing equation (2.36) by equation (2.35), we get

$$\frac{Ir}{IR} = \frac{\varepsilon - V}{V}$$

$$r = \left[\frac{\varepsilon - V}{V}\right] R \qquad (2.37)$$

Since ε, V and R are known, internal resistance r can be determined. We can also find the total current that flows in the circuit. Due to this internal resistance, the power delivered to the circuit is not equal to power rating mentioned in the battery. For a battery of emf ε, with an internal resistance r, the power delivered to the circuit of resistance R is given by $P = I\varepsilon = I(V + Ir)$

Here V is the voltage drop across the resistance R and it is equal to IR. Therefore,

$P = I(IR + Ir)$

$P = I^2 R + I^2 r$

Here $I^2 r$ is the power delivered to the internal resistance and $I^2 R$ is the power delivered to the electrical device (here it is the resistance R). For a good battery, the internal resistance r is very small, then $I^2 r << I^2 R$ and almost entire power is delivered to the external resistance.

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