CBSE 2016

PHYSICS (Theory)

Time allowed: 3 hours Maximum Marks: 70

General Instructions:

1. *All questions are compulsory. There are 26 questions in all.*
2. *This question paper has five sections: Section A, Section B, Section C, Section D and Section E.*
3. *Section A contains five questions of one mark each, Section B contains five questions of two marks each, Section C contains twelve questions to three marks each, Section D contains one value based question of four marks and Section E contains three questions of five marks each.*
4. *There is no overall choice. However, an internal choice has been provided in one question of two marks, one question of three marks and all the three questions of five marks weightage. You have to attempt only one of the choices in such questions.*
5. *You may use the following values of physical constants wherever necessary:*

$c = 3 \times 10^8$ m/s

$h = 6.63 \times 10^{-34}$ Js

$e = 1.6 \times 10^{-19}$ C

$\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}

$\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2}

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^8 \text{ N m}^2 \text{ C}^{-2}$$

Mass of electron = 9.1×10^{-31} kg

Mass of neutron = 1.675×10^{-27} kg

Mass of proton = 1.673×10^{-27} kg

Avogadro's number = 6.023×10^{23} per gram mole

Boltzmann constant = 1.38×10^{-23} JK^{-1}

SECTION – A

1. Write the underlying principle of a moving coil galvanometer.

Solution

Galvanometer works on the principle of conversion of electrical energy into mechanical energy. When a current flows in a magnetic field it experiences a magnetic torque. If it is free to rotate under a controlling torque, it rotates through an angle proportional to the current flowing through it.

2. Why are microwaves considered suitable for radar systems used in aircraft navigation?

Solution

Microwaves have high frequency range 1 GHz to 300 GHz. Thus, they get bounce off smallest aircraft. They can penetrate through clouds. Microwaves have short wavelengths that can pass easily through the atmosphere and thus they are used to transmit information to satellites. Their small wavelength allows convenient-sized antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna.

3. Define 'quality factor' of resonance in series LCR circuit. What is its SI unit?

Solution

The quality factor Q is defined by

$$Q = \omega_0 / \Delta\omega$$

where, $\Delta\omega$ is the width of the resonant power curve at half maximum.

Since that width turns out to be $\Delta\omega = R/L$, the value of Q can also be expressed as

$$Q = \omega_0 \frac{L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

The Q is a commonly used parameter in electronics, with values usually in the range of Q = 10 to 100 for circuit applications. It is unitless.

4. A point charge $+Q$ is placed at point O as shown in the figure. Is the potential difference $V_A - V_B$ positive, negative or zero?

Solution Potential at point A is

$$V_A = \frac{Q}{4\pi\varepsilon_0 r_A}$$

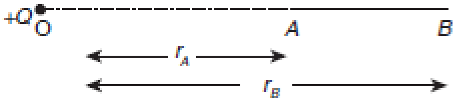
Potential at point B is

$$V_B = \frac{Q}{4\pi\varepsilon_0 r_B}$$

As, $r_A < r_B$

Therefore, $V_A > V_B$

Thus, $V_A - V_B$ is positive.



5. How does the electric flux due to a point charge enclosed by a spherical Gaussian surface get affected when its radius is increased?

Solution

According to Gauss's law, the electric flux of the Gaussian surface only depends on the charge enclosed inside the Gaussian surface and is independent of the radius of the Gaussian surface. Therefore, if we double the radius of the Gaussian surface, the electric flux will remain the same.

SECTION – B

6. A nucleus with mass number A = 240 and BE/A = 7.6 MeV breaks into two fragments each of A = 120 with BE/A = 8.5 MeV. Calculate the released energy.

Solution

Let us take a nucleus with A = 240 breaking into two fragments each of A = 120.

Then, nuclear binding energy, E_{bn} for A = 240 nucleus is about 7.6 MeV,

E_{bn} for the two A = 120 fragment nuclei is about 8.5 MeV.

Therefore, gain in binding energy for nucleon is about 0.9 MeV.

Hence the total gain in binding energy is 240×0.9 or 216 MeV.

OR

Calculate the energy in fusion reaction:

${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_1^3\text{He} + \text{n}$, where BE of ${}_1^2\text{H} = 2.23\,\text{MeV}$ and of ${}_2^3\text{He} = 7.73\,\text{MeV}$.

Solution

Change in binding energy is

$$\Delta E = 7.73 - 2(2.23) = 7.73 - 4.46 = 3.27 \text{ MeV}$$

7. Two cells of emfs 1.5 V and 2.0 V having internal resistances 0.2 Ω and 0.3 Ω respectively are connected in parallel. Calculate the emf and internal resistance of the equivalent cell.

Solution

Let the equivalent internal resistance = R

Two cells having internal resistances 0.2 Ω and 0.3 Ω are connected in parallel, then R is given by

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} = \frac{1}{0.2} + \frac{1}{0.3} = \frac{0.3+0.2}{0.06} = \frac{0.5}{0.06}$$

$$R = \frac{0.06}{0.5} = 0.12\,\Omega$$

Therefore, equivalent emf $= \dfrac{\dfrac{E_1}{r_1} + \dfrac{E_2}{r_2}}{R} = \dfrac{\dfrac{1.5}{0.2} + \dfrac{2}{0.3}}{0.12} = \dfrac{0.45+0.4}{0.06} \times \dfrac{0.012}{1} = 1.7\text{ V}$

8. State Brewster's law.

The value of Brewster angle for a transparent medium is different for light of different colours. Give reason.

Solution

Brewster's law states that the tangent of the polarizing angle of incidence of a transparent medium is equal to its refractive index.

$$\mu = \tan i_p$$

The value of Brewster angle for a transparent medium is different for light of different colors. It is because polarizing angle depends on refractive index according to Brewster's law and refractive index depends on wavelength of light.

9. Explain the terms (i) Attenuation and (ii) Demodulation used in Communication System.

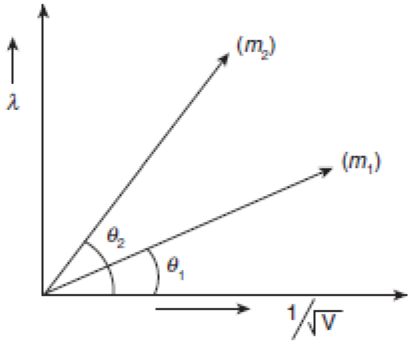
Solution

(i) Attenuation: Loss of strength of a signal while propagating through a medium.

(ii) Demodulation: This is a reverse process of modulation. The process of retrieval of information from the carrier wave at the receiver end is called demodulation.

10. Plot a graph showing variation of de-Broglie wavelength λ versus $\frac{1}{\sqrt{V}}$, where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 ($m_1 > m_2$). Which one of the two represents a particle of smaller mass and why?

Solution



As, according to work-energy principle, $qV = \frac{1}{2}mv^2$

$$qV = \frac{p^2}{2m} \qquad [\text{As, } p = mv]$$

$$\Rightarrow \ p = \sqrt{2mqV}$$

$$\Rightarrow \ \frac{h}{\lambda} = \sqrt{2mqV}$$

$$\Rightarrow \ \lambda = \frac{h}{\sqrt{2mqV}}$$

Therefore, $\text{slope} \propto \frac{1}{\sqrt{m}}$

Thus, particle with smaller mass has greater value of slope.

SECTION – C

11. (i) Define mutual inductance.

(ii) A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil?

Solution

(i) Mutual inductance is defined as the coefficient of mutual induction and gives the amount of magnetic flux linked with one coil when unit current flows through the neighboring coil, that is, production of induced emf in one coil due to change of current or magnetic flux in the neighboring coil.

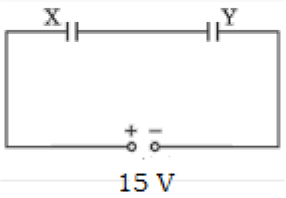
(ii) Mutual inductance M = 1.5 H; I_i = 0 A and I_f = 20 A

Change in current, dI = 20 A

$$M = \frac{d\phi}{dI} \ \Rightarrow \ d\phi = MdI$$

$$d\phi = 1.5 \times 20 = 30 \text{ weber}$$

12. Two parallel plate capacitors X and Y have the same area of plates and same separation between them. X has air between the plates while Y contains a dielectric medium of $\varepsilon_r = 4$



(i) Calculate capacitance of each capacitor if equivalent capacitance of the combination is 4 μF.

(ii) Calculate the potential difference between the plates of X and Y.

(iii) Estimate the ratio of electrostatic energy stored in X and Y.

Solution

(i) Let us assume that capacitance of $X = C_1$

Capacitance of $Y = C_2$

$$C_1 = \frac{\varepsilon_0 A}{d} \text{ and } C_2 = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$\frac{C_1}{C_2} = \frac{\varepsilon_0 A}{d} \times \frac{d}{\varepsilon_0 \varepsilon_r A} = \frac{1}{\varepsilon_r}$$

$C_2 = \varepsilon_r C_1$;

If $C_1 = C$;

then, $C_2 = 4C$ [As $\varepsilon_r = 4$]

Capacitors are connected in series, thus equivalent capacitance $= C_{eq} = 4$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{C} + \frac{1}{4C}$$

$$\frac{1}{4} = \frac{5C}{4C^2} \Rightarrow C = 5\ \mu\text{F}$$

Therefore, $C_1 = 5\ \mu$F and $C_2 = 20\ \mu$F

(ii) Since $C_{eq} V_{net} = Q_{Total}$

$$4 \times 15 = Q_{total} = 60\ \mu\text{C}$$

Because capacitors are in series, therefore they should have equal charges

Therefore, $Q_1 = Q_2 = Q_{total} = 60\ \mu$C

Using, $Q = CV$

$$V_1 = \frac{Q_1}{C_1} = \frac{60}{5} = 12\ \text{V}$$

$$V_2 = \frac{Q_2}{C_2} = \frac{60}{20} = 3\ \text{V}$$

(iii) Electrostatic energy stored in $X = U_1 = \frac{1}{2}\frac{Q_1^2}{C_1}$

$$= \frac{1}{2}\frac{(60)^2}{5} = 360\ \mu\text{J}$$

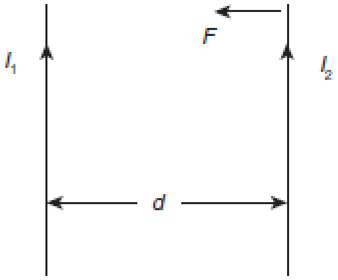
Electrostatic energy stored in $Y = U_2 = \frac{1}{2}\frac{Q_2^2}{C_2}$

$$= \frac{1}{2}\frac{(60)^2}{20} = 90\ \mu\text{J}$$

$$\frac{U_1}{U_2} = \frac{4}{1} \Rightarrow U_1 : U_2 = 4:1$$

13. Two long straight parallel conductors carry steady current I_1 and I_2 separated by a distance d. If the currents are flowing in the same direction, show how the magnetic field set up in one produces an attractive force on the other. Obtain the expression for this force. Hence define one ampere.

Solution



Magnetic field produced on the wire carrying current I_2 due to I_1

$$B = \frac{\mu_0 I_1}{2\pi d} \qquad \ldots\text{(i)}$$

Force acting at l length towards I_1 is

$$F = I_2 l B$$

On putting value of B from (i)

$$F = \frac{I_2 l \mu_0 I_1}{2\pi d}$$

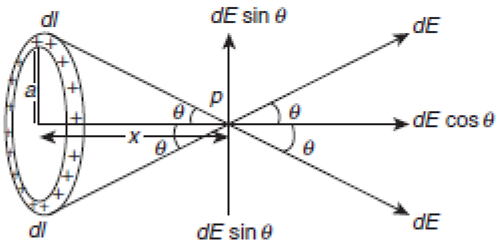
If l = 1m, d = 1m, $I_1 = I_2 = I$ and $F = 2 \times 10^{-7}$N = Attractive force between wires

Therefore, I = 1A

Hence, 1A is defined as current which when maintained in two parallel infinite length conductors held at a one meter distance will produce a force of 2×10^{-7} N.

14. A charge is distributed uniformly over a ring of radius 'a'. Obtain an expression for the electric intensity E at a point on the axis of the ring. Hence show that for points at large distances from the ring, it behaves like a point charge.

Solution Consider a ring of radius a having charge q distributed uniformly. If dl is the length element of the ring having charge dq, then



$$dq = \frac{q}{2\pi a}.dl$$

and, $$dE = \frac{Kdq}{r^2} = \frac{Kq}{2\pi a}.\frac{dt}{r^2}$$

Electric field has two components:

(i) the axial components dE cos θ.

(ii) the perpendicular component dE sin θ are opposite and equal, thus cancel out each other.

Thus, E at point P is given by

$$E = \int_0^{2\sqrt{R}} dE \cos\theta$$

$$= \int_0^{2\pi a} \frac{Kq}{2\pi a}.\frac{dl}{r^2}.\frac{x}{r}$$

$$= \frac{Kqr}{2\pi a}\int_0^{2\pi a} dl$$

$$= \frac{Kqx}{2\pi a}.\frac{1}{r^3}[l]_0^{2\pi a}$$

$$= \frac{Kqx}{2\pi a}.\frac{2\pi a}{(x^2+a^2)^{3/2}} \qquad [\text{As } r^2 = x^2 + a^2]$$

$$= \frac{Kqx}{(x^2+a^2)^{3/2}} = \frac{1}{4\pi\varepsilon_0}\frac{qx}{(x^2+a^2)^{3/2}}$$

If $x >> a$, then $x^2 + a^2 \simeq x^2$. Therefore,

$$E = \frac{1}{4\pi\varepsilon_0}\frac{qx}{(x^2)^{3/2}} = \frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}$$

Hence, its expression is similar to electric field due to a point charge.

15. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation.

Solution Following are the characteristics features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation:

(i) Existence of threshold frequency: According to wave theory, there should not exist any threshold frequency but Einstein's theory explains the existence of threshold frequency.

(ii) Dependence of kinetic energy on frequency of incident light: According to wave theory, the maximum kinetic energy of emitted electrons should depend on intensity of incident light and not on frequency whereas Einstein's equation explains that it depends on frequency and not on intensity.

(iii) Instantaneous emission of electrons: According to wave theory there should be time lag between emission of electrons and incidence of light whereas Einstein's equation explains why there is no time lag between incident of light and emission of electrons.

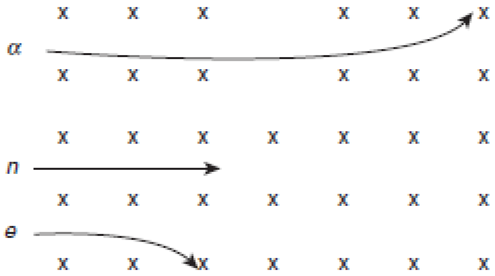
16. (a) Write the expression for the magnetic force acting on a charge particle moving with velocity *v* in the presence of magnetic field *B*.

(b) A neutron, an electron and an alpha particle moving with equal velocities, enter a uniform magnetic field going into the plane of the paper as shown. Trace their paths in the field and justify your answer.

Solution (a) Force acting on a charged particle with charge *q* moving with velocity *v* in a magnetic field of strength *B* is *F* which is given by

$$F = q(\vec{v} \times \vec{B}) = qvB \sin \theta.$$

(b) Alpha particle will deviate anti-clockwise path in direction of $\vec{v} \times \vec{B}$ neutron will pass without any deviation. Electron will deviate in clockwise path in opposite direction of $\vec{v} \times \vec{B}$



17. (a) Calculate the distance of an object of height *h* from a concave mirror of radius of curvature 20 cm, so as to obtain a real image of magnification 2. Find the location of image also.

(b) Using mirror formula, explain why a convex mirror always produces a virtual image.

Solution (a) Mirror formula

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \qquad \ldots\text{(i)}$$

Given, magnification, *m* = 2, therefore,

$$m = \frac{v}{u} = \frac{h_i}{h_0}$$

$$\Rightarrow 2 = \frac{v}{u} \;\Rightarrow\; v = 2u$$

Putting this value in (i), we get

$$\frac{-2}{20}=\frac{1}{-2u}-\frac{1}{u}$$

$$\frac{-1}{10}=\frac{-3}{2u}$$

$$\Rightarrow u = 15 \text{ cm}$$

Thus, $v = 30$ cm

(b) Focal length is positive for convex mirror. Therefore,

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$$

$$\Rightarrow \frac{1}{v}=\frac{1}{f}-\frac{1}{u}$$

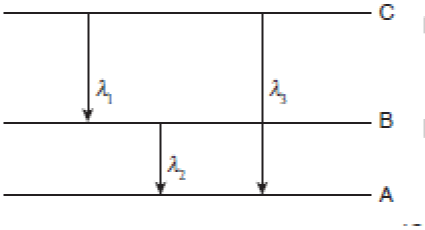
u will be negative, so

$$\frac{1}{v}=\frac{1}{f}-\left(\frac{1}{-u}\right)=\frac{1}{f}+\frac{1}{u}$$

Therefore, v will be positive, thus image will be virtual.

18. (i) State Bohr's quantization condition for defining stationary orbits. How does de–Broglie hypothesis explain the stationary orbits?

(ii) Find the relation between the three wavelengths λ_1, λ_2 and λ_3 from the energy level diagram shown below.



Solution

(i) According to Bohr's quantization condition for stationary orbits: Of all the possible circular orbits allowed by the classical theory, the electrons are permitted to circulate only in those orbits in which the angular momentum of an electron is an integral multiple of $h/2\pi$; h being Planck's constant. Therefore, for any permitted orbit,

$$L = mvr = nh/2\pi;\; n = 1, 2, 3, \ldots$$

where L, m and v are the angular momentum, mass and speed of the electron, r is the radius of the permitted orbit and n is positive integer called principal quantum number.

The above equation is Bohr's famous quantum condition.

When an electron of mass m is confined to move on a line of length l with velocity v, the

$$\lambda=\frac{h}{mv}=\frac{h}{p}$$

$$\Rightarrow p=\frac{h}{\lambda}=\frac{h}{2l/n}=\frac{nh}{2l}$$

When electron revolves in a circular orbit of radius 'r' then $2l = 2\pi r$. Therefore,

$$p = \frac{nh}{2\pi}$$

$$p \times r = \frac{nh}{2\pi}$$

or angular momentum $\left|\vec{L}\right| = p \times r$ is integral multiple of $h/2\pi$ which is Bohr's quantization of angular momentum.

(ii) From the given diagram, we can write that

$$E_{CB} = \frac{h_c}{\lambda_1}, \quad E_{BA} = \frac{h_c}{\lambda_2} \text{ and } E_{CA} = \frac{h_c}{\lambda_3}$$

As we know from given diagram

$$E_{CA} = E_{CB} + E_{BA}$$

Therefore,

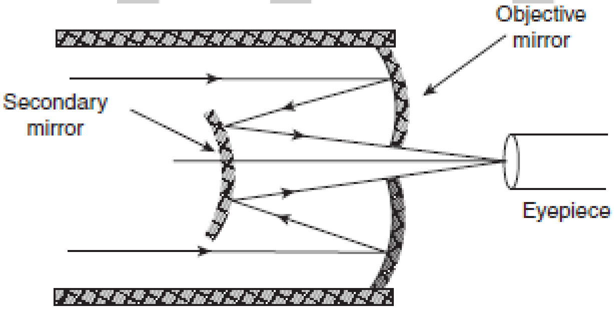
$$\frac{h_c}{\lambda_3} = \frac{h_c}{\lambda_1} + \frac{h_c}{\lambda_2}$$

$$\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

$$\Rightarrow \lambda_3 = \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2}$$

19. Draw a schematic ray diagram of reflecting telescope showing how rays coming from a distant object are received at the eye-piece. Write its two important advantages over a refracting telescope.

Solution



Telescope with mirror objective are called reflecting telescopes. They have several advantages.

(a) There is no chromatic aberration in a mirror.

(b) If a parabolic surface is chosen, spherical aberration is also removed.

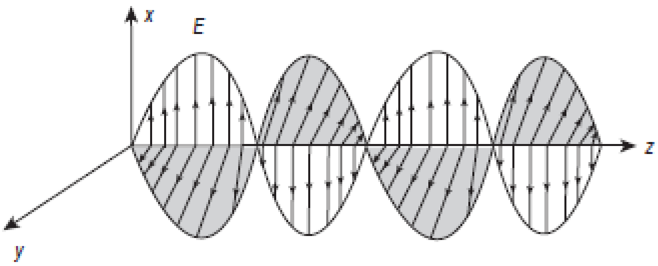
20. How are EM waves produced by oscillating charges?

Draw a sketch of linearly polarized em waves propagating in the Z-direction. Indicate the directions of the oscillating electric and magnetic fields.

Solution

EM waves are produced by oscillating electric and magnetic fields which are produced by oscillating charges. The electric and magnetic fields are perpendicular to each other and are perpendicular to the direction of propagation of wave.

The figure below shows a linearly polarized em wave propagating in Z-direction.



OR

Write Maxwell's generalization of Ampere's Circuital Law. Show that in the process of charging a capacitor, the current produced within the plates of the capacitor is

$$i = \varepsilon_0 \frac{d\phi_E}{dt}$$

where ϕ_E is the electric flux produced during charging of the capacitor plates.

Solution

Ampere's Circuital Law is given by

$$\oint \vec{B}.d\vec{l} = \mu_0 i$$

Modified Ampere's Circuital Law: Maxwell removed the problem of current continuity and inconsistency observed in Ampere's circuital law by introducing the concept of displacement current. Displacement current arises due to change in electric flux with time. As

$$i_d = \varepsilon_0 \frac{d\phi_E}{dt} \qquad \ldots\text{(i)}$$

Electric flux through loop

$$\phi_E = EA = \frac{\sigma}{\varepsilon_0} A = \frac{Q}{A}\frac{A}{\varepsilon_0} = \frac{Q}{\varepsilon_0}$$

Therefore, $$\frac{d\phi_E}{dt} = \frac{1}{\varepsilon_0}\frac{dQ}{dt}$$

$$\Rightarrow \frac{\varepsilon_0\, d\phi}{dt} = \frac{dQ}{dt}$$

$$\frac{dQ}{dt} = \text{Conduction current} = i_C$$

$$\frac{\varepsilon_0 d\phi}{dt} = \text{displacement current} = i_d \qquad \text{[From (i)]}$$

Therefore, $$i_c = i_d$$

Generalization of Ampere's circuital law is

$$\oint \vec{B}.d\vec{l} = \mu_0 (i_c + i_d)$$

21. (a) Explain any two factors which justify the need of modulating a low frequency signal.

(b) Write two advantages of frequency modulation over amplitude modulation.

Solution

(a) Two factors which justify the need of modulating a low frequency signal:

(i) Size of Antenna: The size of antenna required will be of order of $\lambda/4$. When frequency is small, the height of antenna will be large, so audio frequency signal should be modulated over a high frequency carrier wave.

(ii) Effective power radiated by an Antenna: As power radiated $\propto \frac{1}{\lambda^2}$, hence when frequency is increased then the power radiated will be more.

(b) Advantages of frequency modulation over amplitude modulation:

(i) Noise can be reduced.

(ii) Transmission efficiency is more.

22. (i) Write the functions of three segments of a transistor.

(ii) Draw the circuit diagram for studying the input and output characteristics of n-p-n transistor in common emitter configuration. Using the circuit, explain how input, output characteristics are obtained.

Solution

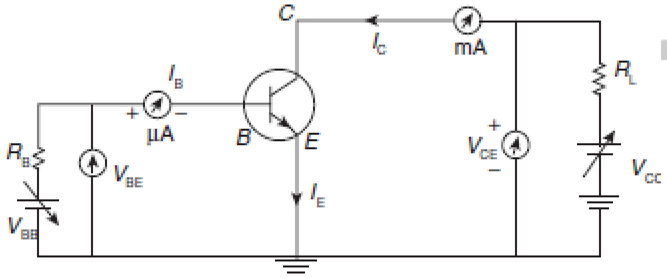
(i) Three segments of transistor are

a) Emitter: It is of moderate size and heavily doped, it supplies a large number of majority carriers which flow through the transistor.

b) Base: It is very thin and lightly doped and it separates emitter and collector region of transistor and controls the flow of charge carriers.

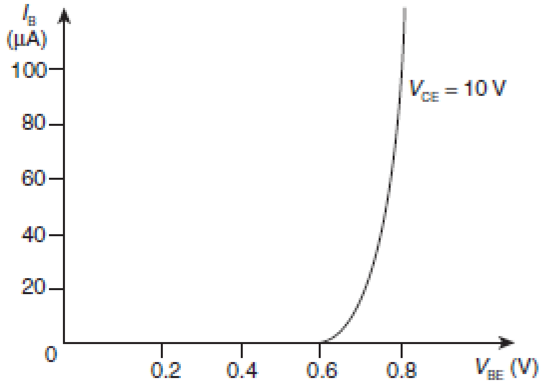
c) Collector: This segment is moderately doped and larger in size as compared to emitter. It collects a major portion of majority carriers supplied by the emitter.

(ii) Circuit diagram for studying the input and output characteristics of n-p-n transistor in common emitter configuration is as shown below:



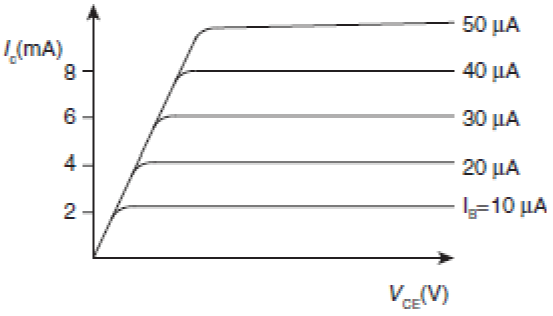
As shown in the figure, the base–emitter circuit is known as the input circuit, and the collector–emitter circuit is known as the output circuit. The input circuit is forward-biased using battery V_{BB} and the output circuit is reverse-biased using battery V_{CC}. In the figure, V_{BE} and V_{CE} represent the base–emitter voltage and the collector–emitter voltage, respectively. Variation of the input current with variation in the input voltage is called input characteristics. In this case, the input current is the base current (I_B) and the input voltage is the base–emitter voltage (V_{BE}). Similarly, variation of the output current with the output voltage is known as output characteristics. In this case, the output current is the collector current (I_C) and the output voltage is the collector–emitter voltage (V_{CE}). We know that the output current (I_C) is controlled by the input current (I_B), therefore, the output characteristics will be controlled by the input characteristics.

Input characteristics: A curve is plotted between the base current I_B and the base–emitter voltage V_{BE} to study the input characteristics of the transistor in CE configuration. The output voltage V_{CE} is kept constant while studying the variation of I_B on V_{BE}. To obtain the input characteristics when the transistor is in active state, the collector–emitter voltage V_{CE} is kept large enough so that the base–collector junction is reverse-biased.



For various V_{CE} values gives almost same curves.

Output Characteristics: The output characteristic is obtained by keeping input current I_B constant and observing the variation of I_C as V_{CE} is varied. With a small increase in V_{BE} both the hole current (in the emitter region) and the electron current (in the base region) will increase due to which both I_B and I_C will increase proportionately. This shows that when input current I_B increases, the output current I_C also increases. The graph between output current I_C and output voltage V_{CE} for different fixed values of input current I_B gives the output characteristic.



Different curves obtained for different values of V_{CE}.

SECTION – D

23. Meeta's father was driving her to the school. At the traffic light was made of many tiny lights instead of a single bulb. When Meeta asked this question to her father, he explained the reason for this.

Answer the following questions based on above information:

(i) What were the values displayed by Meeta and her father?

(ii) What answer did Meeta's father give?

(iii) What are the tiny lights in traffic signals called and how do these operate?

Solution

(i) Meeta is curious and a good observer. And, her father is patient, knowledgeable, has awareness about energy conservation, power saving and traffic rules.

(ii) Meeta's father said that these are LED lights which consume less power and high reliability.

(iii) The tiny lights in traffic signals are Light Emitting Diode (LED). These are operated by connecting the p–n Junction diode in forward biased condition.

SECTION – E

24. (i) Define the term drift velocity.

(ii) On the basis of electron drift, derive an expression for resistivity of a conductor in terms of number density of free electrons and relaxation time. On what factors does resistivity of a conductor depend?

(iii) Why alloys like constantan and manganin are used for making standard resistors?

Solution

(i) Drift velocity is defined as the average velocity with which free electrons get drifted towards the positive end of the conductor under the influence of externally applied electric field. It is given by

$$v_d = \frac{-eE\tau}{m}$$

where v_d is drift velocity, e is the charge on the electron, m is the mass of the electron, E is the electric field applied and τ is the average relaxation time.

(ii) Current flowing through a conductor is given by

$$I = nAev_d$$

$$= nAe\left(-\frac{eE\tau}{m}\right)$$

As, $$E = \frac{-V}{l}$$

$$I = nAe\left(\frac{eV\tau}{ml}\right) = \left(\frac{nAe^2\tau}{ml}\right)V = \left(\frac{1}{R}\right)V$$

$$I \propto V$$

and, $R = \dfrac{ml}{nAe^2\tau}$

$$R = \left(\frac{m}{ne^2\tau}\right)\frac{l}{A} = \rho\frac{l}{A}$$

$\rho = \dfrac{m}{ne^2\tau}$ = specific resistance or resistivity.

Its value depends on number of free electrons per unit volume and temperature.

(iii) Alloys like constantan and manganin are used to make standard resistors because

(a) they have high value of resistivity.

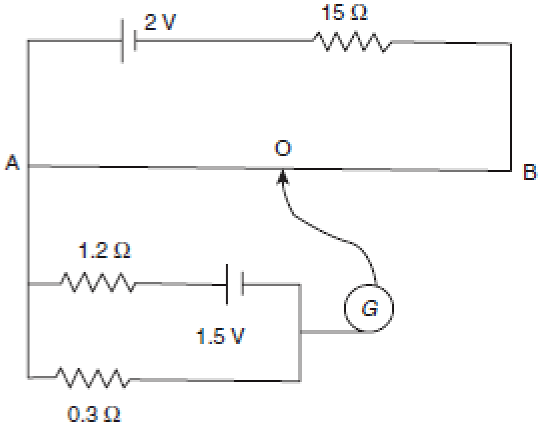
(b) their temperature coefficient of resistance is less.

(c) they are least affected by temperature.

OR

(i) State the principle of working of a potentiometer.

(ii) In the following potentiometer circuit AB is a uniform wire of length 1 m and resistance 10 Ω. Calculate the potential gradient along the wire and balance length AO (= *l*).



Solution

(i) The working of potentiometer is based upon the fact that fall of the potential across any portion of the wire is directly proportional to the length of the wire provided wire has uniform cross section area and constant current flowing through it.

(ii) Consider a length of wire l and current flowing through it is I. Cross section area is A and ρ is resistivity and R is resistance. Then we can say potential across the wire length is

$$V = IR = I\rho l/A = Kl$$

if I and A are constant then

$$V/l = K = constant,$$

which also called potential gradient that is fall of potential per unit length of wire.

(a) Current in the primary circuit, $I = E/(R + R_{\text{wire}}) = 2/(15+10) = 0.08$A
So, potential difference across AB = current × resistance of the wire = $0.08 \times 10 = 0.8$ Vo
So, potential gradient along AB = potential difference along AB /length of AB = 0.8 /1 = 0.8 V/m
(b) Current in the secondary circuit = 1.5 /(1.2 + 0.3) = 1 A
Terminal potential difference of the test cell = $E - (I \times r) = 1.5 - (1 \times 1.2) = 0.3$ V
Since length AO of the potentiometer balances the terminal potential difference of the test cell
so, $V_A - V_O$ = I × resistance of the length AO

$$\Rightarrow 0.3 = 1 \times R_{AO} \Rightarrow R_{AO} = 0.3 \text{ Ohm}$$

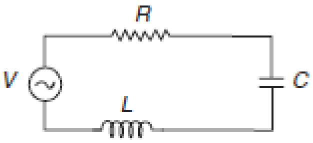
So, length of AO = V_{AO} / potential gradient along AB = 0.3/0.8 = 3/8 m =0.375 m

25. (i) An ac source of voltage $V = V_0 \sin \omega t$ is connected to a series combination of L, C and R. Use the phasor diagram to obtain expression for impedance of the circuit and phase angle between voltage and current. Find the condition when current will be in phase with the voltage. What is the circuit in this condition called?

(ii) In a series LR circuit $X_L = R$ and power factor of the circuit is P_1. When capacitor with capacitance C such that $X_L = X_C$ is put in series, the power factor becomes P_2. Calculate P_1/P_2.

Solution

Let a series LCR circuit connected to an ac source. It is given that

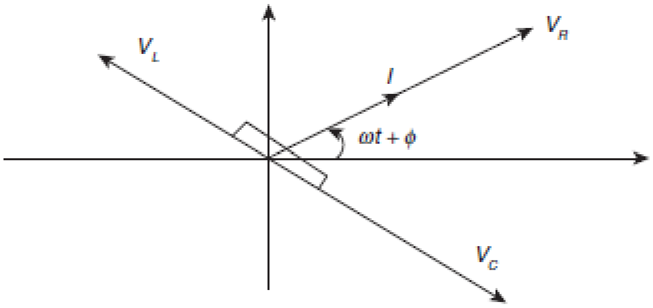


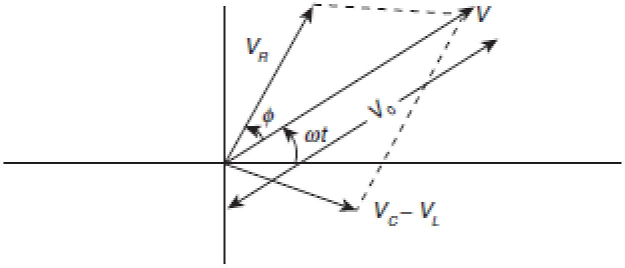
$$V = V_0 \sin \omega t$$

Since ac current is same in each element, so

$$I = I_0 \sin(\omega t + \phi)$$

Phasor diagram for *LCR* circuit





where V_L = Voltage across inductor; V_R = Voltage across resistor; V_C = Voltage across capacitor;

Since $V_C > V_L$

$$V_0^2 = V_R^2 + (V_C - V_L)^2$$

$$V_0^2 = (I_0 R)^2 + (I_0 X_C - I_0 X_L)^2$$

$$V_0^2 = I_0^2[R^2 + (X_C - X_L)^2]$$

$$\Rightarrow \; I = \frac{V_0}{\sqrt{R^2 + (X_C - X_L)^2}} \;\; \Rightarrow \; I_0 = \frac{V_0}{Z}$$

$$Z = \sqrt{R^2 + (X_C - X_L)^2} \text{ = impedance in AC circuit.}$$

Now, we can write

$$\tan\phi = \frac{V_\mathrm{L} - V_\mathrm{C}}{V_\mathrm{R}} = \frac{IX_\mathrm{L} - IX_\mathrm{C}}{IR},$$

which gives us the relation for phase constant of series *LCR* circuit as

$$\tan\phi = \frac{X_\mathrm{L} - X_\mathrm{C}}{R}$$

The current will be in phase with voltage if $X_L = X_C$,

$$\omega L = \frac{1}{\omega C}$$

$$\omega = \frac{1}{\sqrt{LC}} \quad \Rightarrow \;\; 2\pi\nu = \frac{1}{\sqrt{LC}}$$

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

(ii) As we know that power factor is given by

$$\cos\phi = \frac{R}{Z}$$

In given *LR* circuit,

$$P_1 = \cos\phi = \frac{R}{\sqrt{R_1^2 + X_L^2}} = \frac{R}{\sqrt{2R^2}} \qquad [\text{Since } X_L = R]$$

$$\Rightarrow\ P_1 = \frac{1}{\sqrt{2}}$$

In *LCR* circuit when $X_L = X_C$,

$$P_2 = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{R}{R} = 1$$

Therefore,
$$\frac{P_1}{P_2} = \frac{1}{\sqrt{2}}$$

OR

(i) Write the function of a transformer. State its principle of working with the help of a diagram. Mention various energy losses in this device.

(ii) The primary coil of an ideal step up transformer has 100 turns and transformation ratio is also 100. The input voltage and power are respectively 220 V and 1100 W. Calculate

(a) number of turns in secondary

(b) current in primary

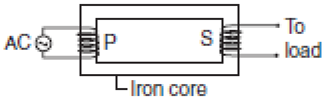
(c) voltage across secondary

(d) current in secondary

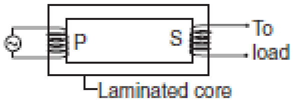
(e) power in secondary

Solution

(i) **Principle:** It works on the principle of mutual induction, that is, when a charging current is passed through one of two inductively coupled coils, an induced emf is set up in other coil.



Step up transform



Step down transform

(ii) Given that $N_p = 100$; $V_p = 220$ V; $P_p = 1100$ W

(a) Turns ratio, $K = \dfrac{N_s}{N_p} \Rightarrow 100 = \dfrac{N_s}{100} \Rightarrow N_s = 10000$

(b) Since $P_p = V_p$. Therefore, current in primary

$$I_p = \frac{P_p}{V_p} = \frac{1100}{220} = 5\text{A}$$

(c) Turns ratio, $K = \dfrac{V_s}{V_p} \Rightarrow 100 = \dfrac{V_s}{220} \Rightarrow V_s = 22000$ V

(d) Turns ratio, $K = \frac{I_p}{I_s} \Rightarrow 100 = \frac{5}{I_s} \Rightarrow I_s = 0.05$ A

(e) Power in secondary, $P_s = V_s I_s$

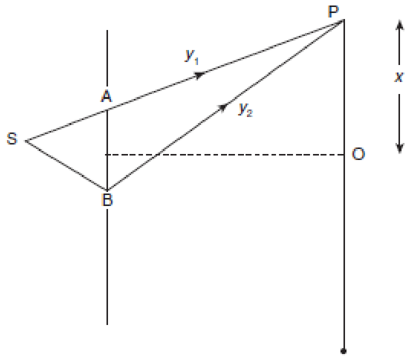
$$\Rightarrow P_s = 22000 \times 0.05 = 1100 \text{ W}$$

26. (i) In Young's double slit experiment, deduce the condition for (a) constructive, and (b) destructive interference at a point on the screen. Draw a graph showing variation of intensity in the interference pattern against position '*x*' on the screen**.**

(ii) Compare the interference pattern observed in Young's double slit experiment with single slit diffraction pattern, pointing out three distinguishing features.

Solution

(i)



Let amplitude of waves arising from slits A and B be *a* and *b* respectively and let their phase difference be ϕ

Therefore, $y_1 = a \sin \omega t$

$$y_2 = b\sin(\omega t + \phi)$$

Displacement is given by

$$y = y_1 + y_2$$

$$= a\sin\omega t + b\sin(\omega t + \phi)$$

$$= a\sin\omega t + b\sin\omega t\cos\phi + b\cos\cot\sin\phi$$

$$= (a + b\cos\phi)\sin\omega t + b\sin\phi\cos\omega t \qquad \text{(i)}$$

Let $a + b\cos\phi = A\cos\delta$ …(ii)

and $b\sin\phi = A\sin\delta$ …(iii)

Putting these in (i)

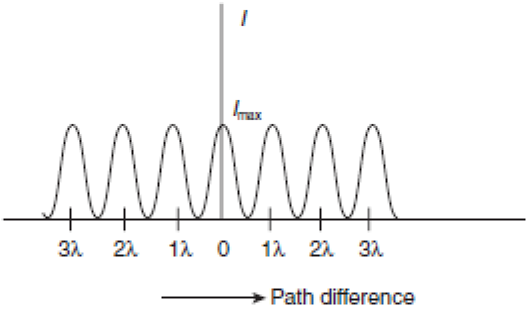
$$y = A\sin\omega t\cos\delta + A\cos\omega t\sin\delta$$

$$y = A\sin(\omega t + \delta)$$

Amplitude of resultant wave is

$$A = \sqrt{a^2 + b^2 + 2ab\cos\phi}$$

And $\tan\delta = \frac{b\sin\phi}{a + b\cos\phi}$ [from (ii) and (iii)]



(a) For constructive interference,

Intensity $I \propto A^2$ and for A to be maximum, the below condition must be satisfied

$$\cos\phi = 1$$

or, $$\phi = 2n\pi$$

and path difference, $\Delta x = n\lambda$, so

$$A_{max} = a + b$$

$$I_{max} = k(a + b)^2$$

(b) For Destructive Interference, condition to be satisfied is

$$\cos\phi = -1$$

Phase difference, $\Delta\phi = (2n+1)\pi$

and, path difference $= \Delta x = (2n+1)\dfrac{x}{2}$

$$A_{min} = a - b$$

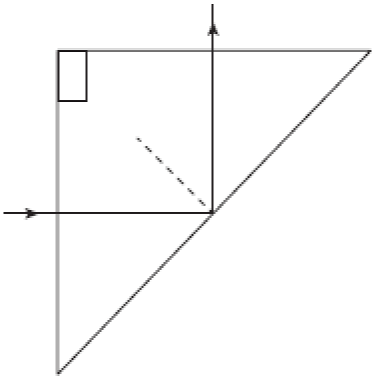
Therefore, $$I_{min} = k(a - b)^2$$

OR

(i) Plot a graph to show variation of the angle of deviation as a function of angle of incidence for light passing through a prism. Derive an expression for refractive index of the prism in terms of angle of minimum deviation and angle of prism.

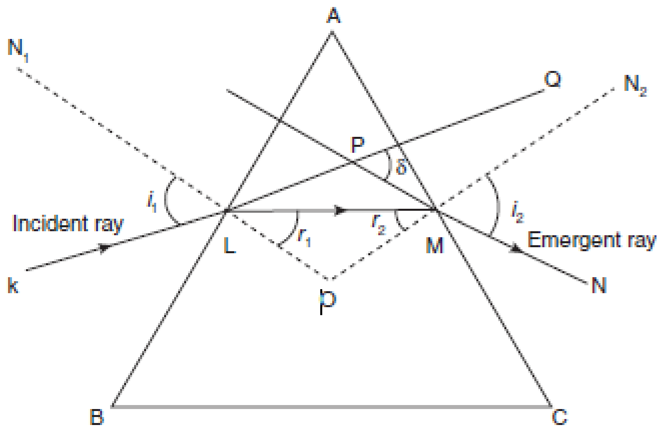
(ii) What is dispersion of light? What is its cause?

(iii) A ray of light incident normally on one face of a right isosceles prism is totally reflected as shown in fig. What must be the minimum value of refractive index of glass? Give relevant calculations.



Solution

(i)



Calculation for angle of Deviation:

In ΔPLM,

$$\delta = \angle PLM + \angle PML$$

$$\delta = (i_1 - r_1) + (i_2 - r_2)$$

$$\delta = (i_1 + i_2) - (r_1 + r_2)$$

In ΔOLM,

$$\angle O + r_1 + r_2 = 180^\circ \qquad \ldots(1)$$

In quadrilateral ALOM,

$$\angle L + \angle M = 180^\circ \text{ (each angel is 90°)}$$

$$A + \angle O = 180^\circ \text{ (sum of opp. Angle of cyclic quadrilateral)}$$

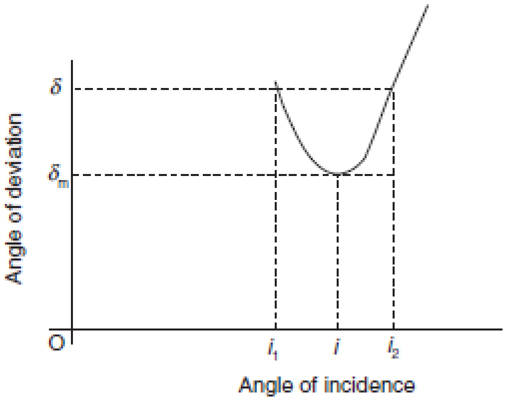
Putting in equation (1),

$$\angle O + r_1 + r_2 = \angle A + \angle O$$

$$\Rightarrow r_1 + r_2 = \angle A$$

Therefore, $$\delta = (i_1 + i_2) - A$$

Graph showing variation of the angle of deviation as a function of angle of incidence for light passing through a prism is as shown below.



Now, if angle of minimum deviation = δ_m, then

$$\delta_m = i + i - A$$

$$\Rightarrow i = \frac{\delta_m + A}{2}$$

According to Snell's law

$$\mu = \frac{\sin i}{\sin r}$$

where, μ is the refractive index of material of prism.

$$\mu = \frac{\sin(A+\delta_m)/2}{\sin A/2}$$

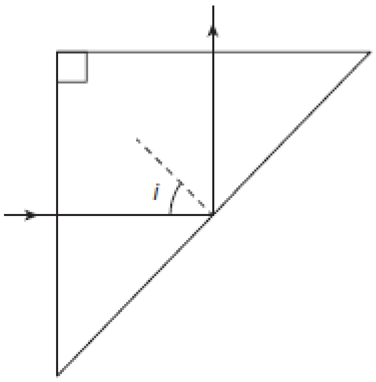
(ii) The separation of visible light into its different constituent colors is known as dispersion. These colors are often observed as light passes through a triangular prism. Upon passing through the prism, the white light is separated into its component colors– red, orange, yellow, green, blue, indigo and violet. Dispersion occurs because for different color of light a transparent medium will have different reflective indices (n).

(iii) For total internal reflection to occur,

$$i > \theta_c$$

or

$$\sin i > \sin \theta_c$$



When a ray of light incident normally on one face of a right isosceles prism is totally reflected as shown in figure, then angle of incidence i = 45°, therefore,

$$\sin 45° > \frac{1}{n}$$

$$\frac{1}{\sqrt{2}} > \frac{1}{n}$$

$$n = \sqrt{2}$$

$$\Rightarrow n_{\min} = \sqrt{2}$$