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Q21. An electron and a photon each have a wavelength 1.00 nm. Find

i. Their momentum.
ii. The energy of the photon and
iii. The kinetic energy of electron.

Answer: Given $\lambda = 10^{-9}\text{m}$

i. For electron or photon's momentum,

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{10^{-9}} = 6.63 \times 10^{-25}\ \text{kg m/s}$$

ii. $E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})\times(3\times10^{8})}{10^{-9}\times(1.6\times10^{-19})} = 1243$ eV [1 eV= 1.6×10^{-19} Joule]

iii. $E_k = \frac{1}{2}\frac{p^2}{m}$

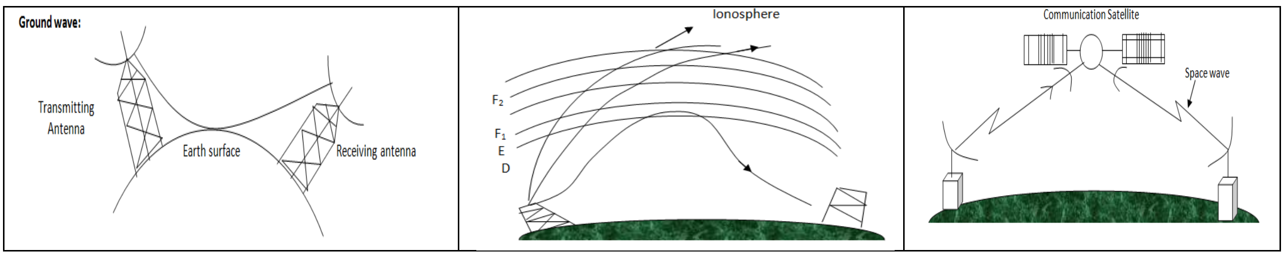
$$= \frac{1}{2}\frac{(6.63\times10^{-25})^2}{9\times10^{-31}\times(1.6\times10^{-19})}$$

$= 1.52$ eV. [1 eV= 1.6×10^{-19} Joule]

Q22. Draw a schematic diagram showing the (I) ground wave (II) sky wave and (III) space wave propagation modes for Electromagnetic waves. Write the frequency range for each of the following:

i. Standard AM broadcast
ii. Television
iii. Satellite communication

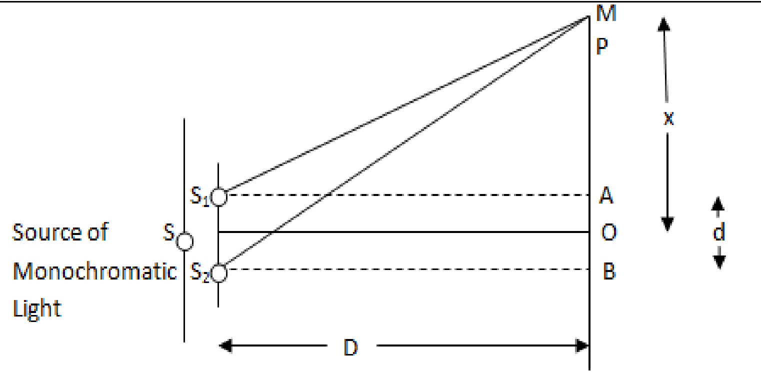
Answer:



i. Standard AM broadcast – 540 – 1600 kHz
ii. Television 54-890 MHz
iii. Satellite communication 5.925 – 6.425 GHz Uplink, 3.7-4.2 GHz Downlink

Q23. Describe Young's double slit experiment to produce interference pattern due to a monochromatic source of light. Deduce the expression for the fringe width.

Answer:



Light waves coming out from S incident on both slit S_1 and S_2. The spherical waves from S_1 and S_2 being coherent source of light will produce interference fringes on the screen M.

In right angle Δ S_1 AP, we have

$(S_1P)^2 = (S_1A)^2 + (AP)^2$

$S_1P = \sqrt{D^2 + (x - \frac{d}{2})^2} = \sqrt{D^2[1 + \frac{(x-\frac{d}{2})^2}{D^2}]}$

$S_1P = D\left[1 + \frac{(x-\frac{d}{2})^2}{D^2}\right]^{\frac{1}{2}}$

By Binomial Theorem and neglecting higher terms, we have

$S_1P = D\left[1 + \frac{1}{2}\frac{(x-\frac{d}{2})^2}{D^2}\right] = D + \frac{(x-\frac{d}{2})^2}{2D}$

Similarly $S_2P = D + \frac{(x+\frac{d}{2})^2}{2D}$

Hence path difference = S_2 P – S_1 P

$= D + \frac{(x+\frac{d}{2})^2}{2D} - D - \frac{(x-\frac{d}{2})^2}{2D}$

$= \frac{1}{2D}\left[x^2 + \frac{d^2}{4} + xd - x^2 - \frac{d^2}{4} + xd\right]$

$= \frac{1}{2D} . 2xd = \frac{xd}{D}$

Now the intensity at point P is maximum or minimum according as the path difference is an integral multiple of wavelength or an odd integral multiple of half wavelength.

(i) **For bright fringe (constructive interference):** We will have constructive interference resulting in a bright fringe when path difference = nλ

$\frac{xd}{D} = n\lambda \Rightarrow x = \frac{n\lambda D}{d}$

$\therefore\ x_n = \frac{n\lambda D}{d}$, where n=0, $\pm$ 1, $\pm$2, … …

Since the separation between the centres of two consecutive bright fringes is called **fringe width**. It is denoted by β.

$\therefore\ \beta = x_{n+1} - x_n$

$or, \beta = \frac{(n+1)\lambda D}{d} - \frac{n\lambda D}{d} = \frac{\lambda D}{d}$ (n+1-n)

$\therefore\ \beta = \frac{\lambda D}{d}$

(ii) **For dark fringe (destructive interference):** We will have destructive interference resulting in a dark fringe when path difference = (2n + 1) $\frac{\lambda}{2}$

$\frac{xd}{D} = (2n+1)\frac{\lambda}{2} \Rightarrow x = \frac{(2n+1)\lambda D}{2d}$

$\therefore\ x_n = \frac{(2n+1)\lambda D}{2d}$, where n=0, $\pm$ 1, $\pm$2, … …

Fringe width, $\beta = x_{n+1} - x_n$

$= \frac{[2(n+1)+1]\lambda D}{2d} - \frac{(2n+1)\lambda D}{2d}$

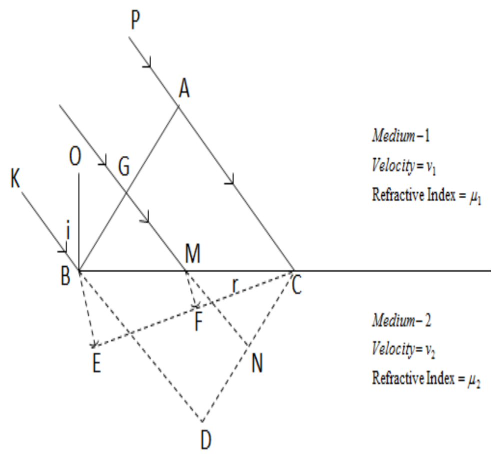
$= (2n+2+1-2n-1)\frac{\lambda D}{2d} = \frac{2\lambda D}{2d}$

$\therefore\ \beta = \frac{\lambda D}{d}$

Hence all bright and dark fringes are of equal width.

Or

Use Huygens's principle to verify the laws of refraction



BC is the section of the refracting surface by the plane of the paper i.e. the out face, separating two media of refractive indices μ_1 and μ_2 ($\mu_1 < \mu_2$)
AB is the section of the incident plane wave front by the plane of the paper at an
instant of time t=0
Both the refracting surface and the plane wave front are perpendicular to the plane of the paper.

v_1 & v_2 = Velocity of light in medium-1 and medium-2 respectively.

PA and KB are perpendiculars dropped on the incident wave front AB and hence they are the incident rays. BO is normal drawn at B on the refracting surface.

$$\angle KBO = i = \text{angle of incidence}$$
$$\angle KBA = 90 \quad \therefore \angle OBA = 90 - i$$
$$\angle OBC = 90 \quad \therefore \angle ABC = 90 - (90 - i) = \text{i}$$

Hence angle of incidence can also be defined as the angle between the incident wave front

and the refracting surface. Similarly the angle of refraction can also be defined as the angle between the refracted wave front and the refracting surface.

Had the two medium been same, then the rays from the point G & B would have gone up to N & D respectively during the time t in which ray from a goes up to C so that

$$AC = GN = BD = v_1 t \qquad (1)$$

Hence CND would have been the position of the wave front after time t. But since the two medium are different let the ray from B go up to E in time t. So that

$$t = \frac{AC}{v_1} = \frac{BE}{v_2} \rightarrow (2)$$

With B as center and BE as radius we imagine a sphere the section of which by the plane of the paper gives an arc of a circle. CE is drawn tangential to that rc. Then a plane through CE and perpendicular to the plane of the paper would represent the refracted wave front after time t provided we can show that ray from any other point G on the incident wave front also touches the plane through CE after time t.To prove it, from M, MF is drawn perpendicular to CE.

ΔBDC & ΔMNC are similar $\therefore \frac{BD}{MN} = \frac{BC}{MC} \to (3)$

ΔBEC & ΔMFC are similar $\therefore \frac{BE}{MF} = \frac{BC}{MC} \to (4)$

From (3) & (4) $\frac{BD}{MN} = \frac{BE}{MF}$

Putting equation (1) & (2) $\frac{v_1 t}{MN} = \frac{v_2 t}{MF}$ or $\frac{MF}{v_2} = \frac{MN}{v_1}$

That is time taken to go from M to F in medium 2 and time taken to go from M to N in medium 1 is same.
Hence the time taken by the light to go from G to M + M to N is same as the time taken to go from G to M + M to F i.e. from G to F.
Hence CE is the refracted wave front after time t.

$\therefore \angle BCE$ = angle between the refracting surface and the refracted wave front = angle of refraction = r (using definition)

We now prove Snell's law :

From ΔABC : $\sin i = \frac{AC}{BC}$

From ΔABC : $\sin r = \frac{BE}{BC}$

$$\therefore \frac{\sin i}{\sin r} = \frac{AC/BC}{BE/BC} = \frac{AC}{BE}$$

Putting equation (1) and (2) : $\frac{\sin i}{\sin r} = \frac{v_1 t}{v_2 t}$

$$\frac{\sin i}{v_1} = \frac{\sin r}{v_2}$$

Multiplying both sides by v_0 where v_0 is the velocity of light in vacuum.

$$\frac{v_0}{v_1}\sin i = \frac{v_0}{v_2}\sin r$$

$\mu_1 \sin i = \mu_2 \sin r$ First law proved

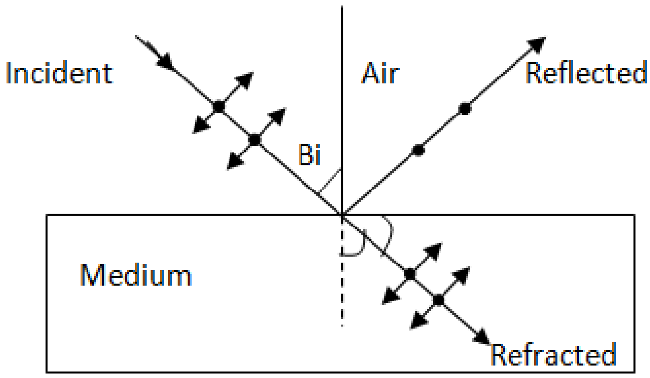
From the nature of construction it is evident that the incident ray refracted ray & normal at the point of incidence all lay on the same plane i.e. on the plane of the paper.

Q24.

a. Describe briefly, with the help of suitable diagram, how the transverse nature of light can be demonstrated by the phenomenon of polarization.
b. When unpolarized light passes from air to a transparent medium, under what condition does the reflected light get polarized?

Answer:

i. Transverse nature of light through Polarization**:**



The independent light waves whose planes of vibrations are randomly oriented about the direction of propagation are said to be unpolarized light. When unpolarized light is incident on the boundary between two transparent media, the reflected light is polarized with electric vector perpendicular to the plane of incidence when the refracted and reflected rays make a right angle with each other. Whenever unpolarized light is incident from air to a transparent medium at an angle of incidence equal to polarizing angle, the reflected light gets polarized as shown in the diagram above. Thus Light can be polarized by reflecting it from a transparent medium. The extend of polarization depend on the angle of incidence, called Brewster's angle.

ii. Whenever the reflected and refracted rays are perpendicular to each other.

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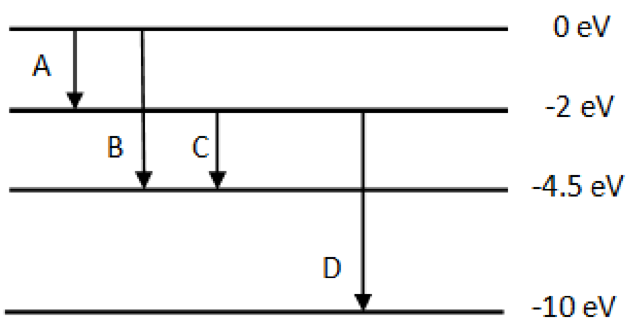
Q25. The energy levels of a hypothetical atom are shown below. Which of the shown transitions will result in the emission of a photon of wavelength 275 nm?
Which of these transitions correspond to emission of radiation of (I) maximum and (II) minimum wavelength?



We know that energy emitted E = hc/λ

Given: λ = 275nm=275X10^{-9} m

$$E = \frac{6.63\times10^{-34}x3x10^{8}}{275X10^{-9}x1.6X10^{-19}} = 4.5eV$$

I. Element A has corresponds to maximum wavelength (621 nm).

II. Element D has corresponds to minimum wavelength (155 nm).

Q26. State the law of radioactive decay.

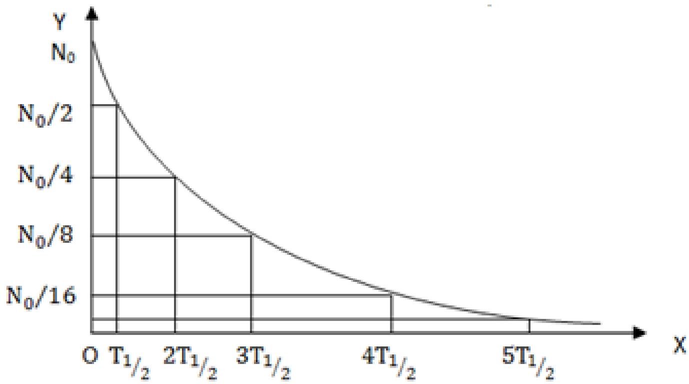
Plot a graph showing the number (N) of undecayed nuclei as a function of time (t) for a given radioactive sample having half life $T_{1/2}$.

Depict in the plot the number of undecayed nuclei at (i) $t = 3\,T_{1/2}$ and (ii) $t = 5\,T_{1/2}$.

Answer: Radioactive decay law**:** The number of atoms disintegrated per second at any instant is directly proportional to the number of radioactive atoms actually present at that time.

$$-\frac{dN}{dt} \propto N \ or \ -\frac{dN}{dt} = \lambda N$$

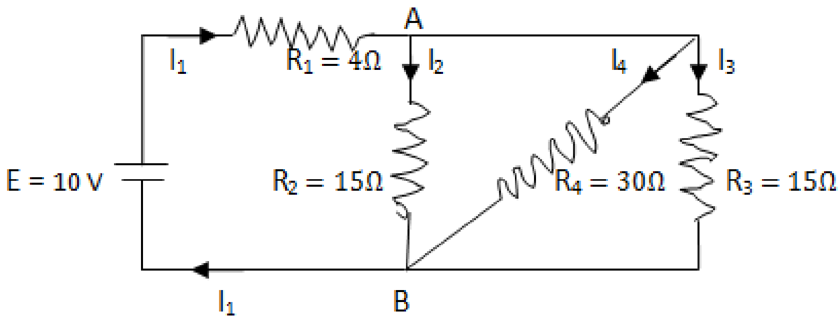
Graph:



Taking number of atoms along Y axis and time along X axis following we find following trend plotted.

The un-decayed nuclei at (i) $t = 3\,T_{1/2}$ and (ii) $t = 5\,T_{1/2}$ marked

Q27. In the circuit shown, $R_1 = 4\ \Omega,\ R_2 = R_3 = 15\ \Omega,\ R_4 = 30\ \Omega$ and $E = 10\ V$. Calculate the equivalent resistance of the circuit and the current in each resistor.



Answer: R_2, R_3 and R_4 are in parallel combination.

$$\frac{1}{R_{234}} = \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{15} + \frac{1}{30} + \frac{1}{15} = \frac{1}{6}$$

$$R_{234} = 6\ \Omega$$

R_{234} and R_1 are in Series

$$R_{1234} = R_{234} + R_1 = 6 + 4$$

$$R_{1234} = 10\ \Omega$$

$$I = \frac{E}{R_{1234}} = \frac{10}{10} = 1\ A$$