Course Module for B.Tech students

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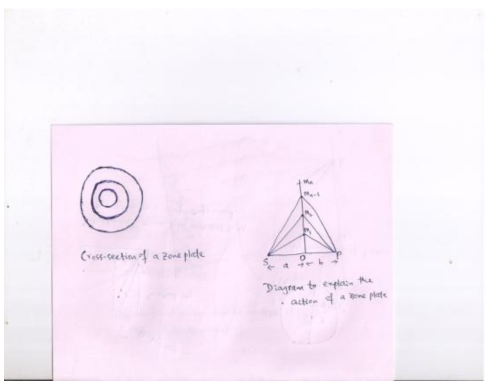
Lecture No 1

Zone Plate

Let PQ be a zone plate .S is the point source of light and S' is the point on the screen where a bright spot is observed due to the action of the zone plate.Light from the source S reaches the point s'through the nth and (n01)th zone of the zone plate through the paths SAS' and SAn-1S'.Let r is the



radius of the zone plate.

Figure

$SA_n = (a^2 + r_n^2)^{\frac{1}{2}} = a + \frac{r_n^2}{2a}$

and$A_nS' = b + \frac{r_n^2}{2b}$

Similarly, $SA_{n-1} = a + \frac{r_{n-1}^2}{2a}$

and $A_{n-1}S' = b + \frac{r_{n-1}^2}{2b}$

The path difference between the two rays reaching A and A n-1 can be calculated as

$SA_n S' - S A_{n-1} S' = \frac{r^2}{2}\left[\frac{1}{a}+\frac{1}{b}\right]$

Or, $\frac{n\lambda}{2} = \frac{r^2}{2}\left[\frac{1}{a}+\frac{1}{b}\right]$

This shows that the path difference between the half period zones ($\frac{n\lambda}{2}$) can be written as a lens formula and the radii of the zone plate are directly proportional to the square root of the natural numbers.

$r_1 = r\sqrt{1}$ (radius of the 1st zone plate)

$r_2 = r\sqrt{2}$ (radius of the 2nd zone plate)

$r_3 = r\sqrt{3}$ (radius of the 3rd zone plate)

$r_n = r\sqrt{n}$ (radius of the nth zone plate)

This implies that the radius of a zone plate is proportional to the square root of natural number.

Lecture No 2

Plane of polarisation and plane of vibration of plane polarised light

An ordinary light consists of large number of transverse waves where the the vibrating particles are transverse to the plane of propagation.There are two sets of vibrations i.e. one vibrates in one plane and the other at right angle to it.The vibrations in either case are considered to be distributed over all possible planes containing the ray, so that in polarised light ,if the vibrations are linear then it is known as plane polarised. If the vibrations are circular ,it is called circularly polarised and if the vibrations are elliptical ,the light is elliptically polarised.Circular and elliptical polarised lights are the result of two plane polarised lights having a phase difference of π/2.

circularly polarised light from a beam of unpolarised light

An unpolarised light can be decomposed into ordinary and extra ordinary rays with a phase difference between them.

$X = A \cos\theta \sin(wt+\delta)$

Y= A sin θ sin wt

Taking A cos θ=a and A sin θ= b

X= a sin (wt+δ) or , X/a = sin wtcosδ+coswtsinδ 1

Y=b sin wt or, Y/b = sin wt 2

From equations 1 &2 ,we will get $\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{2xy}{ab}\cos\delta = sin^2\delta$ 3

Figure

When δ = (2n+1)π/2, n=0,1,2,…………

Sin δ=1 and cos δ= 0

Equation 3 will be reduced to

$X^2+y^2 = a^2$ for a=b which is equation to a circle of radius a implies that the emergent light is circularly polarised.

Lecture No 3

Plane diffraction grating

Ans. A diffraction grating is a plane glass plate on which number of parallel, equidistant lines are drawn with the help of a diamond pen. The lined portion being opaque and the spacing between the lines are transparent to the incident light. A plane diffraction grating is the combined effect of N number of parallel slits.

Let a plane wavefront of monochromatic light be incident normally on the grating. The width of each slit be **c** and the separation between any two consecutive slits be denoted as **d.**

When a plane wavefront is incident normally on the grating, each point on the slit sends out secondary wavelets in all directions. The secondary wavelets in the same direction as of incident light will come to focus at o which is the point of central maximum.The secondary wavelets diffracted along a direction to meet the screen posses different phases. Therefore dark and bright bands are obtained on both sides of the central maximum.

Let S_1, S_2,S_3..... be the mid points of the corresponding slits and S_1M_1, S_2M_2 … be the perpendiculars drawn.The path difference between the waves emanating from points S_{n-1} and S_n is

S_nM_{n-1} = (c+d) sinθ

The corresponding phase difference is given by

$$\Phi = \frac{\pi}{\lambda}(c+ d) \sin \theta$$

For single slit case, the amplitude at p is found to be

$$A = A_0\frac{\sin\propto}{\propto}$$

The resultant of the waves coming from N number of slits is

$$Y = A \sin wt + A \sin (wt + \phi)+ A \sin (wt + 2\phi)+ \ldots\ldots\ldots$$

$$= A\, e^{iwt} \left[\frac{1-e^{iN\varphi}}{1-e^{i\varphi}}\right]$$

Intensity due to the resultant waves (I)= $A_2\frac{sin^2\frac{N\emptyset}{2}}{sin^2\frac{\emptyset}{2}}$

For principal maxima we have

$$\Phi = \pm n \pi$$

Or, $\frac{\pi}{\lambda}(c+ d) \sin \theta = \pm n \pi$

$$(c+ d) \sin \theta = \pm n \lambda$$

In the diffraction pattern obtained by using plane diffraction grating and monochromatic light,few spectral lines are absent. 4

The condition for the principal maxima for nth order spectrum for a plane diffraction grating is

$$(a+ b) \sin \theta = n\lambda \qquad (1)$$

And the condition for minima due to a single slit is

$a \sin \theta = m \lambda$ (2)

Dividing equation (1) by equation (2)

$\frac{(a+b)}{a} = \frac{n}{m}$

When **a = b**, n=2m

So 2^{nd},4^{th},6^{th}…..orders of the spectra will be missing corresponding to the minima given by m=1,2,3

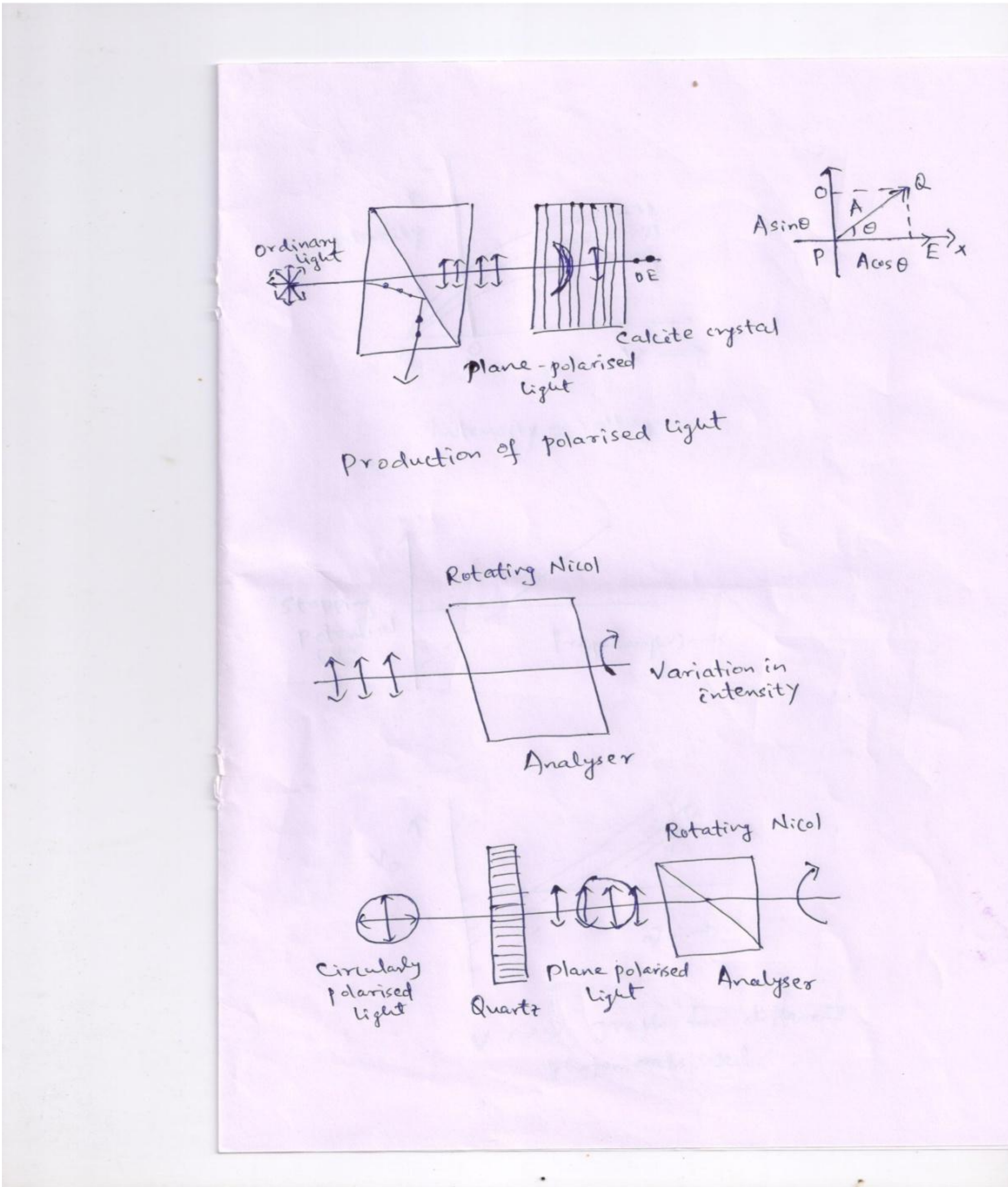
If **b=2a** then n = 3m

So that 3^{rd},6^{th},9^{th}….orders of the spectra will be missing corresponding to the minimas given by m= 1,2,3

Lecture No 4

Differences among plain polarized,circularly polarised,elliptically polarised and unpolarised light.

If the vibrations are along the direction of propagation of a polarised light, then it is known as plane polarised .We can get a plane polarised light by reflection, by transmission through a pile of plates, by double refraction, by selective absorbtion and by scattering.The intensity of the emergent light varies from maximum to minimum twice when it is passed through a nicol prism.

figure 

When the vibrations are scattered in a circular form then it is known as a circularly polarised light.To detect a circularly polarised light, it is first passed through a quarter wave plate and then viewed through a rotating Nichol.Firstly it is converted into a plane polarised light by the quarter wave plate. Then it will show variation in intensity from maximum to zero minimum twice by passing through a Nichol prism.

When the variation of the vibrating particles comes ain an elliptical form then it is known as aelliptically polarised light.If elliptically polarised light beam is passed through a rotating Nichol the intensity of emergent light varies from maximum to minimum.The minimum intensity never be zero.To detect elliptically polarised light, the beam is first passed through a rotating Nichol.In case the beam is elliptically polarised, it will be converted into plane one by quarter wave plate. Then the change in intensity will be observed by passing through a rotating Nichol.

When a ray is incident at an angle 59^0 on a glass slab,refracted ray and reflected ray are found to be perpendicular to each other.Calculate the polarising angle and refractive index of the glass.

$I_i = 59^0$

$I_p = 31^0$

Refractive index = $\tan^{-1}(I_p)$

Lecture No 5

Characteristics of a quantum mechanical wave function

(i) The wave function has both real and imaginary parts.Hence it is complex in nature.

(ii) The wave function is continuous and differential.

(iii) The w.f. Ψ obeys the boundary conditions.

(iv) The w.f .isnormalizable .

(v) The mod square of the wave function represents the probability of finding a particle in a quantum mechanical system.

Heisenberg's uncertainty principle with an example:

According to Heisenberg's uncertainty principle, any pair of conjugate physical variables can not be measured accurately and simultaneously. Position & momentum; energy& time; angle and angular momentum are the main pair of physical variables. If momentum is specified ,clearly defined then the uncertainty lies with the position. Similarly energy & time can't be measured simultaneously and accurately. Mathematically,

$\Delta x \,.\, \Delta p_x \approx \hbar$

$\Delta E \,.\, \Delta t \approx \hbar$

$\Delta\theta.\ \Delta J_z \approx ђ$

The most common example where Heisenberg's uncertainty relation applied is the non existence of electron inside the nucleus.

The diameter of a particle $\approx$ 2 fermi

The uncertainty in momentum $\approx$ ђ/2

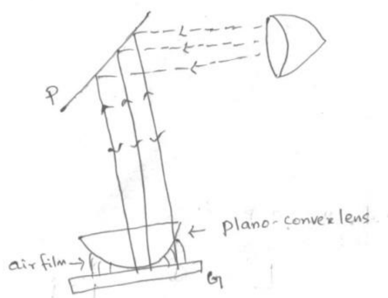
The energy $\approx \frac{ђ^2}{4m}$

The energy of an electron is found to be more compared to the binding energy of the proton and netron inside the nucleus.So an electron can't remain inside a nucleus.

Lecture No 6

Newton''s interference pattern

Newton's interference occurs due to the superposition of two reflected or transmitted rays.There is a thin air film present in between the lower part of the plano convex lens and the upper part of the plane glass plate.The point of contact of the plane glass plate & plano convex lens acts as the centre of the ring pattern.



Interference by Newton's Ring set up

Let the radius of the nth ring is OD = OC = r_n as shown in the diagram.The thickness of the air film at D is t. In the figure two chords AA'and FO intersecting at O.Then

AE . A'É = FE . OE

Or, r_n^2= (2R-t) .t

R is the radius of curvature of the plano convex lens.Since for all practical purposes, t«R

$$r_n^2 = 2Rt$$

The path difference between the two rays ,one reflected from P and another from Q is

=2 ηtcos r=2ηt since the incidence is normal here so r=0.As one of the rays travels from denser to rarer medium so an additional path difference of λ/2 is introduced.So total path difference is 2ηt+λ/2

$D_n^2 = 2R(2n-1)\lambda$for bright rings

$D_n^2 = 4Rn\lambda$for dark rings

By taking n=5, we can determine the diameter for the 5th ring both for bright and dark rings when the values of R & λ are given.

Method to determine the wavelength of light using Newton's rings.

When a parallel rays of monochromatic light fall on a glass plate which is inclined at an angle 45^0 to the incident rays,then the rays get reflected and transmitted to the plano convex lens placed on a plane glass plate.Interference occur btween the light rays getting reflected from the lower and upper portion of the air film placed in the space between the plano convex lens and the glass plate.

Lecture No.7

Similarities and dissimilarities between a zone plate and a convex lens. 3

Zone plate and convex lens are used for both real as well as virtual images.

b)Zone plate & convex lens are both optical devices.

c)Zone plate is used in diffraction phenomena while convex lens in used in convergence

phenomena.

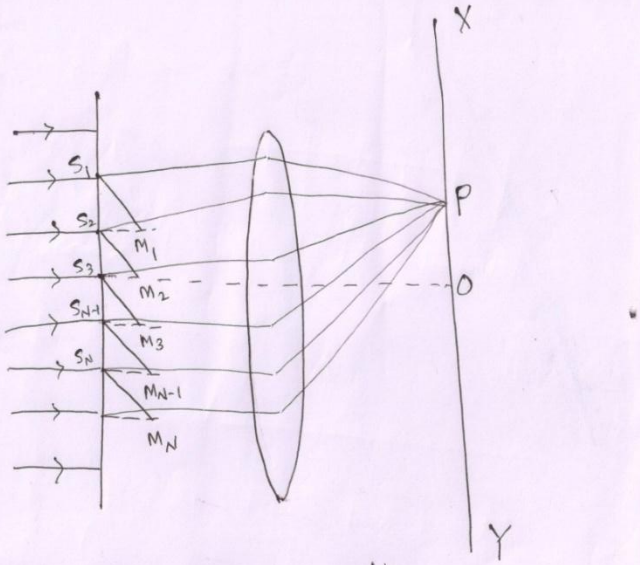
d) Both zone plate & convex lens used for lens formulae

e)Zone plate has multiple foci compared to that of a convex lens.

An expression for the angular width of the central maximum in a single slit Fraunhoffer diffraction pattern.

Figure

S is a source of monochromatic light.L is the converging lens.According to the Huygen's theory, each point on the wavefront is asource of secondary disturbance and the secondary waves travelling along the distances XQ and YQ'meet at P, centre of the screen.The secondary waves from points equidistant from O and situated in the upper and lower half OX and OY of the wavefront travel the same distance in reaching at P.Hence the path difference between them is zero. Therefore at P ,a bright fringe is observed and the intensity is maximum.



plane diffraction grating
(Fraunhofer diffraction due to multiple slits)

Let us consider the secondary waves travelling along the directions XR and YR'.This makes an angle θ with the central axis OP.All the secondary waves travelling in this direction will meet the screen at P'.

Considering the tringle ΔXYL , sin θ = XL/XY=XL/a or, XL=a sin θ

Where a is the width of the slit. Θ is the angle of diffraction.

The whole wavefront is considered to be of two halves OX and Oy. The path difference between the secondary waves from X and O is λ/2.For every point in the upper half OX, there is a corresponding point in the lower half OY and the path difference between the secondary waves from these points is λ/2.

The general condition for maximum intensity at point P on the screen is

$a \sin \theta_n = (2n+1) \lambda/2$

And the condition for minimum at P'point on the screen is

$a \sin \theta_n = n\lambda$

Thus the diffraction pattern due to a single slit consists of a central bright maximum at p followed by secondary maxima and minima on both sides of the central maxima.

Width of the central maxima :

Let the lens L_2 is very near the slit or the screen is far from the lens.Then

OP' = focal length of the lens $L_2 = f$

From ΔOPP' , $\sin \theta = x/f$

Where x is the distance between the central maxima and first secondary minima

But $\sin \theta = \lambda/a$

So $x/f = \lambda/a$ or $x = (f\lambda)/a$

The width of the central maxima$(2x) = 2f\lambda/a$

We see that the width of the central maxima is

a)Proportional to λ. For red light (longer wavelength) the width of the central maxima is more

b)For narrow slit,it is more

c)For white light, the central maxima is white but the rest of the diffraction bands are coloured.

d)From the relation $\sin \theta = \lambda/a$, it is clear that if ''a'' is large, then $\sin\theta$ is small.Then maxima and minima are very close to the central maxima. Distinct diffraction fringe pattern on both sides of the central maxima are observed.

A plane transmission grating having 5000 lines/cm diffracts monochromatic light of wavelength 5000A.Find out the angle of diffraction for the 2^{nd} order maximum.

Using the formula for the plane diffraction grating i.e.

$(c+d) \sin \theta = n\lambda$, θ is the angle of diffraction

$(c+d)=5000$lines/cm, $\lambda=5000A$ $n = 2$

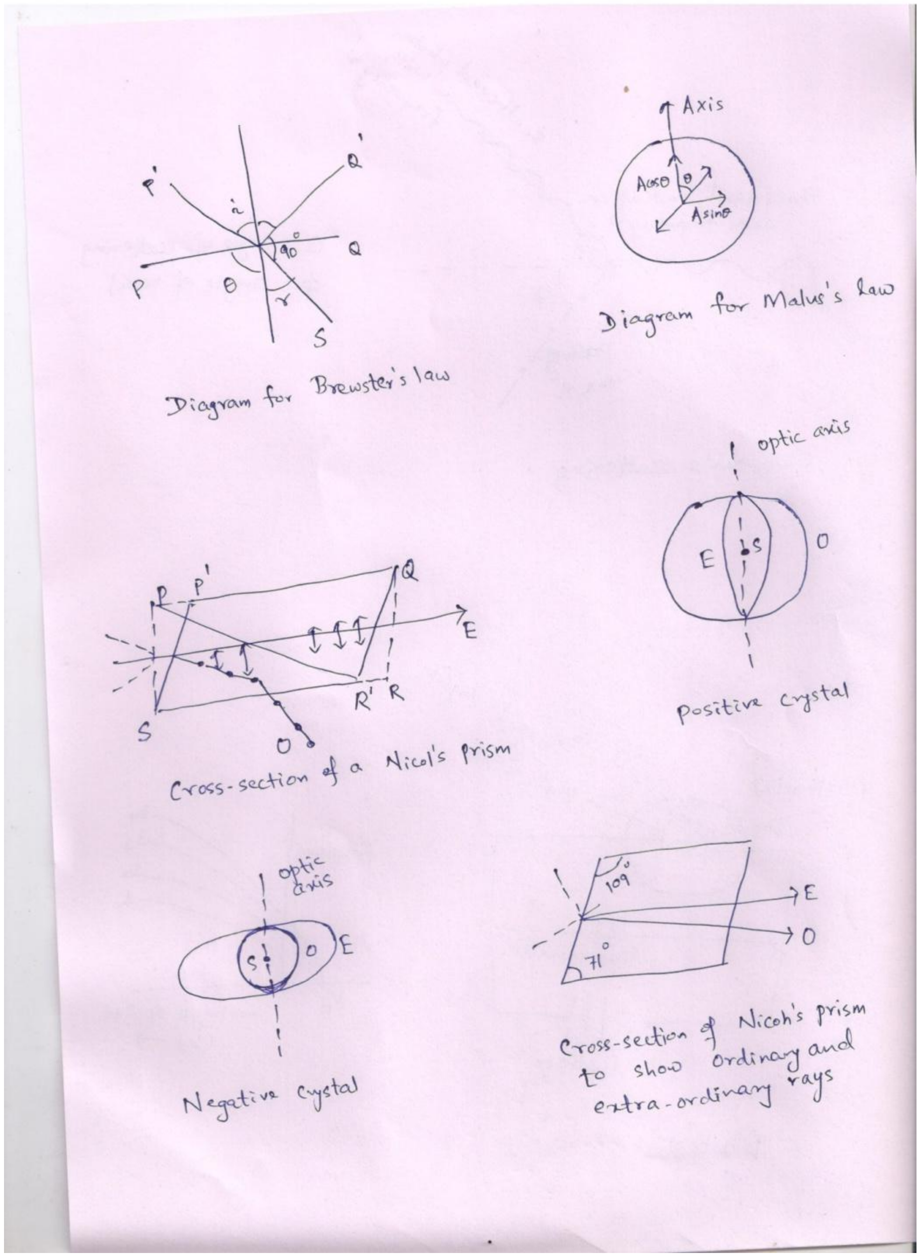
$\Theta = \sin^{-1} [n\lambda/(c+d)]$

Lecture No.8

Construction of a Nichol prism

A Nichol prism is an optical device used for producing and analysing polarised light.It is made up of calcite crystal which is transparent to visible and uvlight ,rhombohedral in shape and each of the six faces of the crystal form a parallelogram having angles of 78^0 and 120^0 approximately.

When a Nichol prism



is used for polarisation case, it is known as a polariser otherwise it can be used as an analyser for analysing the transmission of light.There is one axis known as the optic axis through the crystal where no double refraction takes place and a ray passing through the optic axis does not break into O- and E- rays.The two sides of the prism having angles of 68^0 and the crystal is cut into two parts along the planes P'R' passing through the blunt corners and perpendicular to both the principal section and end faces so that p'Q' makes an angle of 90^0 with R'Q and P'S.

The two cut faces are grinded and polished to make very smooth surfaces until they are optically flat. These surfaces are cemented by a thin layer of Canada Balsm, a clear transparent material having refractive index midway for O- and E- ray.

Generally ,η_O = 1.65

η_m=1.55

η_E=1.49 are taken in the case of a Nichol prism.

The two end faces of the crystal are left open while its sides are coated with lamp black and kept in abrasstube.The O-ray going from the denser to the rarer medium suffers total internal reflection provided the angle of incidence at Canada Balsm layer is greater than the critical angle for the two media i.e. its value is greater than 69^0.

The totally reflected ray get absorbed by the lamp black on the side of the prism.Optically,

Canada Balasm is more dense than the calcite for the E-ray and less dense for O-ray. That is why the E-ray travels from an optically rarer to a denser medium and will emerge out of the crystal whereas O-ray will be totally reflected for large angles of incidence. The E- and O-ray have same velocities along the optic axis and in all other directions they have different velocities.E-ray is having maximum velocity at right to the optic axis.

Lecture No 9

Brewster's law.   4

Brewster's law states that the refractive index of the material medium is equal to the angle of polarisation.

Mathematically, if ip is the angle of polarisation and η is the refractive index

then η = tan ip

Figure

Let PQ is the surface of separation of a transparent medium

P'Q is the incident beam,OQ' is the reflected beam and OS is the transmitted beam i is the angle of incidence and r is the angle of reflection

$\eta = \tan ip = \frac{sini}{cosi}$ 1

$\eta = \frac{\sin i}{\sin\ r}$ (according to Snell's law) 2

From equations 1& 2

$$\frac{sini}{cosi} = \frac{\sin i}{\sin\ r}$$

Or, $\frac{sini}{\sin(90-i)} = \frac{sini}{sinr}$

Or, sin r= sin (90^0-i)

Or,r = 90^0-i

Or, i+r = 90^0

According to Brewster, maximum polarisation occurs at ip=57.5^0 .At this angle of polarisation,the reflected from both the upper and lower surfaces will be plane polarised.

The refractive indices of quartz for ordinary and extraordinary rays of light of wavelength 5893A are 1.54 and 1.55 respectively.What must be the thickness of a quarter wave plate ? 2

Given η_o=1.54

η_e=1.55 and λ= 5893A

Thickness of a quarter wave plate (t) = $\frac{\lambda}{4(\eta e-\eta o)}$

Lecture No 10

Maxwell's equations to determine the electromagnetic field equations in terms of the vector and scalar potentials. 4.5

Maxwell's four electromagnetic equations are

$$\nabla . E = 0 \text{ , for free space} \qquad (1)$$

$$\nabla . B = 0 \qquad (2)$$

$$\nabla X E = -\frac{dB}{dt} \qquad (3)$$

$$\nabla X B = \mu 0 \varepsilon 0 \frac{dE}{dt} \qquad (4)$$

If we write B= $\nabla X A$ then the identity $\nabla . B = 0$ is proved. Here A is known as the vector potential.

Equation (3) can be written in terms of A as

$$\nabla X E = -\frac{d}{dt}\nabla X A \qquad (5)$$

$\nabla X(-\nabla \emptyset) + \frac{d}{dt}\nabla X A$ =0

Or, $\nabla\ X\ (-\nabla \emptyset + \frac{dA}{dt}) = 0$

Then we can write E = $-\nabla \emptyset\ +\ \frac{dA}{dt}$ so that the vector identity $\nabla X(-\nabla \emptyset) = 0$ is satisfied.

$\nabla . E =\ \nabla . (-\nabla \emptyset\ +\ \frac{dA}{dt})$ = 0

Or, $\nabla^2 \emptyset - \frac{d}{dt}\nabla . A = 0$

Or, ,$\nabla^2 \emptyset - \frac{1}{c^2}\frac{d^2 \emptyset}{dt^{\,2}} = 0$ Electromagnetic wave equation in term of scalar potential

Equation (4) $\quad \nabla X \nabla X A = \frac{1}{c^2}\frac{dE}{dt}$

Or, $\nabla . (\nabla . A) - \nabla^2 A$= $\frac{1}{c^2}\frac{dE}{dt}$

Or, $\nabla^2 A - \frac{1}{c^2}\frac{d^2 A}{dt^{\,2}} = 0$ By applying the Lorentz condition $\nabla . A + \frac{1}{c^2}\frac{d^2 \emptyset}{dt^{\,2}} = 0$ and putting the expression for E= $(-\nabla \emptyset - \frac{dA}{dt})$

Then the electromagnetic wave equations in terms of scalar and vector potential for free space non conducting media will be written as

$\nabla^2 \emptyset$ - $\frac{1}{c^2}\frac{d^2\emptyset}{dt^2} = 0$

$\nabla^2 A$ - $\frac{1}{c^2}\frac{d^2 A}{dt^2} = 0$

Lecture No 11

A particle of energy E strikes a potential barrier of height V_0>E.Write the Schrodinger equation for the problem and state the boundary conditions. 7

The particle is having potential (V_o)greater than the energy. The potential acts as a barrier .The Schrodinger's equation for the particle where Vo >E is written as

Figure

In the region 1, when V=0, Schrodinger's equation is written as

$\frac{d^2\Psi 1}{d^2x}$+ $\frac{2m}{\hbar^2}$ E Ψ_1 = 0

Or, $\frac{d^2\Psi}{d^2x}$ + k_1^2 Ψ = 0

Sol. Ψ(x) = A $e^{ik1x} + B\, e^{-ik_1x}$

In region 2, when V=V_0 Schrodinger's equation is

$\frac{d^2\Psi 2}{d^2x}$ + $\frac{2m}{\hbar^2}$ (V_o – E) Ψ_2= 0

Or ,$\frac{d^2\Psi 2}{d^2x}$ + k_2^2 Ψ_2= 0

Sol. Ψ_2(x) = C $e^{ik_2x} + D\, e^{-ik_2x}$

As there is no reflection part in region 2, the second term in the above expression becomes zero.

A,B,C are the proportionality constants to be determined by applying the boundary conditions.

Boundary conditions:

(i)Ψ(x) at reg.1 = Ψ(x) at reg.2 =0 at x=0

Ψ_1(x)=Ψ_2(x) at x=0

(ii) $\frac{d\Psi}{dx}\ at\ reg.1 = \frac{d\Psi}{dx}\ at\ reg.2 = 0$

$\frac{d\Psi 1(x)}{dx} = \frac{d\Psi 2(x)}{dx}$ at x=0

From the above two boundary conditions we get A+B=C

and $(k_1-k_2)A = (k_1+k_2)B$

$B = \frac{k_1-k_2}{k_{1+k_2}} A$ and $C = \left(\frac{2k1}{(k1+k2)}\right) A$

Reflection co-efficient (R)= $\frac{Reflected\ flux}{Incident\ flux} = \left(\frac{k_1-k_2}{k_{1+k_2}}\right)^2$

Transmitted co-efficient (T) = $\frac{Transmitted\ flux}{Incident\ flux} = \frac{4k_{1k_2}}{(k_1+k_2)^2}$

T + R = 1

When the potential of the particle is more than the total energy, then the transmitted flux along with the incident (total reflected) is equal to unity.

Lecture No 12

Gauss's law of electrostatics and give mathematical expressions of the law in integral and differential form. 3

Gauss's law in electrostatics

The divergence of the electric field over a surface area is equal to 1/ε0 times the total charges included within that surface area.

Mathematically,

$$\int_s \nabla.E\ ds = \frac{1}{\epsilon_0}\sum_i q_i$$

c)Prove the transverse nature of the electromagnetic wave in free space. 4

Sol. An electromagnetic wave is represented by the equation

E(x,t) =$\hat{e}E_0 e^{(kx-iwt)}$; E represents the electric field and E_0 is the magnitude of it at t=0

B(x,t) = $\hat{b}B_0 e^{(kx-iwt)}$; B is the magnetic field and $B_0$is the magnitude of the magnetic field at t=0

Transverse nature of electromagnetic wave

Considering Maxwell's electromagnetic equation

$$\overline{\nabla \ \times B = \ \mu_0 J \ + \ \epsilon_0} \ \mu_0 \frac{dE}{dt}$$

$\overline{\nabla}$ X $\hat{b} B_0 e^{(kx-wt)}$ = -$iw\mu_0\epsilon_0 \ \hat{e} E_0 e^{(kx-iwt)}$

Lecture No 13

Schrodinger wave equation for a particle moving in cubic potential box

Schrodinger's time independent wave equation is written as

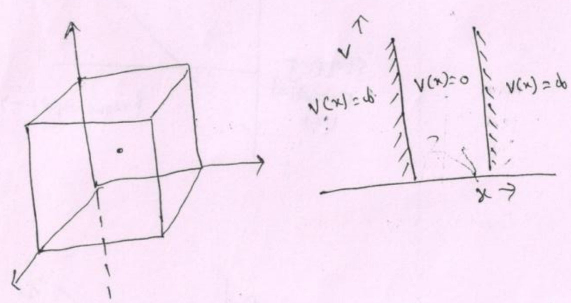
$(\nabla^2 + \frac{2mE}{\hbar^2})\Psi\ (\bar{r}\ , \mathrm{t}\ )= 0$

Let us consider a particle inside a cubical box whose sides are equal. The width of the box along the x-direction is taken as a within which the particle is free to move.

Hence the type of potential used here is

$$\mathrm{V}\ (x) = \begin{cases} \ 0\ , 0\ < x < a \\ \infty, 0 \lesssim \ \ x \lesssim 0 \end{cases}$$

Figure



particle inside a box

For 0< x < a, Schrodinger's time independent equation is written as

$$\frac{d^2\Psi}{dx^2} + \frac{2mE}{\hbar^2}\Psi = 0 \text{ as } V(x) = 0$$

Or, $\frac{d^2\Psi}{dx^2} + \alpha^2\Psi = 0$ where $\frac{2mE}{\hbar^2} = \alpha^2$

Sol. $\Psi(x) = A \sin \alpha x + B \cos \alpha x$

A & B are the proportionality constants to be determined by applying boundary conditions.

Boundary conditions

As the wave function is continuous in nature, hence

$\Psi(x)\,|_{x=0} = \Psi(x)|_{x=a}$

$\frac{d\Psi}{dx}\,|_{x=0} = \frac{d\Psi}{dx}|_{x=a}$

By using these boundary conditions the expression for the wave function for a particle inside a box is written as

$\Psi(x) = A \sin \alpha a$ as $B = 0$

A can be found out by applying normalization condition i.e.

$\int_0^a \Psi(x)\,\Psi^*(x)dx = 1$

This implies $A = \sqrt{\frac{2}{a}}$

For nth state the wave function is written as

$$\boldsymbol{\Psi_n(x) = \sqrt{\frac{2}{a}}\ \sin\frac{n\pi}{a}\ x}$$

Where $\alpha = \frac{n\pi}{a}$ (applying the boundary condition)

The energy eigen values are $E_n = \frac{n^2h^2}{8ma^2}$

As E is directly proportional to the square of the integer hence the energy values are discrete.

Lecture No 14

black body radiation 5

The body which absorbs all the radiations falling on it and radiates all the radiations after sometime is known as a black body.In actual practice it is not possible to realise a perfectly black body but an enclosure provided with a small opening serves the purpose because the radiation entering the enclosure will be reflected many times inside it and ultimately get absorbed.

In 1859, Kirchoffderivedtwo laws about the black body which are of radical importance in arriving at the properties possessed by the black body radiation.

i)A black body not only completely absorbs all the radiations falling on it but conversely behaves as a perfect radiator when heated.

ii)The radiation given out by a black body depends only on the temperature to which the black body is raised and is independent of the nature of the body.

In 1884, Stefan and Boltzmann showed that the energy of radiation in unit volume of space due to all wavelengths in the spectrum is proportional to the fourth power of the absolute temperature of the black body

In 1893, Wien in order to find the actual distribution of energy in thermal spectrum tackled the problem in a more precise and analytical manner and obtained thermodynamically the following two relations:

i) λT = a constant

ii) $E_\lambda \lambda^{-5}$ = a constant

$Where$ λ is the wavelength corresponding to the temperature T and E_λ is the emissive power.

In 1900,Rayleigh and Jeans tackled the problem of energy distribution in a different manner.They derived the radiation law considering that the radiation is broken up into monochromatic wave trains and the number of such wave trains or equivalent degrees of freedom lying between frequency range ν and ν + dν is determined. The energy carried by each degree of freedom is calculated from general statistical theory and hence energy density distribution can be determined.

$E_\lambda = 8\pi\lambda^{-4} k T$

Wien's formula agreed with the experimental curves for the short wavelengths and Rayleigh- Jean's formula for long wavelengths .None of the above could explain the whole experimental curves and hence a new revolutionary hypothesis emerged due to Planck .

In 1905, Max Planck explained the energy distribution throughout the black body radiation based on the following points:

i) A chamber containing blackbody radiations is considered as it contains simple harmonic oscillators of molecular dimension which can vibrate with all possible frequencies.

ii)The frequency of radiations emitted by an oscillator is the same as the frequency of its vibration.

iii)An oscillator can't emit energy in a continuous manner . It radiates the energy in terms of photon ,the quanta of electromagnetic radiation.

According to Planck, the black body radiation can be taken as number of harmonic oscillators coantained within a container.The harmonic oscillators have the frequency equal to the frequency of the black body radiation.In Planck's quantum theory , the energy of oscillating particle is = hγ

Where h is the Planck's constant, γ is the oscillating frequency and n=0,1,2……

In plank's radiation theory the vibrating particle does not radiate energy continuously but discontinuously in terms of discrete quanta or photon.When the oscillator moves from one state to the other state it emits or absorbs energy.

Energy of the photon= hc/λ

Mass of photon= $\frac{E}{c^2} = \frac{h\nu}{c^2}$

Momentum of the photon = h/λ

Let us calculate the number of states in a black body radiations in the frequency range of ν and ν+dν by finding the spherical volume bounded by the spheres of radii $\frac{\nu+d\nu}{c}$ and $\frac{h\nu}{c}$

The volume of the spherical shell = 4π$\frac{h^3}{c^3}\nu^2$dν

The phase space has a volume V=h^3 and there are two states of polarisation of the radiation.Number of states in the black body radiation in the frequency range ν and ν+dνis given as

dn= $\frac{8\pi V}{c^3} \cdot \frac{\nu^2 d\nu}{e^{\frac{h\nu}{kT-1}}}$

For dn photons in the frequency range ν and ν+dν , the energy is equal to hνdn and the energy per unit volume = $\frac{h\nu\, dn}{V}$

So the energy distribution for black body radiation will be

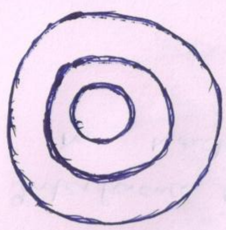
E(ν) = $\frac{8\pi V}{c^3}\frac{1}{V}\frac{h\nu^3 d\nu}{(e^{\frac{h\nu}{kT-1}})\, d\nu} = \frac{8\pi h}{c^3}\nu^3 \frac{1}{(e^{h\nu}/_{kT-1})}$ represents the Planck's law for black body radiation

Lecture No.15

Fresnel's half period zones and why they are named so ?Show that the radius of the Fresnel half period zone is directly proportional to the square root of natural numbers. 4

Let's consider a point source S of monochromatic light which ia at sufficiently large distance so that for all practical purposes, we consider plane wavefront only.

Figure



Cross-section of a zone plate

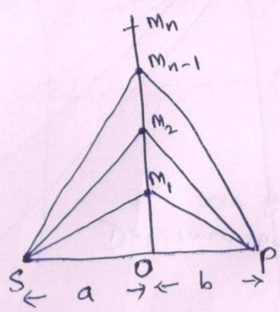


Diagram to explain the action of a zone plate

We have to find out the resultant amplitude at O due to the exposed part of the wavefront XY having its pole at P.

To find the resultant effect at O, let ABCD be the plane wave front of the monochromatic light of wavelength λ at any time.

Every point on ABCD become the centre of disturbance and the net effect can be found due to all these disturbances reaching at O.All the points on ABCD are in the same phase and the secondary originating from ABCD will reach O with different phases.

The wave front ABCD is divided into number of half period zones.

Let OP=b

Radii of different sections can be obtained

$OM_1= b+\lambda/2$

$OM_2=b+\lambda$

$OM_3= b+3\lambda/2$

……………………

……………………

A series of concentric spheres can be cut the wave front ABCD in circles of radii PM_1,PM_2……The areas enclosed between PM_1,M_1M_2,M_2M_3….etc are known as half period zones. The area corresponding to PM_1 is known as the first half period zone.

$PM_1= \sqrt{\mathrm{OM1}^2 - OP2}$

$= \sqrt{\left(b + \frac{\lambda}{2}\right)^2 - b\hat{}2}$

$=\sqrt{b\lambda}$

$PM_2= \sqrt{OM_2^2 - b^2}$

$= \sqrt{(b + \lambda)^2 - b^2}$

$= \sqrt{2b\lambda}$

$PM_{n-1} = \sqrt{(n-1)b\lambda}$

$PM_n = \sqrt{nb\lambda}$

The area enclosed between M_1M_2gives the second half period zone, M_2M_3 gives the third half period zone and so on.

Area of the 1st half period zone : $\pi r_1^2 = \pi b \lambda$

Area of the nth half period zone :$\pi r_n^2 = n \pi b \lambda$

From the above expressions we see that r_n is directly proportional to the square root of the natural number.

Lecture No16

potential barrier:

Obtain the solution for Schrodinger's equation for different regions.

Figure

If the force field acting on a particle is zero or nearly zero everywhere except in a limited region, it is said to be a potential barrier. At x=0, the force field acting on a particle is V_0. V_0 is called the height of the potential barrier.

Classical concept : Classically a particle in region 1 can move freely as the force field is zero but at x=0, discontinuity occurs and we have to consider two cases.

Case 1 ($E < V_0$) :In this case the particle will remain in the region 1 for ever. If sometimes the particle is moving towards the x-direction ,it will be reflected back at x=0

Case 2 ($E > V_0$) : Classically we expect that the particle would not be reflected at x=0. This is due to the fact that the particle has enough energy to enter the region x >0.

Quantum theory for single step potential barrier:

For E>V_0, when the wave packet reaches the barrier a part is reflected and apart is transmitted. The Schrodinger equation for the first region is

$$\frac{d^2\Psi 1(x,t)}{dx^2} + \frac{2m}{\hbar^2}\,E\Psi1(x,t) = 0$$

Or,

$\frac{d^2\Psi 1(x,t)}{dx^2} + \alpha^2\Psi1(x,t) = 0$ where $\alpha^2 = \frac{2m}{\hbar^2}E$

General solution: Ψ_1(x,t)= A $e^{i\propto x} + Be^{-i\propto x}$ (i)

For region 11 where x> 0, V > V_0

$$\frac{d^2\Psi 2(x,t)}{dx^2} + \frac{2m}{\hbar^2}(\,E - V0\,)\Psi2(x,t) = 0$$

Or, $\frac{d^2\Psi 2(x,t)}{dx^2} + \beta^2\Psi2(x,t) = 0$ where $\beta^2 = \frac{2m}{\hbar^2}(E - V_0)$

General solution:Ψ_2(x,t)= C$e^{i\beta x} + De^{-i\beta x}$ (ii)

In equation (i), $e^{i\propto x}$represents a wave advancing in the positive direction of x i.e. the incident wave and $e^{-i\propto x}$ represents a wave moving in the negative direction of x i.e. reflected wave.

In equation (ii), $e^{i\beta x}$ represents a wave advancing in the positive direction of x i.e. transmitted wave and$e^{-i\beta x}$ represents a wave moving in the negative direction of x i.e. reflected wave. As discontinuity only occurs at x=0, hence there should not arise a question of reflection in this region.Due to this fact the term $e^{-i\beta x}$ is dicarded inthe second region.

Hence Ψ_2(x,t)= C$e^{i\beta x}$ (iii)

A,B,C are the constants whose values can be obtained by applying boundary conditions.

Since Ψ is continuous, we have the following boundary conditions :

Ψ_1 (x,t)=Ψ_2(x,t) at x=0

$\frac{d^2\Psi 1(x,t)}{dx^2} = \frac{d^2\Psi 2(x,t)}{dx^2}$ at x=0

Using the above boundary conditions we have A+B=C

$(\alpha - \beta)A = (\alpha + \beta)B$ or, $B = \frac{(\alpha - \beta)}{(\alpha + \beta)} A$

$C = \frac{2\propto}{(\alpha + \beta)} A$

If V and V_1 are the velocities if incident and transmitted particles, then $\alpha = \frac{mV}{\hbar}$

Or, $V = \frac{\propto\hbar}{m}$

$B = \frac{mV1}{\hbar}$ or, $V_1 = \frac{\beta\hbar}{m}$

Since $V_1 < V$, the velocity of transmitted particle in such a region is less than the incident velocity which is same as the velocity of the incident beam, some of the particles can come to the region 2 even $E < V_0$.

Lecture No 17

Standing wave 2

When two identical progressive waves travel through a medium along the same line in opposite directions with equal velocities, they superpose over each other and produce a new type of wave which is known as the stationary wave or standing wave.They are stationary as there is no flow of energy.There are certain points ,half a wavelength apart which are permanently at rest called ‘nodes’ , midpoint between the nodes ántinodesoccurs where amplitude is maximum.

The characteristics that distinguish a standing wave from a travelling one 3

(i)A travelling wave is an advancing wave which moves in the medium continuously with a finite velocity.

There is no advancement of the wave in any direction.

(ii)As the particles move with certain velocity, flow of energy occurs.

There is no flow of energy in case of stationary waves.

(iii)Each particle of the wave executes simple harmonic motion about the mean position with the same amplitude.

Every particle executes SHM except the nodes.

(iv) No particle is permanently at rest position in a travelling wave.

Nodes are permanently at rest position in case of standing wave.

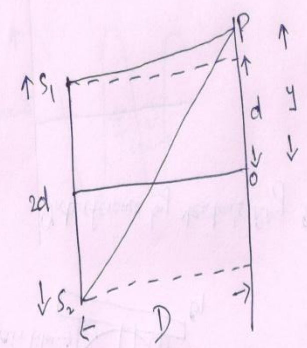
(v) The phase of vibration varies from point to point in a travelling wave.

All the points vibrate with the same phase in the case of a standing wave.

(vi)All the particles do not pass through the mean position but in case of standing wave all the particles pass through the mean position and reach the outermost positions simultaneously twice in periodic time.

Lecture No 18

meaning of fringe width and show that in a Young's double slit arrangement ,the fringe width for bright or dark fringes are same. 4



Young's double slit experimental arrangement

Let's consider a point P on the screen at a distance y from the axial point O. The distance between the source and the screen (D) is quite large compared to the the distance between the slits (d) and the distance of the point P from the centre of the screen(y).

The path difference is

$\Delta = S_2P - S_1P$

Now $S_1P = [\, D^2 + (y-d)^2]$ ^1/2

Or, $S_1P = D + \frac{(y-d)^2}{2D}$

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

Then the path difference $(\Delta) = \frac{2yd}{D}$

Now for maximum intensity $\frac{2yd}{D} = n\lambda$, n=1,2,3…… (for bright fringes)

For minimum intensity $\frac{2yd}{D} = (2n+1)\frac{\lambda}{2}$, n=1,2,3…..(for dark fringes)

Where n=1,2,3,…. Correspond to the $1^{st}, 2^{nd}, 3^{rd}$…. fringes.

Expression for fringe width: It is the separation between two consecutive bright or dark fringes.

The position of the pth bright fringe is $y_p = \frac{D\lambda}{2d}\, p$

The position of the (p+1)th bright fringe is $y_{p+1} = \frac{D\lambda}{2d}\,(p+1)$

Fringe width $(\beta) = y_{p+1} - y_p = \frac{D\lambda}{2d}$

In a plane diffraction grating the width of a slit is double the width of a line.Find the orders of the missing spectral lines. 4

Ans.Let the width of the slit is denoted as 'a' and the width of the line is 'b'

a=2b

We know that

(a+b) sin θ = nλ

is the condition for the principal maxima for nth order and the condition for the minima due to a single slit is

a sin θ = mλ

So $n = (\frac{a+b}{a})m$

When a=2b, n=(3/2)m

So 3/2, 3^{rd},9/2th ,………..orders of spectra will be missing corresponding to the minima given by m=1,2,3…

Lecture No 19

Einstein's theory explains this ?

Einstein explained the photoelectric effect on the basis of quanta of electromagnetic radiation known as photon.When the suitable energy more than that of the threshold value incident on the photometal, some part of its energy is used to eject the loosely bound electron measured in terms of work function and part of the energy of the photon provides kinetic energy to the electron.

$$\mathbf{h\nu = W_0 + \frac{1}{2} m v^2}$$

This is known as Einstein 's photoelectric equation.

$W_0$is known as the work function of the electron. When the kinetic energy term is equal to zero ,then$h\nu = W_0$i.e the total energy of the photon is utilised to eject the electron. So we have to define a minimum frequency known as the threshold frequency above which this photoelectric effect occurs only.

Corresponding to the threshold frequency, a long wavelength limit is defined below which photoelectric effect occurs only.This value of wavelength is known as the threshold wavelength(λ_0) ,radiations having wavelength greater than this value will not be able to eject electrons from the metal surface.

$$\lambda_0 = \frac{c}{\nu 0} = \frac{12400}{W0} \text{A}$$

Substituting the value of W0=hv0 , we have

$$h\nu = h\nu_0 + \frac{1}{2} m V^2$$

or, $\frac{1}{2} m V^2 = h(\nu - \nu_0)$

This is another form of Einstein's photoelectric equation. Einstein's photoelectric equation predicts all the experimental results. For a particular emitter, work function W_o is constant and hence

K.E= $\frac{1}{2} mV^2$ispropotional to the frequency.

Thus the increase in frequency ν of incident light causes increase in velocity of photoelectrons provided intensity of incident light is constant. If V_0 is the stopping potential , then

$eV_0 = h\nu - h\nu_0$

or, $V_0=\frac{h\nu}{e} - \frac{h\nu 0}{e}$

This the form of Einstein's photoelectric equation written in terms of Stopping potential.

c)Star X with aenergy of 600J gives out its maximum radiation of wavelength 3000A.What is its surface temperature ? 3

Ans.E=600J, λ=3000A

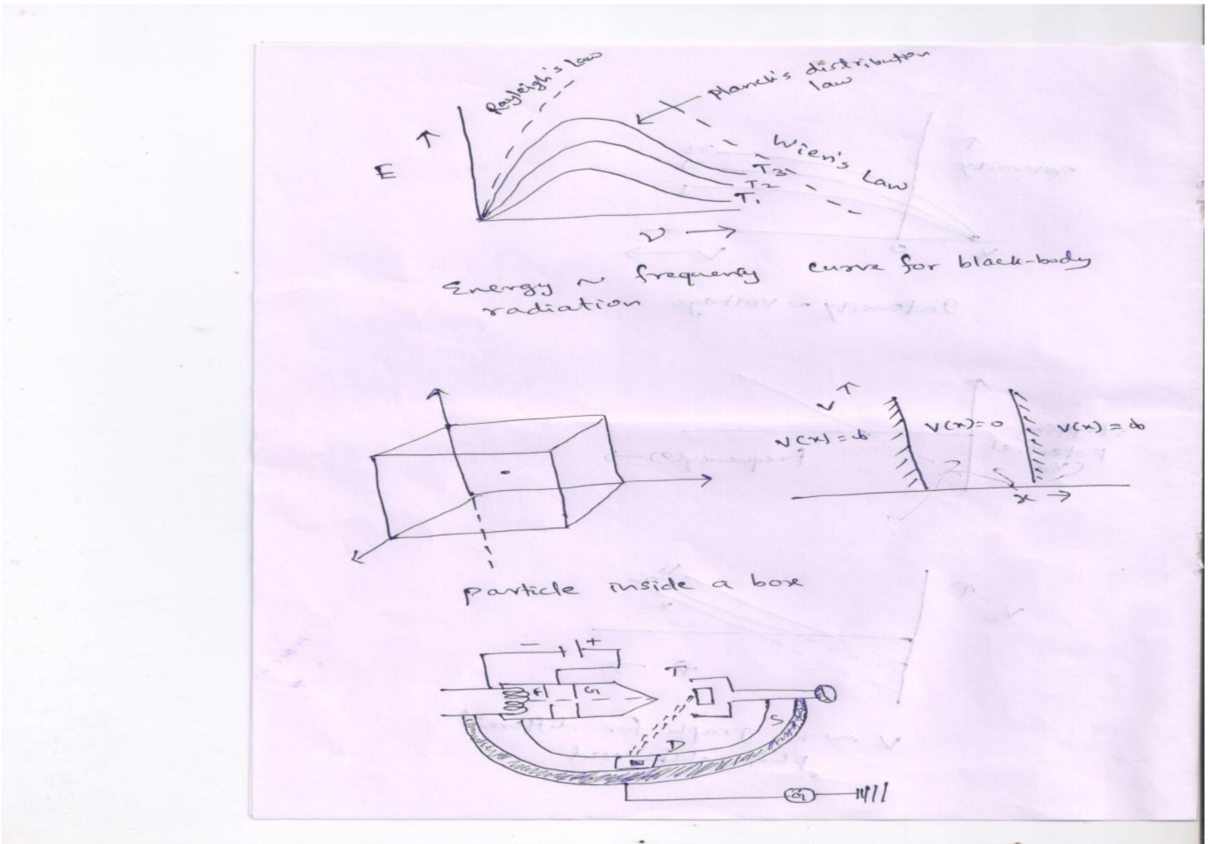
S_T= E. λ/ ; σ is the conductivity of the medium

Lecture No 20

de Broglie hypothesis

De Broglie's hypothesis is concerned with a special type of wave known as matter waves which show both particle and wave nature of radiation. When the particles are having certain velocity the only a wave can be generated.In 1927,two American physicists Davisson and Germer predicted experimentally about the existence of matter waves.

Figure



In the diagram F is the filament which is heated to eject electrons by thermionic emission.

G is a system of electrodes with central holes maintained at increasing potential from which electron beam is produced.T is a target made up of a crystal of nickel on which monoenergic electrons fall. C is the Faraday cylinder known as collector on which some of the scattered electrons entered.G is the Galvanometer to measure the amplified collector current.The collector can be moved on a graduated circular scale S to receive electrons. The collector has two walls insulated from each other.A retarding potential is applied between the inner and outer walls of the collector such that only fast moving electrons coming from the electron gun may enter into the collector and not the secondary slow electrons from the target.

The experiment was carried out in two different positions i.e (i)normal incidence and (ii) oblique incidence position.In the normal incidence position the beam of electrons fall normally on the circular scale tovarious positions and the galvanometer current was recorded at each position .A graph aws plotted between the colatitude and galvanometer current.Several curves are obtained for different voltage electrons.

It is observed that a bump begins to appear in the curve for 44V electrons.This bump moves upward as the volatage increases and attains the greatest development for 54 volts and a colatitude of 50^0.Above 54 V the bump again diminishes.The bump at this voltage offers the existence of electron waves.The surface rows of atoms act like the rulings of adiffraction grating producing the 1^{st} order spectrum of 54 V electrons at $\theta = 50^0$.

Applying the plane diffraction of a grating

$n\lambda = (c+d)\sin\theta$For n=1 ,(c+d)=2.54 A we found λ=1.65 A

Again according to the de Broglie electron wave

$\lambda = \frac{150}{V}\ A = 1.66$ A

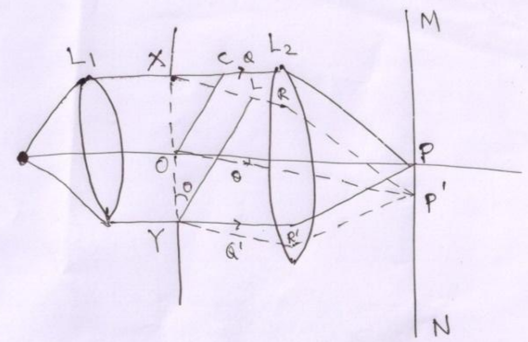
This shows that the electrons have wave like characteristics

Lecture No 21

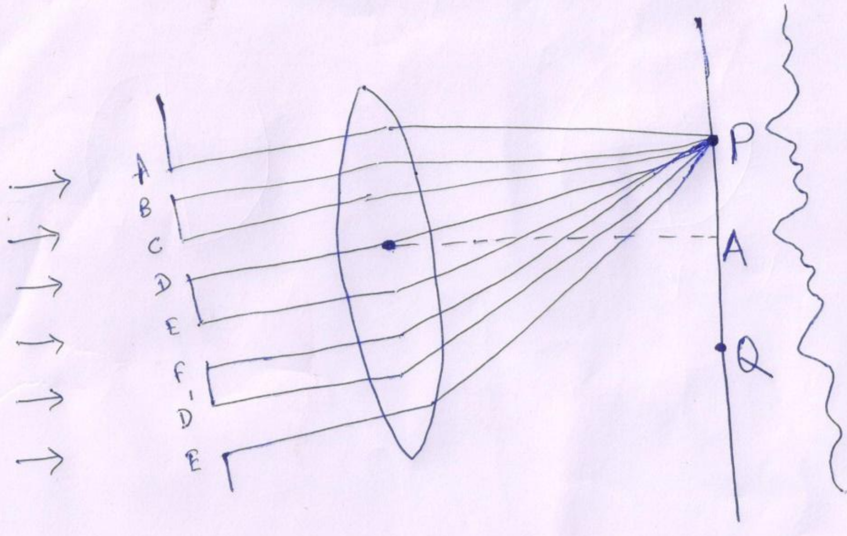
Diffraction pattern due to a plane diffraction grating:

A plane diffraction grating is a plane glass plate on which number of parallel, equidistant lines are drawn with the help of a diamond pen.The lined portion being opaque and the spacing between the lines is transparent to the light.A plane diffraction grating is the combined effect of N number of parallel slits.

Ray diagram



Fraunhoffer diffraction due to a single slit



plane diffraction grating

Let a plane wavefront of monochromatic light is incident normally on the grating.

c is the width of each slit and d is the separation between two consecutive slits.

(c+d) is the grating element

Θ is the angle of diffraction

XY is the screen on which diffraction is observed

When a plane wavefront is incident on normally on the grating, each point on the slit sends out secondary wavelets in all directions . The secondary wavelets in the same direction as of incident light will come to focus at O which is the point of central maximum. The secondary wavelets diffracted along a direction to meet the screen ‘P’posses different phases. Therefore dark and bright bands are obtained on both sides of the central maximum.

Let S_1,S_2,S_3……. Be the midpoints of the corresponding slits and S_1M_1, S_2M_2,S_3M_3……. be the perpendiculars drawn.The path difference between waves emanating from points S_{n-1} and S_n is

S_nM_{n-1} = (c+d) sin θ

The corresponding phase difference is given by,

$\Phi = \frac{\pi}{\lambda}(c+d) \sin \theta$

Lecture No. 22

positive and negative uniaxial crystal with examples. 3

The wavefronts surrounding a point source S in a calcite crystal is shown as follows:

Figure

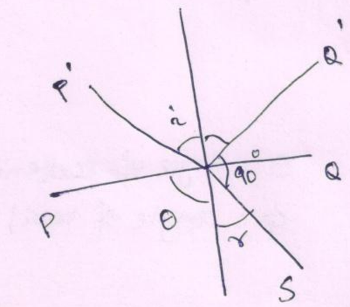


Diagram for Brewster's law

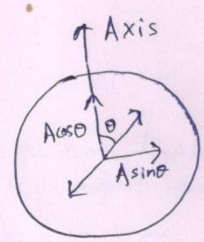
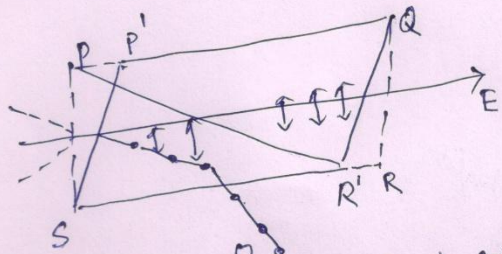
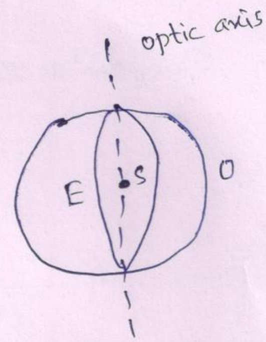


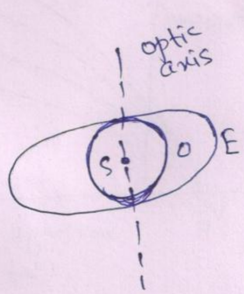
Diagram for Malus's law



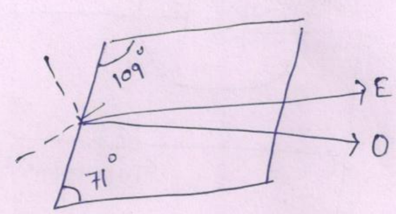
Cross-section of a Nicol's prism



Positive crystal



Negative crystal



Cross-section of Nicol's prism to show ordinary and extra-ordinary rays

Differences and similarities between +ve & - ve crystals:

(i) O-ray is outside to the E-ray in a positive crystal whereas O-ray surface lies inside E-ray surface

(ii) Velocity of O-ray is constant in all directions both for +veand -ve crystals.

(iii) Velocity of E-ray varies with direction. Maximum along the optic axis where it will be equal to velocity of O-ray and minimum perpendicular to the direction of optic axis for the +ve crystal.

Velocity of E-ray is minimum along the direction of optic axis whereas it will be equal to the velocity of O-ray and maximum perpendicular to the direction of optic axis for –Ve crystal

(iv) Refractive index of extra-ordinary ray is more compared to the refractive index of the ordinary ray for positive crystal e.g. Quartz

In case of negative crystal the refractive index of extra-ordinary ray is less compared to the refractive index of the ordinary ray for positive crystal e.g. calcite

Lecture No 23

Poynting theorem: 5

The electromagnetic waves carry energy and momentum when they propagate .The conservation of energy in electromagnetic wave phenomena is described by Poynting theorem.

The electric and magnetic fields store some energy while they propagate through any medium.The electric energy stored per unit volume i.e.electric energy density $(U_E) = \frac{1}{2}\varepsilon E^2$

The magnetic energy stored per unit volume i.e.magnetic energy density $(U_B) = \frac{1}{2}\mu H^2$

The total electromagnetic energy (U_{EM}) in a region is obtained by taking the volume integral of the electromagnetic energy density over the volume under consideration.

$$U_{EM} = \frac{1}{2}\varepsilon E^2 + \frac{1}{2}\mu H^2 = \frac{1}{2}(\epsilon E^2 + \mu H^2)$$

The rate of energy transport per unit area per unit time in electromagnetic wave is described by a vector known as the Poynting vector. Its unit is Watt/m^2.Direction of Poynting vector is along the direction of propagation of the electromagnetic wave which is perpendicular to the plane containing both electric and magnetic fields.

Maxwell's electromagnetic equation is

$\bar{\nabla} \times \bar{E} = -\frac{dB}{dt}$ ……………(i)

and $\bar{\nabla} \times \bar{H} = \bar{J} + \frac{dD}{dt}$ …………………(ii)

Taking the dot product of equation (i) with $\bar{H}$ and equation (ii) with $\bar{E}$ and taking the difference

$\bar{H} \cdot \bar{\nabla} \times \bar{E} - \overline{\bar{H} \cdot \nabla} \times \bar{H} = -\bar{H} \cdot \frac{dB}{dt} - \bar{E} \cdot \frac{dD}{dt} - \bar{E} \cdot \bar{J}$……………….(iii)

$\bar{H} \cdot \frac{dB}{dt} = \frac{d}{dt}(\frac{1}{2}\mu H^2)$ …………..(iv)

$\bar{E} \cdot \frac{dD}{dt} = \frac{d}{dt}\left(\frac{1}{2}\varepsilon E^2\right)$ …………………………(v)

Equation (iii) will become

$\bar{H} \cdot \bar{\nabla} \times \bar{E} - \overline{\bar{H} \cdot \nabla} \times \bar{H} = -\frac{d}{dt}\left(\frac{1}{2}\varepsilon E^2\right) - \frac{d}{dt}(\frac{1}{2}\mu H^2) - \bar{E} \cdot \bar{J}$

$= -\frac{d}{dt} U_{EM} - \bar{E} \cdot \bar{J}$

Or, $\bar{\nabla} \cdot (\bar{E} \times \overline{H}) = -\frac{d}{dt} U_{EM} - \bar{E} \cdot \bar{J}$ ……………….(vi)

Or, $\bar{\nabla} \cdot \bar{P} = -\frac{d}{dt} U_{EM} - \bar{E} \cdot \bar{J}$ ……………….(vii)

Where $\bar{P} = (\bar{E} \times \overline{H})$,is known as the Poynting vector.

The left hand side of equation (vii) is the rate of flow of total electromagnetic energy through the closed surface area enclosing the given volume.The 1st term on the right hand side of equation (vii) is the rate of change of electromagnetic energy per unit volume

The 2nd term represents the work done by the electromagnetic field due to the source of current.

Lecture No.24

Maxwell's 4 electromagnetic equations for free space (J=0 and ρ =0) are

$$\overline{\nabla}.\overline{E} = 0, \overline{\nabla}.\overline{B} = 0 \text{ , } \overline{\nabla}\text{X}\overline{E} = -\frac{d\overline{B}}{dt} \text{ , } \overline{\nabla}\text{X}\overline{B} = \epsilon 0 \mu 0 \ \frac{dE}{dt}$$

The magnetic field (B) in terms of vector potential (A) can be written as $\overline{B}$=$\overline{\nabla}$ X $\overline{\text{A}}$

Taking the cross product of Maxwell's 3rd equation with ∇ operator

$$\overline{\nabla} \text{ X } \overline{\nabla}\text{X } \overline{E} = -\frac{d}{dt}\overline{\nabla} \text{ X } \bar{A} \text{ or, } \overline{\nabla} \text{ (} \overline{\nabla}. \ \overline{E} \text{)} - \nabla^2\overline{E} = -\frac{d}{dt}\overline{\nabla} \text{ X } \bar{A}$$

Using the Lorentz gauge condition $(\overline{\nabla}. \bar{A}) - \frac{1}{c^2}\frac{d\emptyset}{dt} = 0$

Maxwell's electromagnetic wave equation in terms of electric field is

$$\nabla^2\overline{E} - \frac{d^2E}{dt^2} = 0$$

Maxwell's electromagnetic wave equation in terms of magnetic field is

$$\nabla^2\overline{B} - \frac{d^2B}{dt^2} = 0$$

Lecture No 25

The expression for the transmission probability when the energy of the the incident particle is more than the height of the barrier is the ratio of the transmitted flux to the incident flux.

Transmisson probability = $\frac{transmitted\ flux}{Incident\ \ flux} = \frac{\Psi^*_{trans}\Psi_{trans}}{\Psi^*\Psi} = \frac{4\alpha\beta}{(\alpha+\beta)^2}$

Where $\alpha^2 = \frac{2mE}{\hbar^2}$, $\beta^2 = \frac{2m(E-V_0)^2}{\hbar^2}$

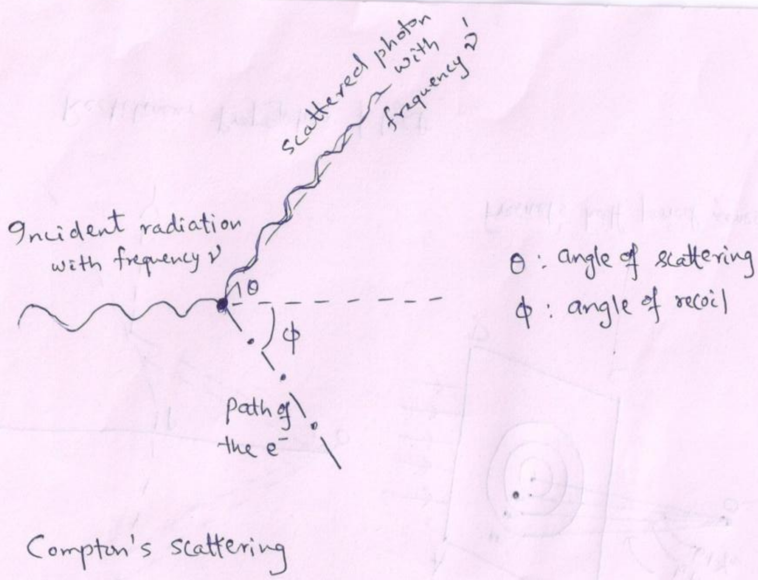
When energy of the particle (E)= Height of the barrier (V_0), then transmission probability is equal to zero.

Lecture No.26

An expression of the Compton shift.

Ans.The scattering process of an electromagnetic radiation incident on a metal where the electron is free and at rest considered as an elastic collision between the photon and electron is known as Compton effect. The scattered photon has more wavelength compared to the incident one and the change in wavelength is described in terms of the Compton shift.

Figure 6 :Compton scattering effect



Two conservation laws are applied here:

i)Conservation of energy

ii)Conservation of momentum

The total energy carried by the electron photon system before collision = Energy of the e^- + energy of the photon = m_0c^2 + hv

The total energy carried by the electron photon system after collision= mc^2 + hv'

According to conservation of energy ,

m_0c^2 + hν = mc^2 + hν' ………………..(1)

The momentum carried by the electron photon system along the direction of incidence before collision

= 0 + $\frac{h\nu}{c}$

The momentum carried by the electron photon system along the direction of incidence after

collision =mv + $\frac{h\nu'}{c}$

Considering the conservation of momentum along the direction of incidence

0 + $\frac{h\nu}{c}$ = mv + $\frac{h\nu'}{c}$...................(2)

Conservation of momentum perpendicular to the direction of incidence

0+0 = mv sin ϕ + $\frac{h\nu'}{c}$sin θ ………………….(3)

Where θ is known as the scattering angle and ϕ is the angle of recoil.

The collision process is an elastic and relativistic one.

m = $\frac{m_0}{\sqrt{(1-\frac{v^2}{c^2})}}$, $E^2 = p^2c^2 + m_0^2c^4$

Using the equations (1),(2),(3) and above relations we will get

$\frac{1}{\nu'} - \frac{1}{\nu} = \frac{2h}{m_0c^2} sin^2\frac{\theta}{2}$

Or, λ' – λ = $\frac{2h}{m_0c} sin^2\frac{\theta}{2}$

This is the expression for the Compton shift.

Lecture No 27

Characteristics of lasers:

Lasers have the following characteristics:

1.High monochromaticity

In ideal case,the LASER emits all photons with the same energy and same wavelength.The laser light has a single spectral colour and is almost the purest monochromatic light available.

2.high frequency stability : It is the most important characteristic of laser used in interferrometric measurements.

3.Switching characteristic of laser : Broad band video transmission systems promise attractive applications for future optical fibre subscriber loop systems.For such transmission systems it would be extremely convenient to be able to switch broad band optical signals without optical to electrical signals.

4.In medical sciences laser has the most important application .Due to monochromaticity bloodless surgeries are performed with the help of laser.

5.In mechanical welding, yielding laser can be used.

When a material is in thermal equilibrium state, derive the relation between population in higher and lower state.

The atoms are distributed at thermal equilibrium according to the Boltzmann equation

$N=e^{-E/kT}$

K is the Boltzmann constant and E is the energy levels. At thermal equilibrium, the number of atoms (population) decreases when the energy increases. At E_1 and E_2 the number of atoms are written as

$N_1 = e^{-E1/kT}$

$N_2 = e^{-E2/kT}$

$N_2/N_1 = e^{-E2/kT} / e^{-E1/kT}$

Or, $N_2 = N_1 e^{-\Delta E/kT}$

Where $\Delta E = (E_2 - E_1)$

Let us consider hydrogen gas to be a mono atomic gas and find out the atomic population at room temperature at the first excited level. Here E_1=—13.6eV, E_2= 3.39eV and T=300K.

$N_2/N_1=0$

This implies that at room temperature all atoms are in ground state.If the temperature is raised to 6000K.

Then $N_2/N_1 = 2.5X\ 10^{-9}$

We thus find that in a material at thermal equilibrium, more atoms are in the lower energy state than in the higher energy state.

In the limiting case $E_2-E_1=0$, we find that $N_2/N_1=e^0=1 \Rightarrow N_2=N_1$

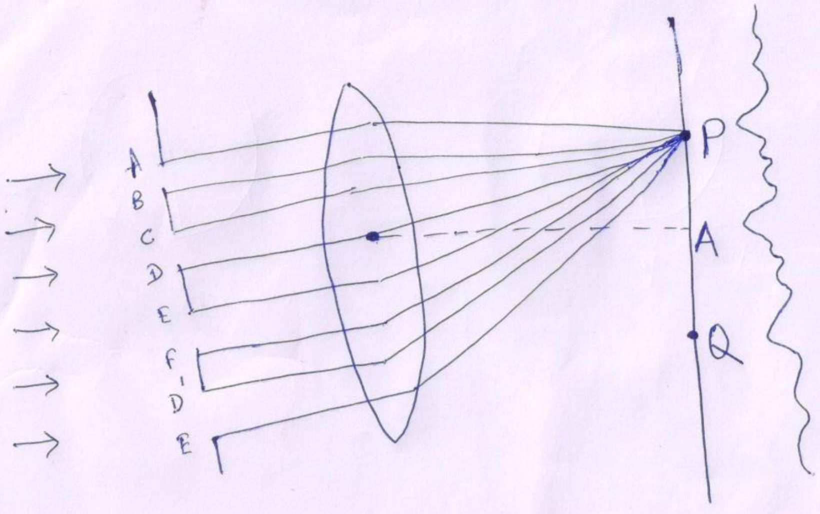
From the above relations we see that at room temperature the number of population is higher at lower energy compared to the population at higher energy.As long as the material is in thermal equilibrium, the population of the higher state can not exceed the population of the lower state.

Lecture No 28

Determine wavelength of sodium light by using plane diffraction grating:

Ans. A diffraction grating is a plane glass plate on which number of parallel, equidistant lines are drawn with the help of a diamond pen. The lined portion being opaque and the spacing between the lines are transparent to the incident light. A plane diffraction grating is the combined effect of N number of parallel slits.

Figure 9 : Plane diffraction grating

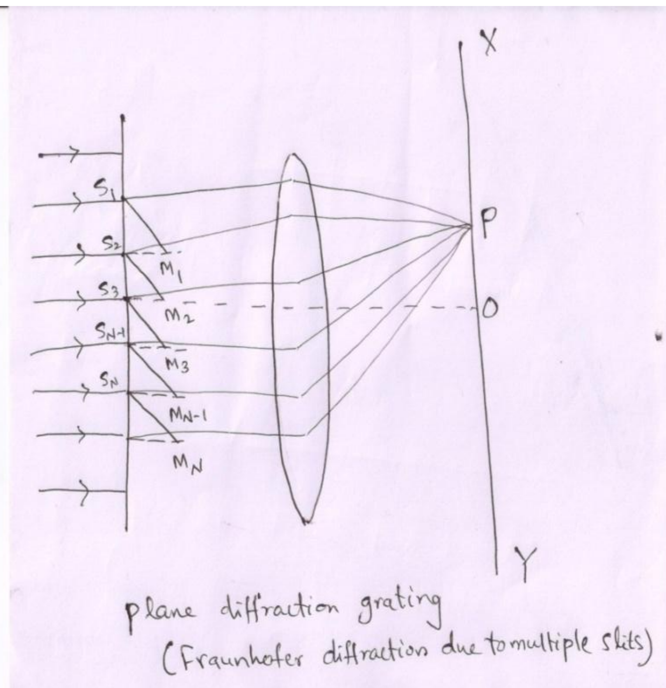


plane diffraction grating

Let a plane wavefront of monochromatic light be incident normally on the grating. The width of each slit be **c** and the separation between any two consecutive slits be denoted as **d.**

When a plane wave front is incident normally on the grating, each point on the slit sends out secondary wavelets in all directions. The secondary wavelets in the same direction as of incident light will come to focus at o which is the point of central maximum. The secondary wavelets diffracted along a direction to meet the screen posses different phases. Therefore dark and bright bands are obtained on both sides of the central maximum.

Figure 10 : Fraunhofer diffraction due to multiple slits



Let S_1, S_2,S_3….. be the mid points of the corresponding slits and S_1M_1, S_2M_2 … be the perpendiculars drawn.The path difference between the waves emanating from points S_{n-1} and S_n is

S_nM_{n-1} = (c+d) sinθ

The corresponding phase difference is given by

$\Phi = \frac{\pi}{\lambda}(c+ d) \sin \theta$

For single slit case, the amplitude at p is found to be

The resultant of the waves coming from N number of slits is

Y = A sin wt + A sin (wt + ϕ)+ A sin (wt + 2ϕ)+………..

$= A\, e^{iwt} \left[\frac{1-e^{iN\varphi}}{1-e^{i\varphi}}\right]$

Intensity due to the resultant waves (I)= $A^2 \frac{sin^2\frac{N\emptyset}{2}}{sin^2\frac{\emptyset}{2}}$

For principal maxima we have

Φ = ± n π

Or, $\frac{\pi}{\lambda}(c+ d) \sin \theta = \pm n \pi$

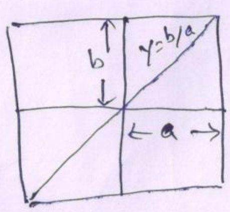
Or,(c+ d) sin θ = ± n λ

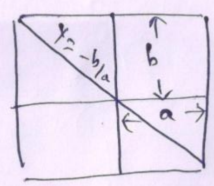
Lecture No 29

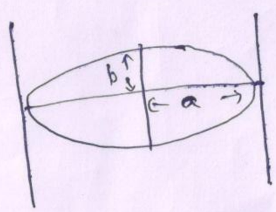
Differences among plain polarized,circularly polarised,elliptically polarised and unpolarised light.

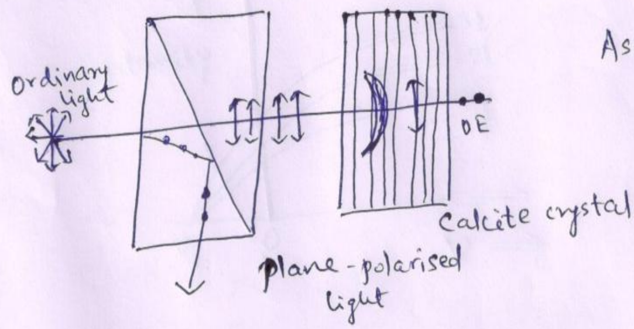
Ans. If the vibrations are along the direction of propagation of a polarised light, then it is known as plane polarised .We can get a plane polarised light by reflection, by transmission through a pile of plates, by double refraction, by selective absorption and by scattering.The intensity of the emergent light varies from maximum to minimum twice when it is passed through a nichol prism.

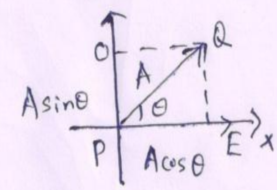
Figure 11 : Different types of polarisation


b
y=b/a
a

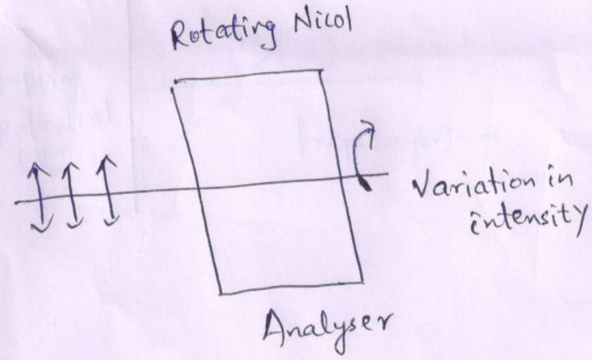

y=-b/a
b
a

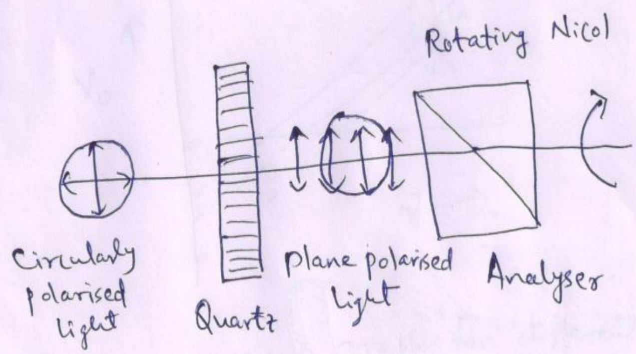

b
a





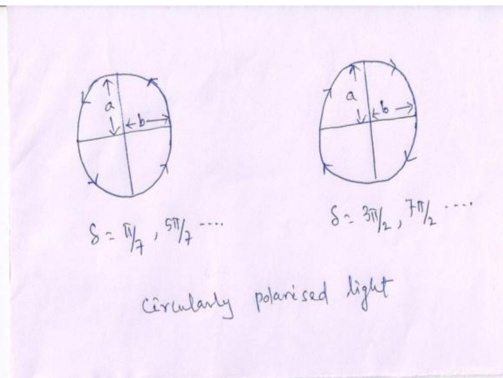
Production of polarised light





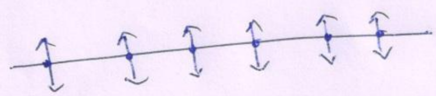
When the vibrations are scattered in a circular form then it is known as a circularly polarised light.To detect a circularly polarised light, it is first passed through a quarter wave plate and then viewed through a rotating Nichol.Firstly it is converted into a plane polarised light by the quarter wave plate. Then it will show variation in intensity from maximum to zero minimum twice by passing through a Nichol prism.

Figure 12 : Circularly polarised light

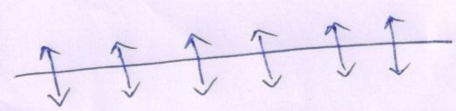


When the variation of the vibrating particles comes ain an elliptical form then it is known as elliptically polarised light.If elliptically polarised light beam is passed through a rotating Nichol the intensity of emergent light varies from maximum to minimum.The minimum intensity never be zero.To detect elliptically polarised light, the beam is first passed through a rotating Nichol.In case the beam is elliptically polarised, it will be converted into plane one by quarter wave plate. Then the change in intensity will be observed by passing through a rotating Nichol.

Figure 13 :Different types of polarised light



plane polarised light



Polarised light $\perp^r$ to the plane

Polarised light along the plane of incidence

When a ray is incident at an angle 59^0 on a glass slab,refracted ray and reflected ray are found to be perpendicular to each other.Calculate the polarising angle and refractive index of the glass.

$I_i = 59^0$

$I_p = 31^0$

Refractive index = $\tan^{-1}(I_p)$

Lecture No 30

Einstein's relations for lasers.

The upward transition between two energy levels (absoption) , the downward transition from the upper to the lower level(emission) and stimulated transition are described by certain equations known as Einstein's relations.

Under thermal equilibrium condition the mean population in the lower and upper levels are same.The transition from the upper to lower energy level must be equal to the transition from the lower to the upper level. Thus,

The number of atoms absorbing photons per sec per unit volume = The number atoms emitting photons per second per unit volume

The number of atoms absorbing photons per second per unit volume = $B_{12}\rho(\nu)N_1$

The number of atoms emitting photons per second per unit volume = $A_{21}N_2 + B_{21}\rho(\nu)N_2$

In equilibrium condition , the number of transitions from E_2 to E_1 must be equal to the number of transition from E_1 to E_2. Thus,

$B_{12}\rho(\nu)N_1 = A_{21}N_2 + B_{21}\rho(\nu)N_2$

Or,$\rho(\nu) = = A_{21}N_2 / B_{12}N_1 - B_{21}N_2$

where B_{12} is the co-efficient of absorption,B_{21} is the co-efficient of emission and A_{21} is the co-efficient of stimulated emission.

On dividing both the numerator and denominator on the right hand side of the above equation with $B_{12}N_2$, we get

$$\rho(\nu) = \frac{\frac{A21}{B12}}{\frac{N1}{N2} - \frac{B21}{B12}}$$

It follows from the above equation that

$N_1/N_2 = e^{(E2-E1)/kT}$

As $(E_2-E_1) = h\nu$

$$\rho(\nu) = \frac{A21}{B12}\left[\frac{1}{e^{h\nu/kT - \frac{B21}{B12}}}\right]$$

To maintain thermal equilibrium, the system must release energy in the form of electromagnetic radiation.

Energy density will be consistent with Planck's law only if

$B_{12} = B_{21}$

And $A_{21}/B_{12} = 8\boldsymbol{\pi} h\nu^3\mu^3/c^3$

Therefore, $B_{12} = B_{21} = (c^3/8\boldsymbol{\pi} h\nu^3\mu^3)A_{21}$

The above equations are known as Einstein's relations.

Lecture No 31

Tunneling effect

In quantum mechanics, when the energy of the particle is less than the total energy of the system then also there is some probability to get the particle free which is not possible in classical mechanics.This phenomenon of crossing over the potential barrier when the total energy of the particle (E) < height of the potential barrier(V_o) is known as the tunnelling effect.

The time independent Schrodinger;s equation is written as

$$\frac{d^2\Psi 1}{d^2x} + \frac{2m}{\hbar^2}(E - V_o)\,\Psi_1 = 0 \;, \qquad (1)$$

Where Ψ_1 represents the wave function in region 1.In the region 1 the particle is assumed to be free so V_0 =0, the particle does not have to pass through a barrier.

In region 2, let the wave function be denoted as Ψ_2, here the particle has to overcome a potential barrier and let it be denoted as V_0.

The time independent Schrodinger;s equation in region 2 is written as

$$\frac{d^2\Psi 2}{d^2x} - \frac{2m}{\hbar^2}(E - V_o)\,\Psi_2 = 0 \;, \qquad (2)$$

In the region 2, the particle has to make several head on collisions with the wall s of the potential barrier and after about 10^{38} collisions/sec the particle can get over to the third region and again become free. Here the energy of the particle is much less than that of the potential strength.

In region 3, let the wave function be denoted as Ψ_3.

$$\frac{d^2\Psi}{d^2x} + \frac{2m}{\hbar^2}E\;\Psi_3 = 0 \qquad (3)$$

By applying appropriate boundary conditions ,the above three Schrodinger's equation can be solved

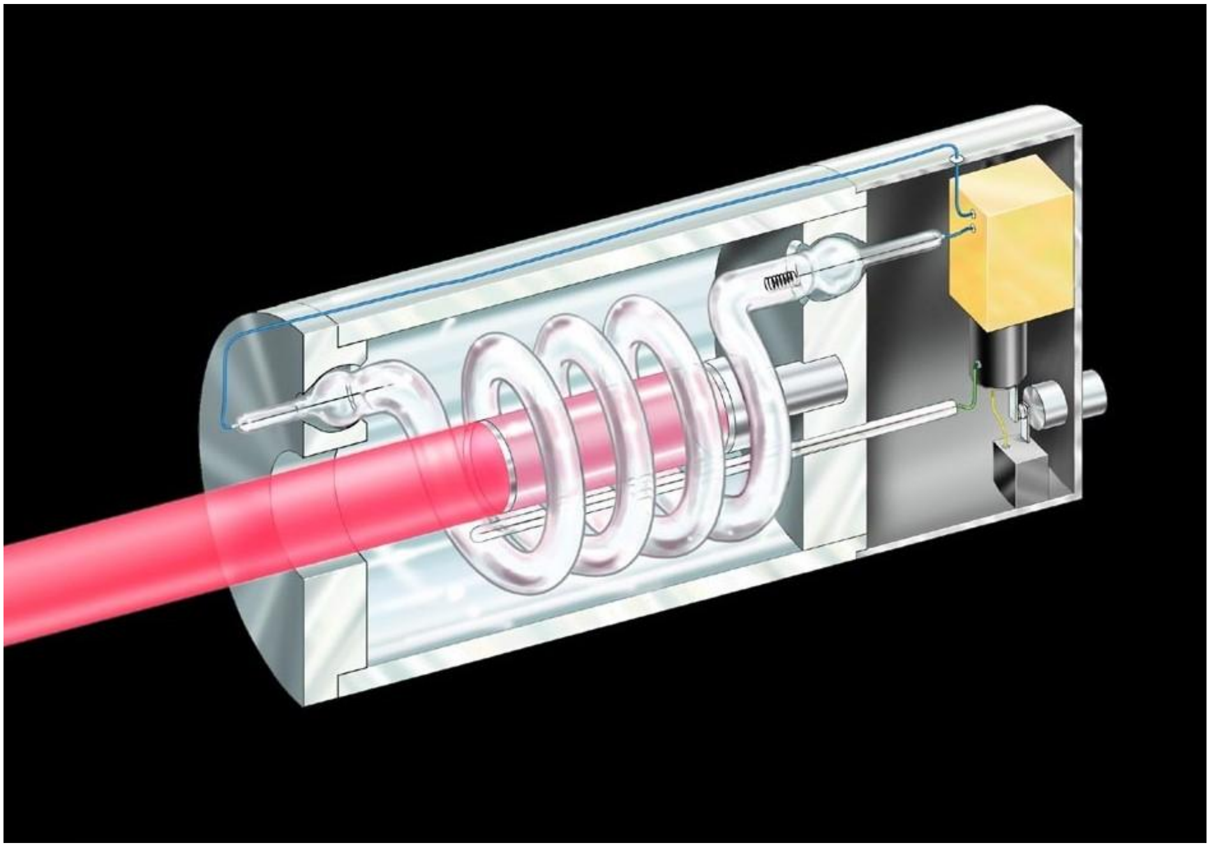
to get the expression for transition probability.

Lecture no 32

Working principle of Ruby laser.

Ruby laser is the first one .It is a three level laser system and the energy levels of Cr^{3+} ions in the crystal lattice play the role for lasing action. There are two wide bands E_3 and E_3' and a pair of closely spaced levels at E_2.When the ruby rod is irradiated with an intense beam of white light from xenon lamp, the ground state Cr^{3+} ions absorb light in two bands(i) one centred near 5500A and the other at about (ii)4000A and are excited to the broad upper bands.The energy levels in these bands have a very small lifetime $\leq 10^{-9}$sec.The excited Cr^{3+} ions rapidly lose some of their energy to the crystal lattice and undergo non-radiative transition to the pair of adjacent levels denoted as E_2.These levels are metastable states having a lifetime $3x10^{-3}$ sec.The transition from E_2 to E_1 is radiative.

Figure 26:Ruby laser



The population inversion occurs in E_2 with respect to the ground level when the pumping energy above a critical threshold value.One of the spontaneously emitted fluorescent photons travelling parallel to the axis of the ruby rod would initiate stimulated emissions.The photons get many relections and the lasing action starts.The laser beam from the ruby rod is red in colour and corresponds to a wavelength of 6943 A.The green and the blue components of light act as the agent and these components are not amplified by the active medium.It is a spontaneous fluorescent photon red in colour emitted by one of the Cr^{3+} ions that act as input and gets amplified.

The xenon flash operates for a few milliseconds. The output occurs in the form of irregular pulses of microsecond duration as the stimulated transitions occur faster than the rate at which population inversion is maintained in the crystal. Once the stimulated transitions started , the metastable states get depopulated very rapidly and at the end of each pulse, the population falls below the threshold value and results in end of the lasing action.The ruby laser has the high energy storage capability because of long upper laser level lifetime of 3msec.Thus,pulse energies of upto 100 J are possible.

Figure 27: Ruby laser with internal and external mirror ,energy levels of Ruby laser

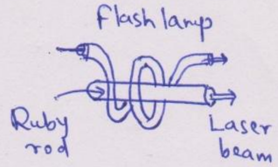


Fig. a) Ruby laser with internal mirror

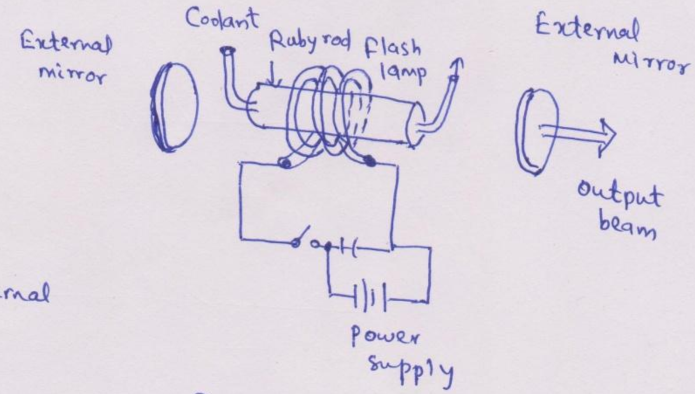


Fig. b) Ruby laser with external mirror

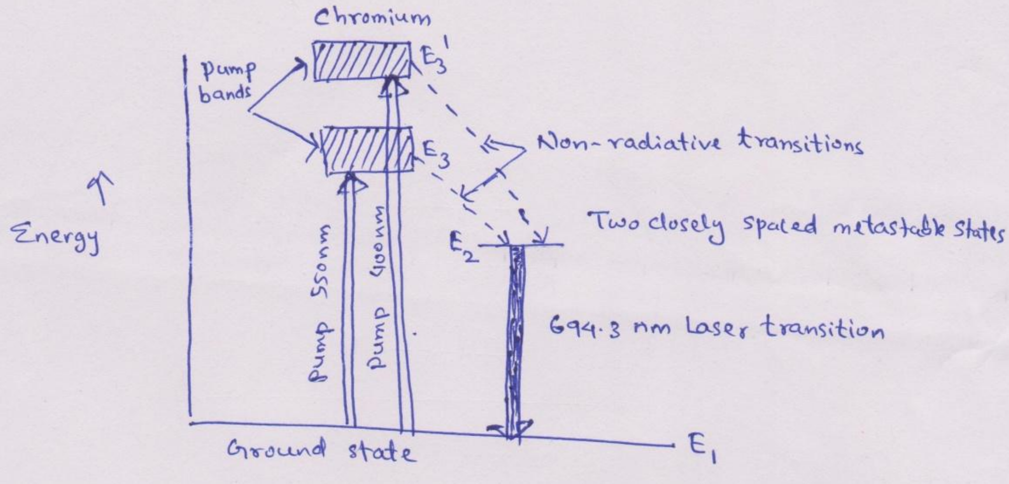


Fig. Energy levels of chromium atoms in ruby laser

Lecture 33

Applications of different types of lasers.

(i)Ruby laser is used in holography.

(ii)Neodymium laser is used a)to produce green light used for traffic signal.

b)widely in material processing and resistor trimming

c) in medical applications in association with optical fibre delivery systems to deliver energy to the appropriate location in the body.

d)in nuclear fusion and and in military applications such as range finding.

(iii) Solid state laser s are used for remote sensing and in space crafts..

(iv)Alexandrite laser is widely used in cancer therapy, pollution detection and kidney stone removal.

(v)Fiber lasers are highly useful in under sea communication and long haul communication skills.

(vi) He-Ne gas lasers are widely used in laboratories as a monochromatic source in interferrometry, laser printing, bar code reading, reference beam in surveying for alignment in pipe laying.

(vii)Krypton ion laser is used for multicolour display.

(viii)He-Cd laser is used in photolithography, inspections of electronic circuit boards,CD-ROM mastering,fluorescence analysis and so on.

(ix)Copper vapour lasers are used to pump tunable dye lasers, high speed flash photography and material processing. Gold vapour laser is used in photodynamic therapy for destroying the cancerous cells.

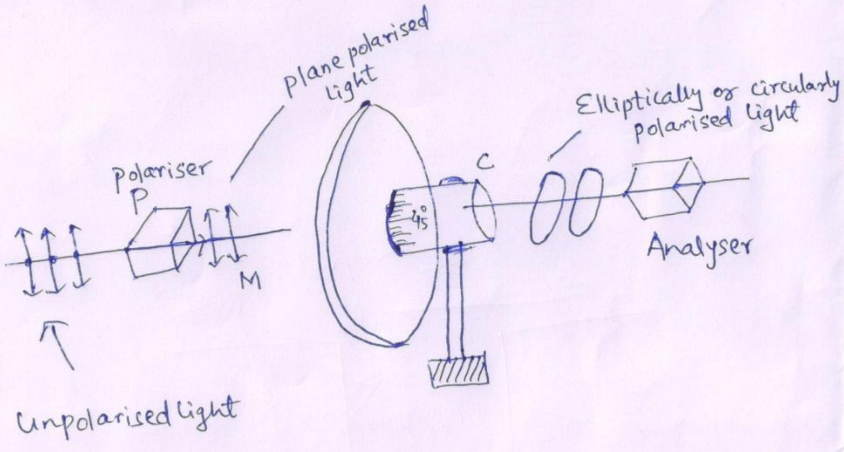
(x)CO_2 laser is used in the field of material processing, cutting, drilling, material removal, welding, etching, melting, annealing, hardening etc.

Lecture No 34

Experimental arrangement for production of elliptically polarised light from unpolarised light.

The unidirectional path of light perpendicular the plane of propagation/vibration is known as the polarisation of light.

Figure 31: Elliptically polarised light from unpolarised light



production of elliptically polarised light from unpolarised light (Experimental arrangement)

Referring to the figure P is the polariser through which unpolarised light passes through

A is the analyser through which elliptically polarised light can be easily analysed after passing through the clamp and screw arrangement

The amplitude of the plane polarised light while entering the quarter wave plate splits into two mutually perpendicular components having a phase angle of $\pi/2$ between the ordinary and extra ordinary rays.The quarter wave plate Q is again rotated about the outer fixed tube till the field again becomes dark. C is rotated that the mark M on Q coincides with mark 45^{0} on the tube.

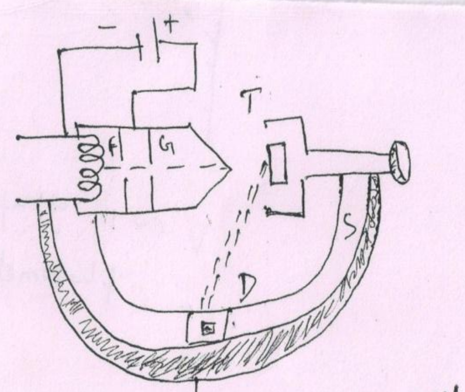
Elliptically polarised light is produced when the two waves of unequal amplitudes vibrating at right angle to each other and having a phase difference of $\pi/2$ or path difference of $\lambda/4$ occurs between them.When plane polarised light falls normally on aquarter wave plate in such a way that the plane of vibration of the incident light makes an angle other than 45^{0} with the direction of optic axis, then elliptically polarised light is produced.

Lecture No 35

de Broglie hypothesis was confirmed by Davisson and Germer ?

Ans. De Broglie’s hypothesis is concerned with a special type of wave known as matter waves which show both particle and wave nature of radiation. When the particles are having certain velocity the only a wave can be generated.In 1927,two American physicists Davisson and Germer predicted experimentally about the existence of matter waves.

Figure 36: Davisson Germer experiment


−
+
T
F
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In the diagram F is the filament which is heated to eject electrons by thermionic emission.

G is a system of electrodes with central holes maintained at increasing potential from which electron beam is produced.

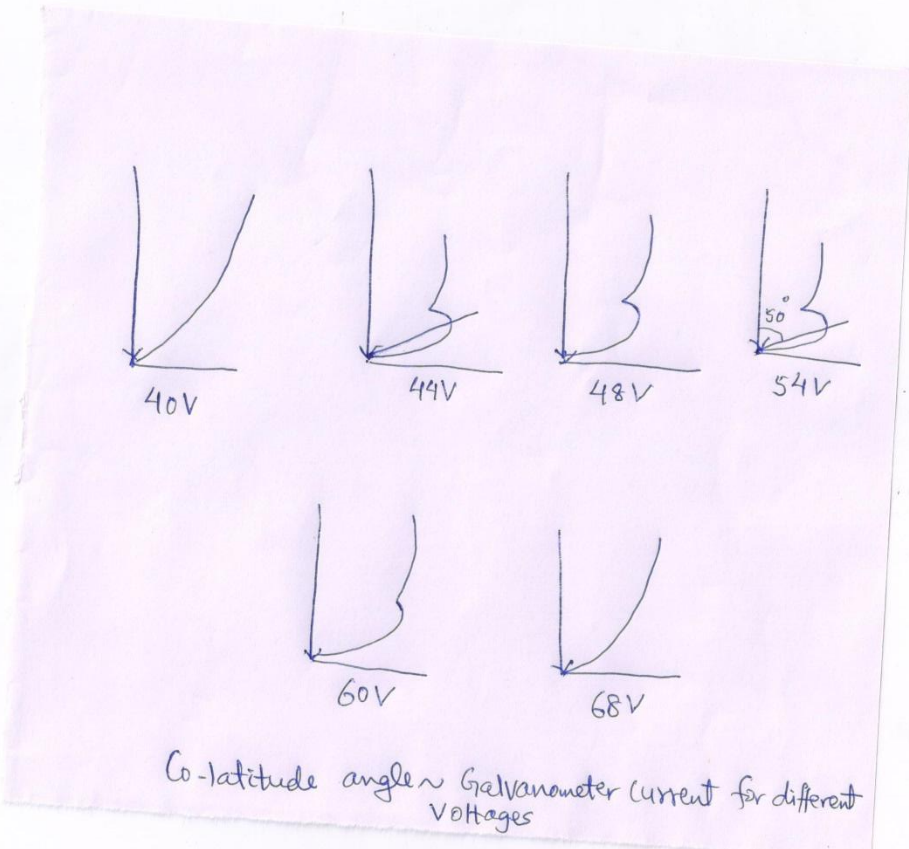
Tis a target made up of a crystal of nickel on which monoenergetic electrons fall.

C is the Faraday cylinder known as collector on which some of the scattered electrons entered.

G is the Galvanometer to measure the amplified collector current.The collector can be moved on a graduated circular scale S to receive electrons. The collector has two walls insulated from each other.A retarding potential is applied between the inner and outer walls of the collector such that only fast moving electrons coming from the electron gun may enter into the collector and not the secondary slow electrons from the target.

The experiment was carried out in two different positions i.e (i)normal incidence and (ii) oblique incidence position.In the normal incidence position the beam of electrons fall normally on the circular scale tovarious positions and the galvanometer current was recorded at each position .A graph was plotted between the colatitude and galvanometer current.Several curves are obtained for different voltage electrons.

Figure 37: The experiment carried out at different voltages



It is observed that a bump begins to appear in the curve for 44V electrons.This bump moves upward as the volatage increases and attains the greatest development for 54 volts and a colatitude of 50^0.Above 54 V the bump again diminishes.The bump at this voltage offers the existence of electron waves.The surface rows of atoms act like the rulings of adiffraction grating producing the 1^{st} order spectrum of 54 V electrons at $\theta = 50^0$.

Applying the formula for plane diffraction of a grating

$n\lambda = (c+d)\sin\theta$

For n=1 ,(c+d)=2.54 A we found λ=1.65 A

Again according to the de Broglie wave particle dualism electron wavelength

$\lambda = \frac{150}{V} A = 1.66$ A

This shows that the electrons have wave like characteristics.

Lecture No 36

An **optical fiber** is a flexible, transparent fiber made by silica or plastic to a diameter slightly thicker than that of a human hair. Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data rates) than wire cables. Fibers are used instead of metal wires because signals travel along them with lesser amounts of loss; in addition, fibers are also immune to electromagnetic interference, a problem which metal wires suffer from excessively. Fibers are also used for illumination, and are wrapped in bundles so that they may be used to carry images, thus allowing viewing in confined spaces, as in the case of a fiberscope. Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers.

Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by the phenomenon of total internal reflection which causes the fiber to act as a waveguide. Fibers that support many propagation paths or transverse modes are called multi-mode fibers (MMF), while those that support a single mode are called single-mode fibers (SMF). Multi-mode fibers generally have a wider core diameter and are used for short-distance communication links and for applications where high power must be transmitted. Single-mode fibers are used for most communication links longer than 1,000 meters (3,300 ft).

When the light passes from air into water, the refracted ray is bent *towards* the perpendicular... When the ray passes from water to air it is bent *from* the perpendicular... If the angle which the ray in water encloses with the perpendicular to the surface be greater than 48 degrees, the ray will not quit the water at all: it will be *totally reflected* at the surface.... The angle which marks the limit where total reflection begins is called the limiting angle of the medium. For water this angle is 48°27′, for flint glass it is 38°41′, while for diamond it is 23°42′.

Practical applications, such as close internal illumination during dentistry, appeared early in the twentieth century. Image transmission through tubes was demonstrated independently by the radio experimenter Clarence Hansell and the television pioneer John Logie Baird in the 1920s. The principle was first used for internal medical examinations by Heinrich Lamm in the following decade. Modern optical fibers, where the glass fiber is coated with a transparent cladding to offer a more suitable refractive index, appeared later in the decade. Development then focused on fiber bundles for image transmission. Harold Hopkins and Narinder Singh Kapany at Imperial College in London achieved low-loss light transmission through a 75 cm long bundle which combined several thousand fibers. Their article titled "A flexible fibrescope, using static scanning" was published in the journal *Nature* in 1954. The first fiber optic semi-flexible gastroscope was patented by Basil Hirschowitz, C. Wilbur Peters, and Lawrence E. Curtiss, researchers at the University of Michigan, in 1956. In the process of developing the gastroscope, Curtiss produced the first glass-clad fibers; previous optical fibers had relied on air or impractical oils and waxes as the low-index cladding material.

NASA used fiber optics in the television cameras that were sent to the moon. At the time, the use in the cameras was classified *confidential*, and only those with sufficient security clearance or those accompanied by someone with the right security clearance were permitted to handle the cameras

The emerging field of photonic crystals led to the development in 1991 of photonic-crystal fiber, which guides light by diffraction from a periodic structure, rather than by total internal reflection. The first photonic crystal fibers became commercially available in 2000. Photonic crystal fibers can carry higher power than conventional fibers and their wavelength-dependent properties can be manipulated to improve performance.

Optical fiber can be used as a medium for telecommunication and computer networking because it is flexible and can be bundled as cables. It is especially advantageous for long-distance communications, because light propagates through the fiber with little attenuation compared to electrical cables. This allows long distances to be spanned with few repeaters. For short distance application, such as a network in an office building, fiber-optic cabling can save space in cable ducts. This is because a single fiber can carry much more data than electrical cables such as standard category 5 Ethernet cabling, which typically runs at 100 Mbit/s or 1 Gbit/s speeds. Fiber is also immune to electrical interference; there is no cross-talk between signals in different cables, and no pickup of environmental noise. Non-armoured fiber cables do not conduct electricity, which makes fiber a good solution for protecting communications equipment in high voltage environments, such as power generation facilities, or metal communication structures prone to lightning strikes. They can also be used in environments where explosive fumes are present, without danger of ignition.

Lecture No.38

Characteristics of fiber optics:

The advantages of optical fiber communication with respect to copper wire systems are:

Broad bandwidth

A single optical fiber can carry 3,000,000 full-duplex voice calls or 90,000 TV channels.

Immunity to electromagnetic interference

Light transmission through optical fibers is unaffected by other electromagnetic radiation nearby. The optical fiber is electrically non-conductive, so it does not act as an antenna to pick up electromagnetic signals. Information traveling inside the optical fiber is immune to electromagnetic interference, even electromagnetic pulses generated by nuclear devices.

Low attenuation loss over long distances

Attenuation loss can be as low as 0.2 dB/km in optical fiber cables, allowing transmission over long distances without the need for repeaters.

Electrical insulator

Optical fibers do not conduct electricity, preventing problems with ground loops and conduction of lightning. Optical fibers can be strung on poles alongside high voltage power cables.

Material cost and theft prevention

Conventional cable systems use large amounts of copper. In some places, this copper is a target for theft due to its value on the scrap market.

Security of information passed down the cable

Copper can be tapped with very little chance of detection

Optical fibers can be used as sensors to measure strain, temperature, pressure and other quantities by modifying a fiber so that the property to measure modulates the intensity, phase, polarization, wavelength, or transit time of light in the fiber. Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. A particularly useful feature of such fiber optic sensors is that they can, if required, provide distributed sensing over distances of up to one meter. In contrast, highly localized measurements can be provided by integrating miniaturized sensing elements with the tip of the fiber. These can be implemented by various micro- and nanofabrication technologies, such that they do not exceed the microscopic boundary of the fiber tip, allowing such applications as insertion into blood vessels via hypodermic needle.

Extrinsic fiber optic sensors use an optical fiber cable, normally a multi-mode one, to transmit modulated light from either a non-fiber optical sensor—or an electronic sensor connected to an optical transmitter. A major benefit of extrinsic sensors is their ability to reach otherwise inaccessible places. An example is the measurement of temperature inside aircraft jet engines by using a fiber to transmit radiation into a radiation pyrometer outside the engine. Extrinsic sensors can be used in the same way to measure the internal temperature of electrical transformers, where the extreme electromagnetic fields present make other measurement techniques impossible. Extrinsic sensors measure vibration, rotation, displacement, velocity, acceleration, torque, and twisting. A solid state version of the gyroscope, using the interference of light, has been developed. The *fiber optic gyroscope (FOG)* has no moving parts, and exploits the Sagnac effect to detect mechanical rotation.

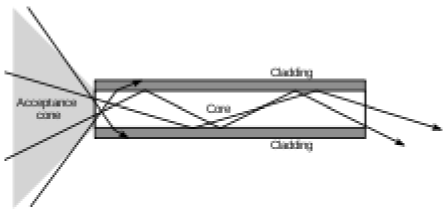
Common uses for fiber optic sensors includes advanced intrusion detection security systems. The light is transmitted along a fiber optic sensor cable placed on a fence, pipeline, or communication cabling, and the returned signal is monitored and analyzed for disturbances. This return signal is digitally processed to detect disturbances and trip an alarm if an intrusion has occurred.

Optical fibers have a wide number of applications. They are used as light guides in medical and other applications where bright light needs to be shown on a target without a clear line-of-sight path. In some buildings, optical fibers route sunlight from the roof to other parts of the building. Optical fiber lamps are used for illumination in decorative applications, including signs, art, toys and artificial Christmas trees. Swarovski boutiques use optical fibers to illuminate their crystal showcases from many different angles while only employing one light source. Optical fiber is an intrinsic part of the light-transmitting concrete building product, LiTraCon.

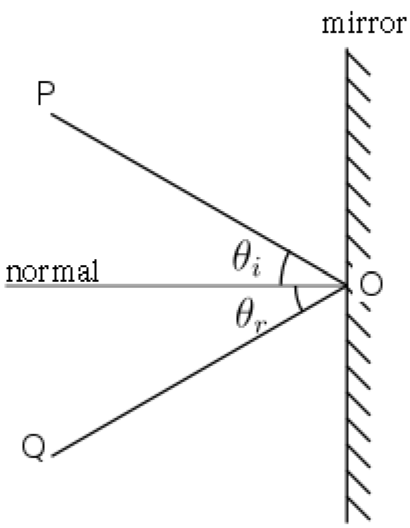
Use of optical fiber in a decorative lamp or nightlight.

Optical fiber is also used in imaging optics. A coherent bundle of fibers is used, sometimes along with lenses, for a long, thin imaging device called an endoscope, which is used to view objects through a small hole. Medical endoscopes are used for minimally invasive exploratory or surgical procedures. Industrial endoscopes are used for inspecting anything hard to reach, such as jet engine interiors. Many microscopes use fiber-optic light sources to provide intense illumination of samples being studied.

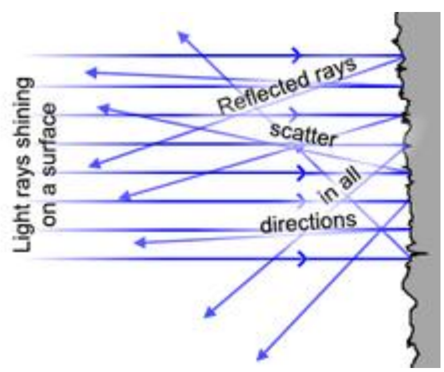
In spectroscopy, optical fiber bundles transmit light from a spectrometer to a substance that cannot be placed inside the spectrometer itself, in order to analyze its composition. A spectrometer analyzes substances by bouncing light off and through them. By using fibers, a spectrometer can be used to study objects remotely.



The propagation of light through a multi-mode optical fiber



Specular reflection



Diffuse reflection