Engineering Physics 1
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Module-01
Lecture-01
Introduction

I am M. K. Srivastava of Physics department IIT, Roorkee. This is the first lecture of a five lecture series on Polarization of light. In these lectures on polarization of light, we shall begin with introduction to the Maxwell's equations and electromagnetic waves. We shall then take a problem of polarization of light, what is meant by it?

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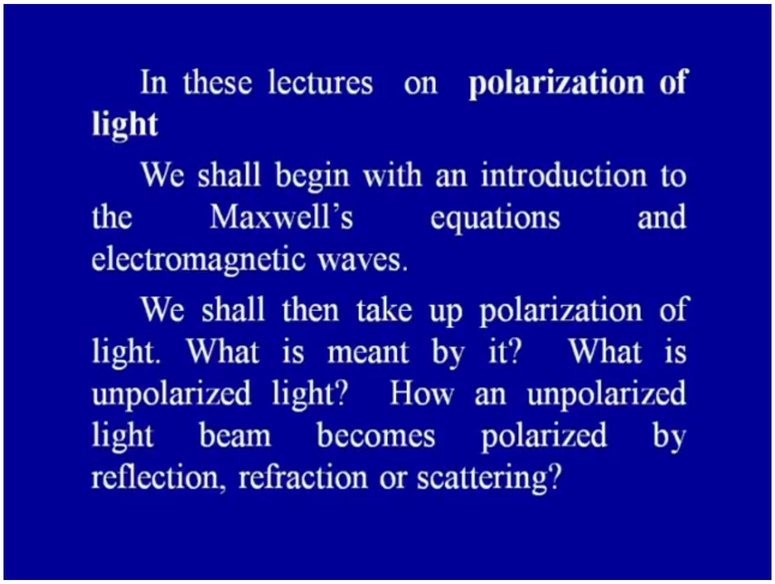

What is unpolarized light? How an unpolarized light beam becomes polarized by reflection, refraction or a scattering? Then, we shall look at Brewster's Law, shall try to understand working of a Polaroid;

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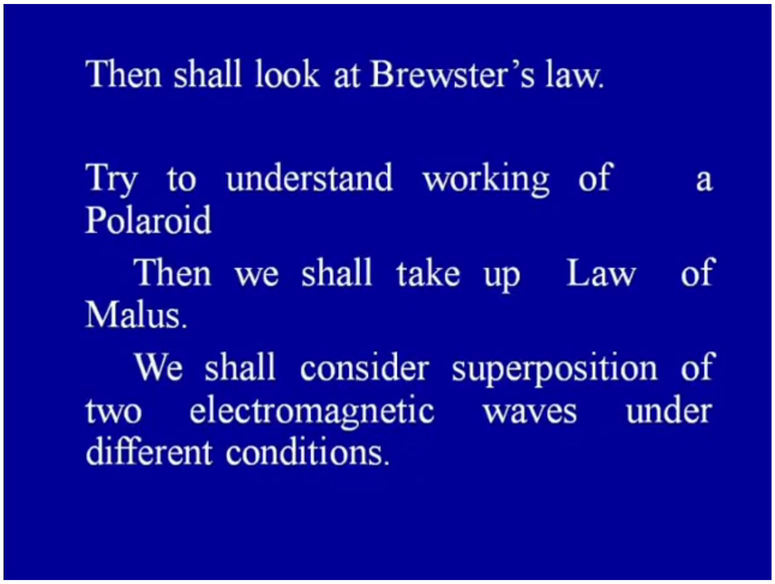

Then, we shall take up Law of Malus. Then, we shall consider a superposition of two electromagnetic waves under different conditions.

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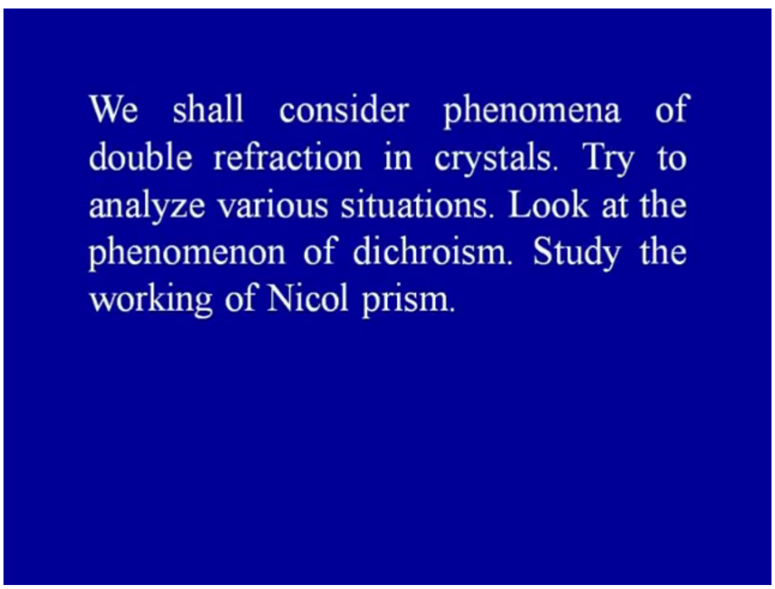

We shall consider phenomena of double refraction in crystals and isotropic crystals. Try to analyze various situations therein. We shall try to look at the phenomena of dichroism, we shall study the working of Nicole prism.

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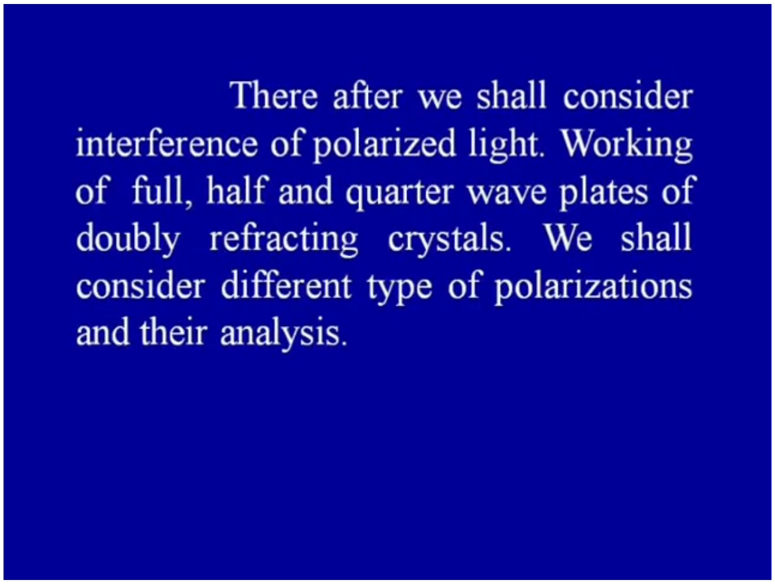

Thereafter we shall consider interference of polarized light, working of full wave plate half wave plate and quarter wave plate of doubly refracting crystals. We shall consider different types of polarizations and then their analysis.

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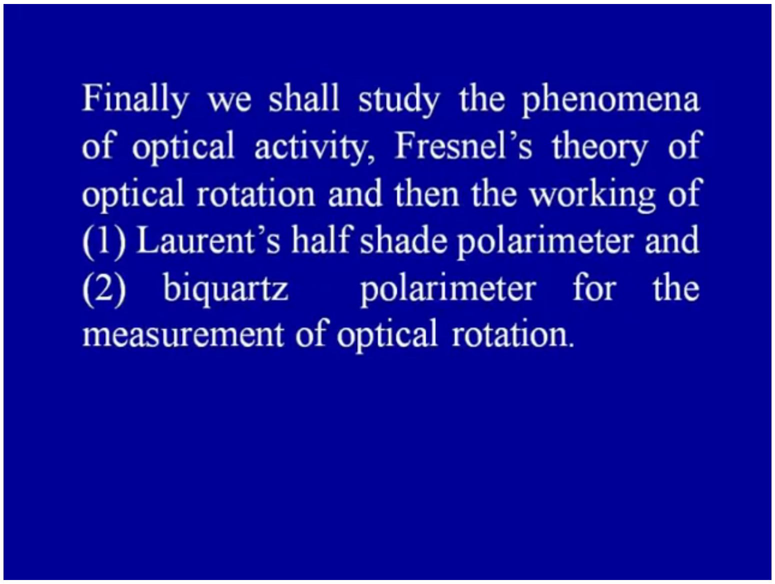

And finally, in the last lecture, we shall study the phenomena of optical activity, Fresnel's theory of optical rotation and then the working of polarimeters: Number one, Laurent's half spade polarimeter and biquartz polarimeter for the measurement of optical rotation. So, let us begin. You see the light waves are an electromagnetic phenomenon.

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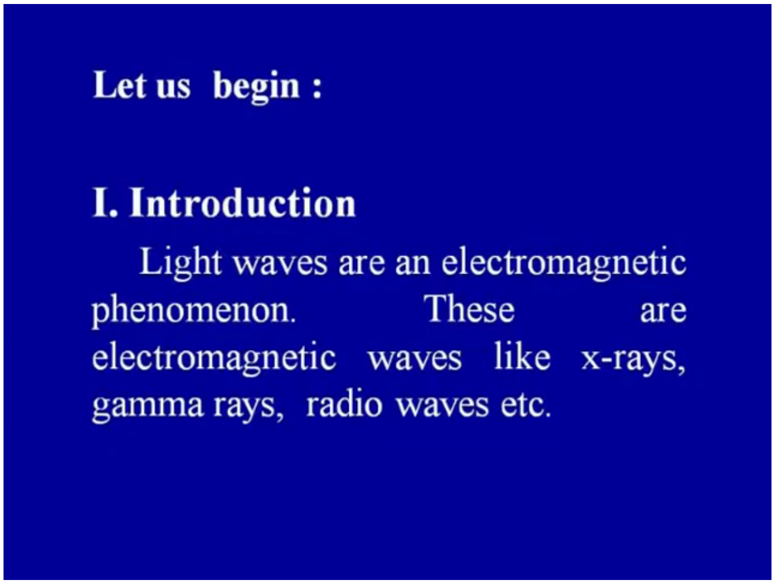

These are electromagnetic waves like x-rays, gamma rays, radio waves, etcetera.

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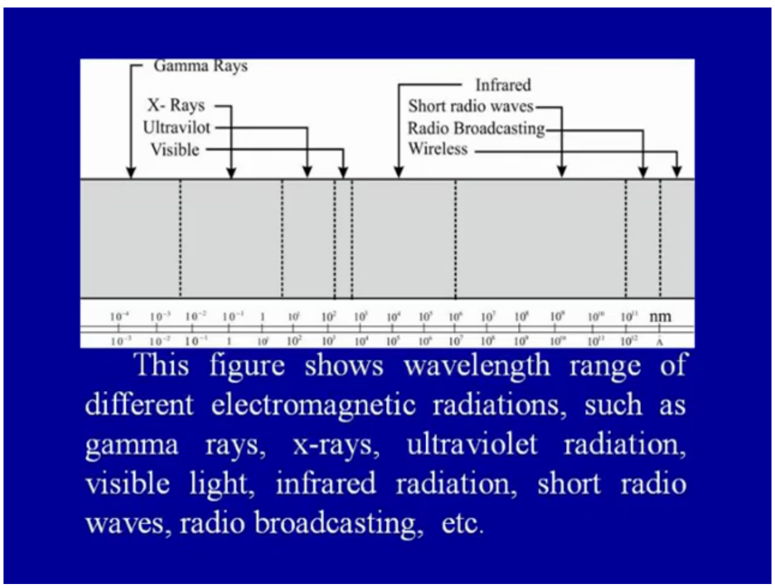

If this figure shows wavelength range of different electromagnetic radiations such as, gamma rays, as I said, x-rays, ultraviolet radiation, visible light, infrared radiation, short radio waves, radio broadcasting, etcetera.

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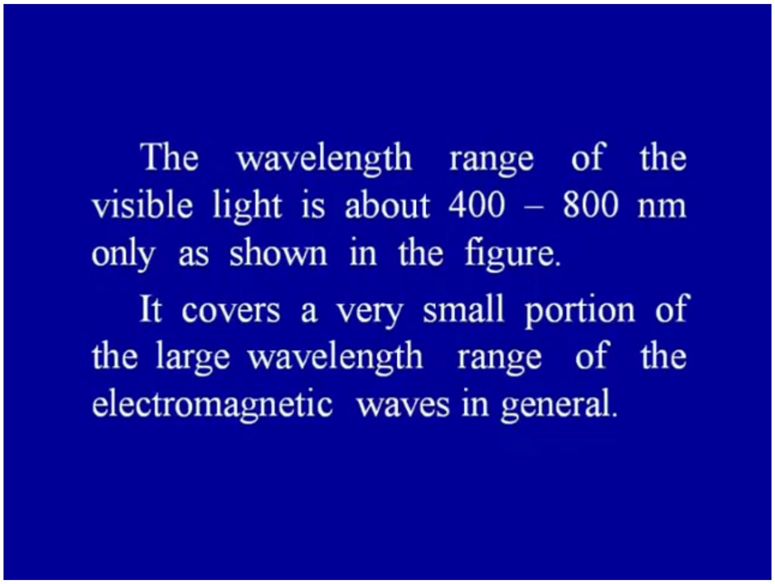

If the wavelength range of the visible light is about 400 to 800 nanometers only. I have shown in the figure. It covers a very small portion of the large wavelength range of the electromagnetic waves in general.

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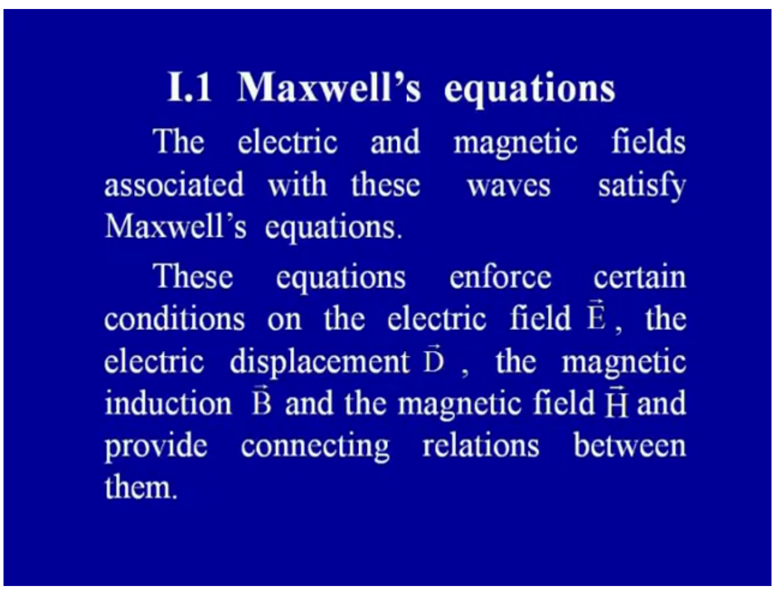

The electric and magnetic fields associated with these waves satisfy Maxwell's equations. These equations enforce certain conditions on the electric field E, the electric displacement D, the magnetic induction B and the magnetic field H and provide connecting relations between them.

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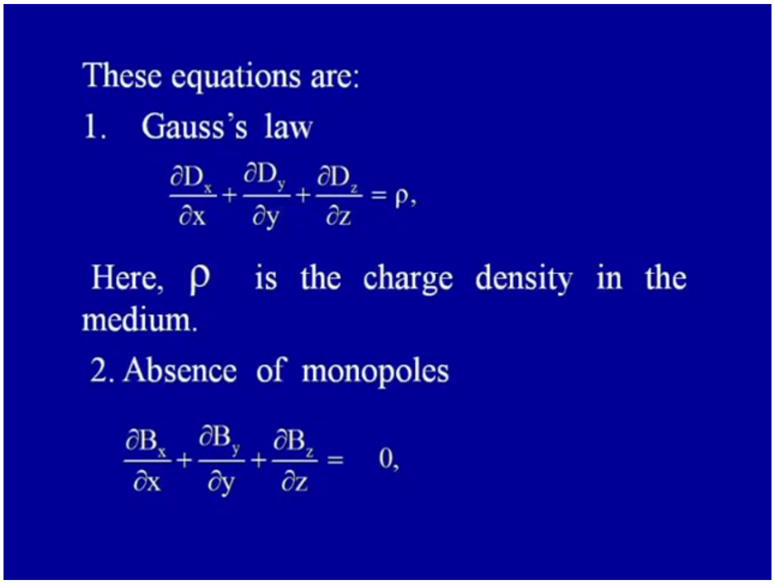

These equations are: Number one, Gauss's law del Dx by dx + del D y by dy + del Dz by dz = Rho. Here the Rho is the charge density in the medium. Number two, absence of mono poles del Bx by del x + del By by del y + del Bz by del z = 0.

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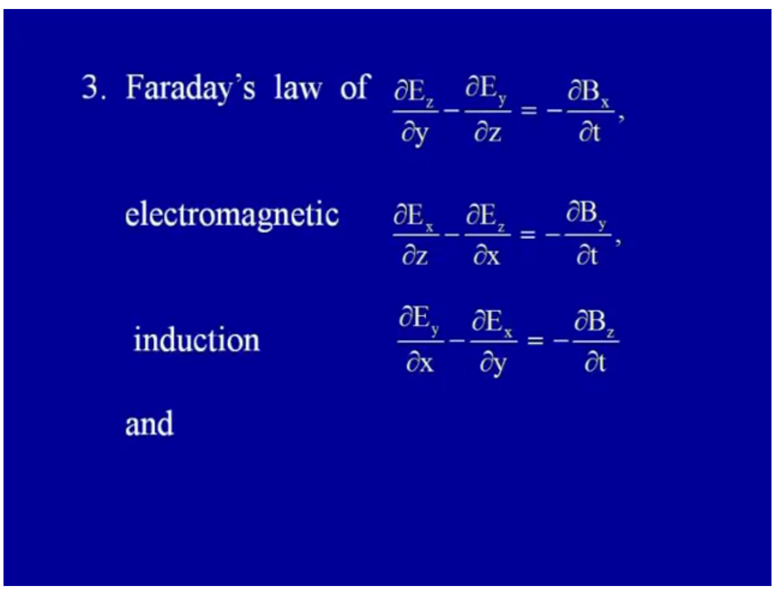

Number three, Faraday's law of electromagnetic induction del Ex by del Ey - del Ey by del Ex is = - del Bz by del t, similarly, for the other three components.

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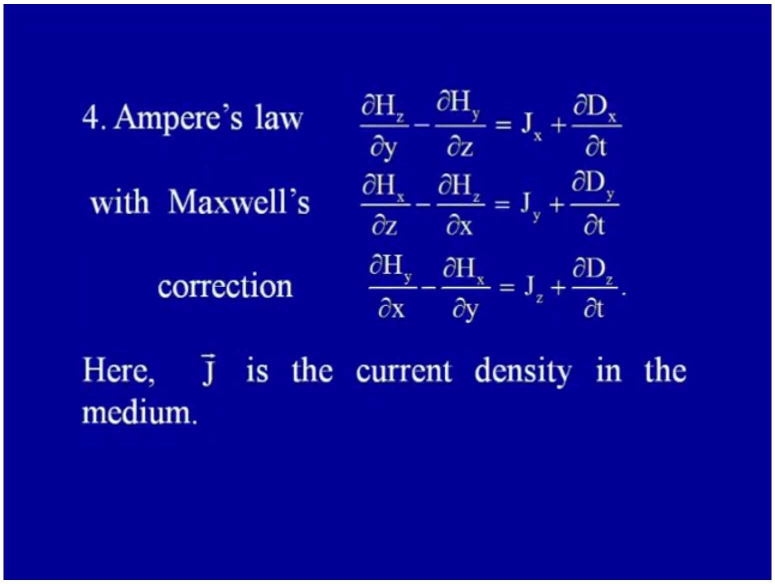

Number four: Ampere's law with Maxwell's Corrections. This is again a equation relating H, D and J. Here J is the current density in the medium using vector notation if you like that. The above equations can be written in the following compact form.

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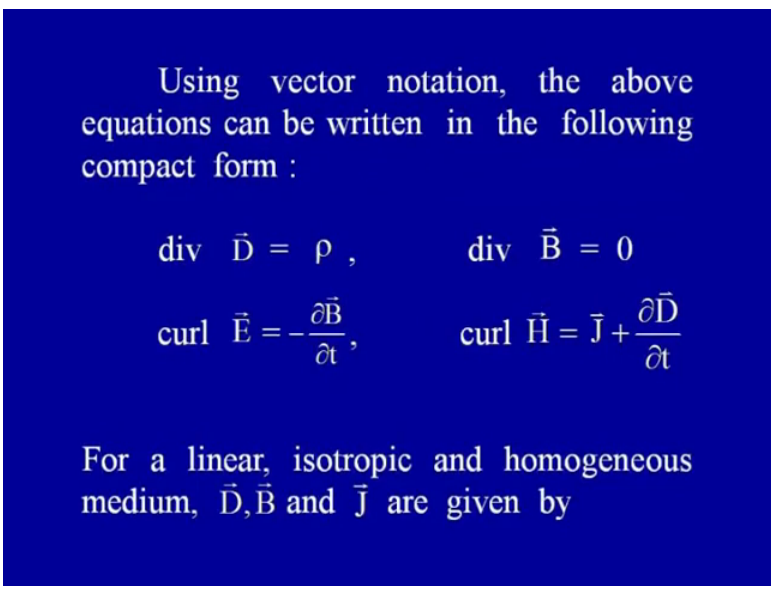

Divergence of D is = Rho, divergence of B is = 0 indicating absence of multipoles, curl of E is = - del B by del t. That is Faraday's law and curl H is = J + del D by del t. That is Ampere's law with Maxwell's Corrections for a linear isotropic and homogeneous medium. These quantities is D, B and J are given by

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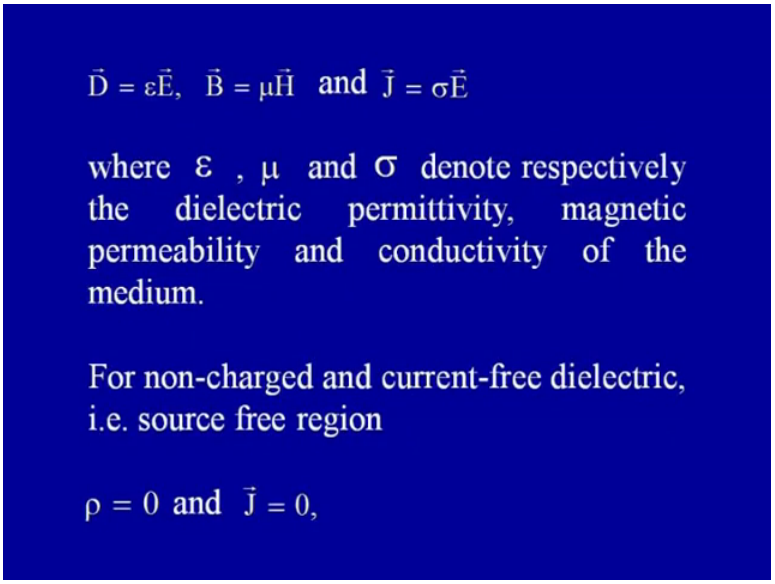

D is = Sigma times E, B is = MU times H, J = sigma times E, where at silent sigma, MU and Sigma denote respectively the dielectric permittivity magnetic permeability and conductivity of the medium. For non-charged and current free dielectric that is the source free region, where Rho is = 0 and J is also = 0.

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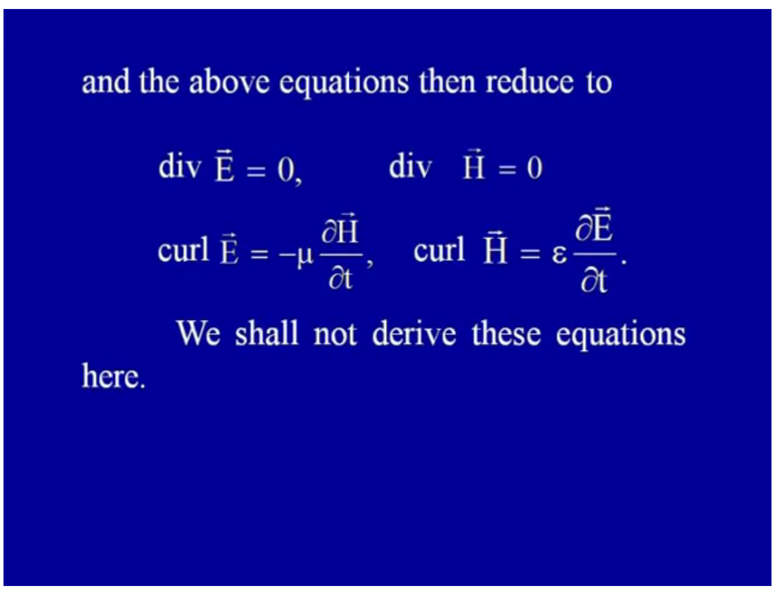

The above equations in that case they reduce to evidence of E = 0, divergence of H is also = 0, curl of E is = - del H by del t and curl of H is = epsilon times del E by del t. You see we shall not derive these equations here. Now the other equations you have seen, they are coupled equations.

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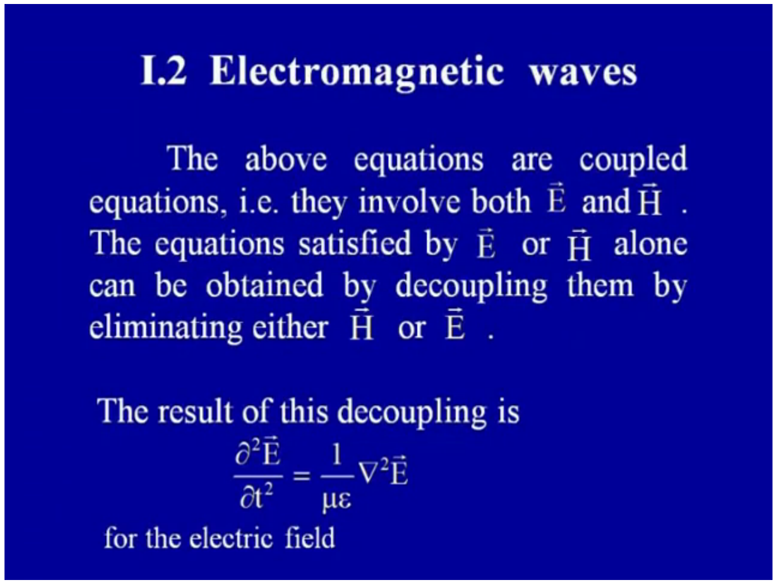

They involve both E and H in an equation. The equations satisfied by E or H alone can be obtained by decoupling them by eliminating either H from the equation or E from the equation. The result of this decoupling is del 2 E by del t square is = 1 upon MU epsilon times del square E for the electric field.

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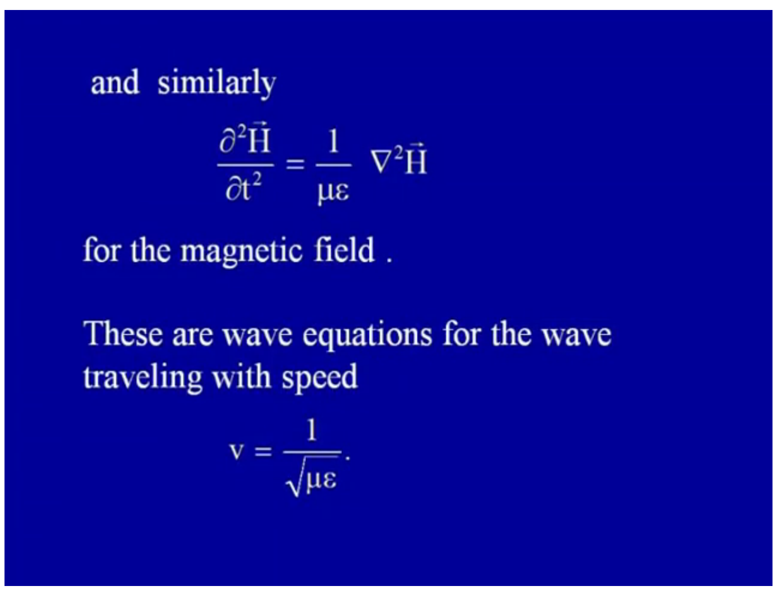

And similarly, del 2 H by del t square = 1 upon MU epsilon del square H for the magnetic field. These are wave equations for the wave traveling with the speed V given by 1 upon a square root of MU times epsilon in free space. That is in vacuum, no medium.

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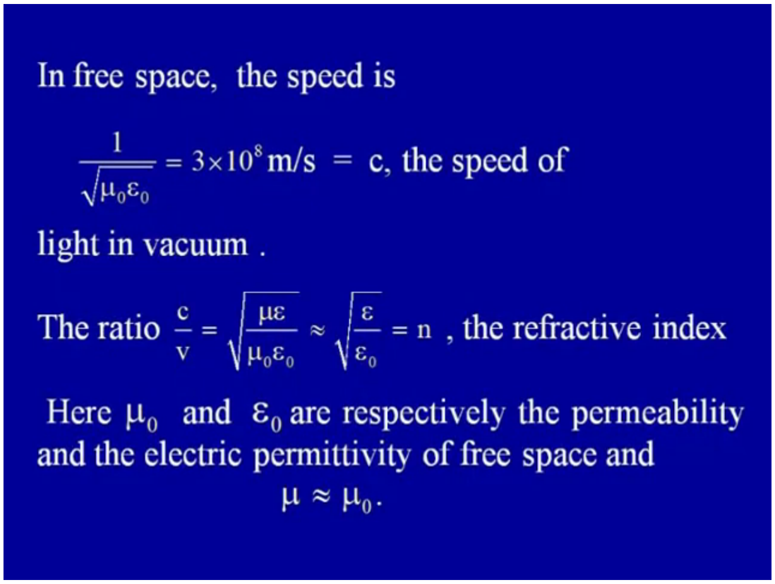

The speed is 1 upon a square root of MU naught times epsilon naught which is = 3 into 10 raised to the power 8 meters per second denoted by c. Usually the speed of light in vacuum. Now ratio c by v which is = square root of MU epsilon divided by MU naught epsilon naught, which is almost = the square root of epsilon upon epsilon naught is = n, the effective index of the medium. Here MU naught and epsilon naught are respectively the permeability and the electric permittivity of free space. And MU is almost = MU naught.

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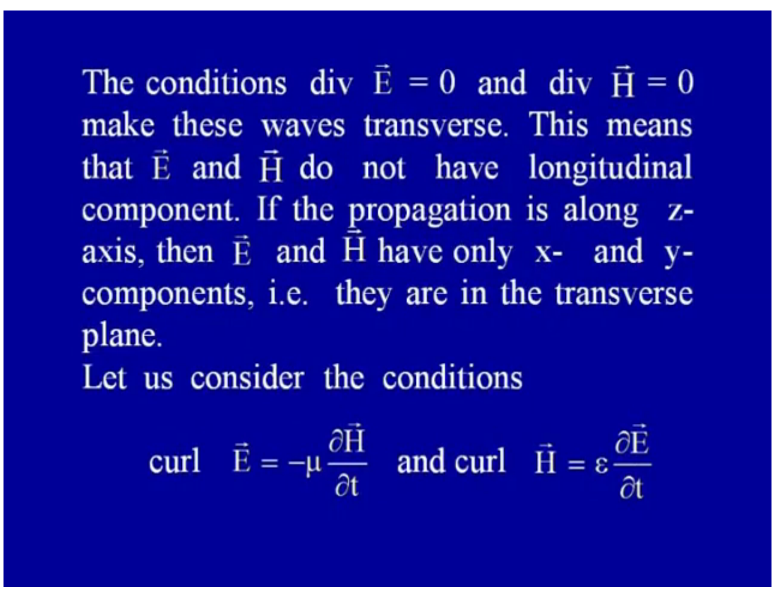

If the conditions, divergence of E = 0 and divergence of H = 0, make these waves transverse. This means that E and H do not have longitudinal components. If the wave is propagating along the x that axis then E and H have only x and y components, knows that component. They are in the transverse plane. Let us consider the conditions curl E is = - MU times del H by del t and the other one curl H is = epsilon times del E by del t.

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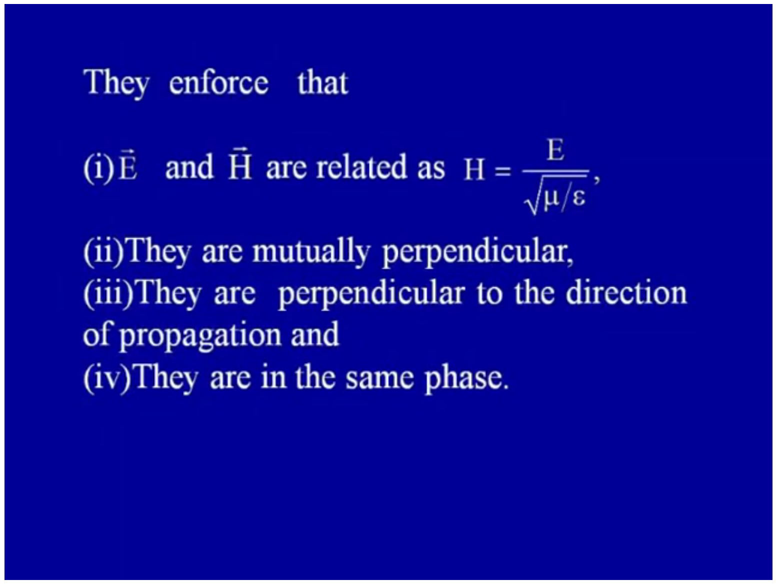

These conditions they enforce that number one, E and H are related as H is = E divided by square root of MU by epsilon. Number two, they are mutually perpendicular. That is E and H are mutually perpendicular. They are perpendicular to the direction of propagation. That is, if the wave is propagating along the z direction, they are perpendicular to the z axis. That is they are in the xy plane. And number four, they are in the same phase. E and H are in the same phase.

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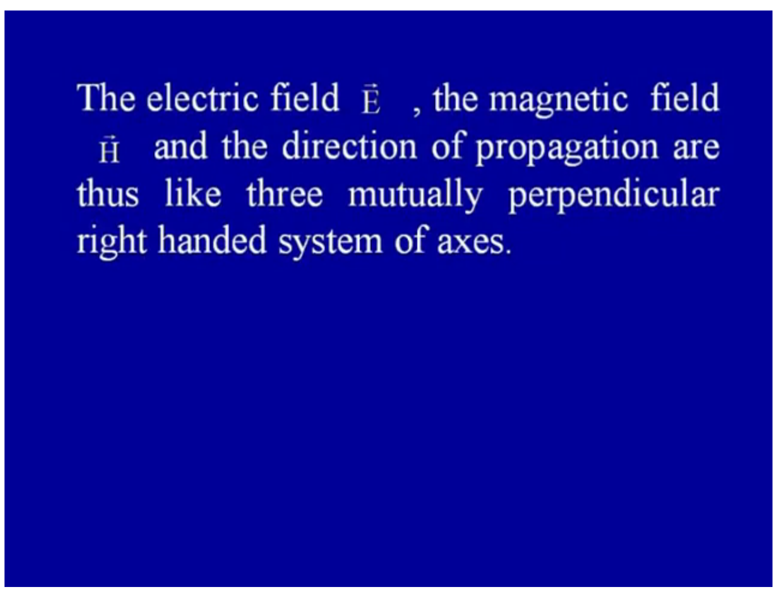

The electric field E, the magnetic field H and the direction of propagation are thus like three mutually perpendicular right handed system of axes x, y, z. So, let us now consider the polarization its meaning and what is unpolarized light. For plane monochromatic waves, traveling along the positive z axis, the electric and magnetic fields may be written in the form:

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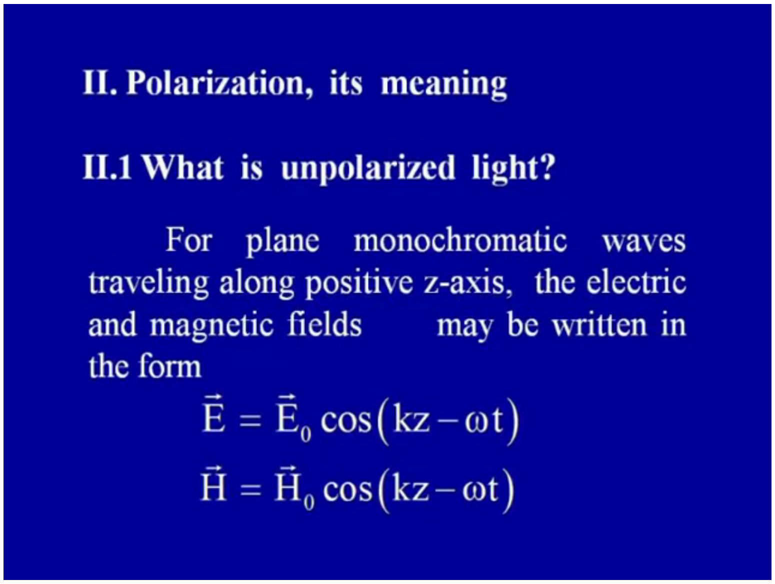

E is = E naught cos of kz minus Omega t and H is = H naught cos of kz minus Omega t because they are in the same phase.

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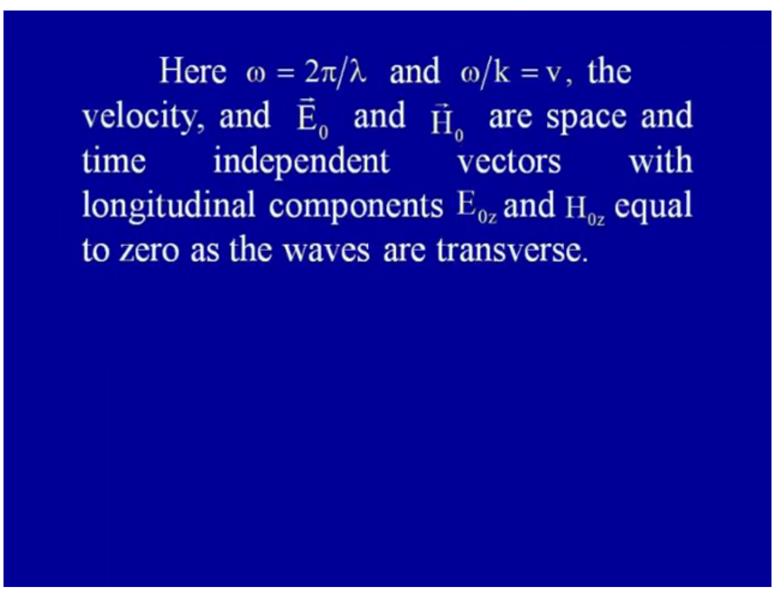

Here, Omega is = 2 pi by lambda and Omega by k is = v this velocity and E naught and H naught are space and time independent vectors with longitudinal components E naught z and H naught z = 0 as the waves are transverse.

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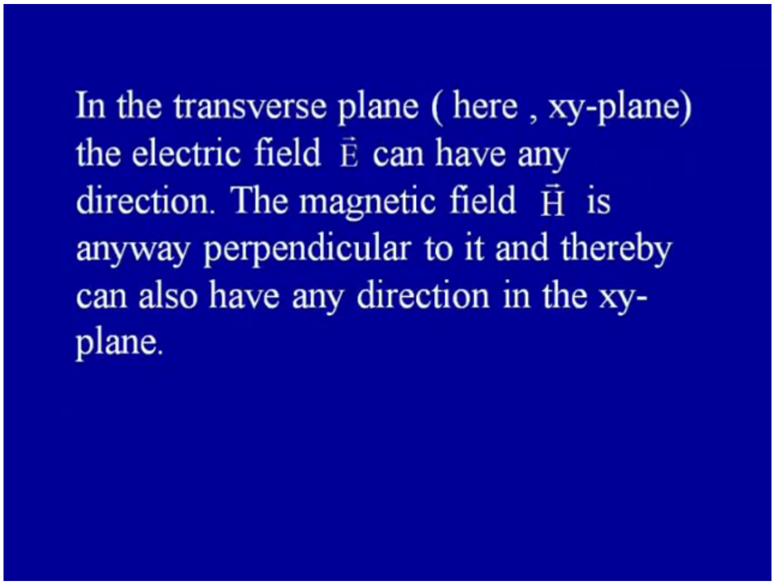

In the transverse plane which is the xy plane here. The electric field E can have any direction remaining within the xy plane. The magnetic field H is anyway perpendicular to it as we have seen. And thereby can also have any direction in the xy plane.

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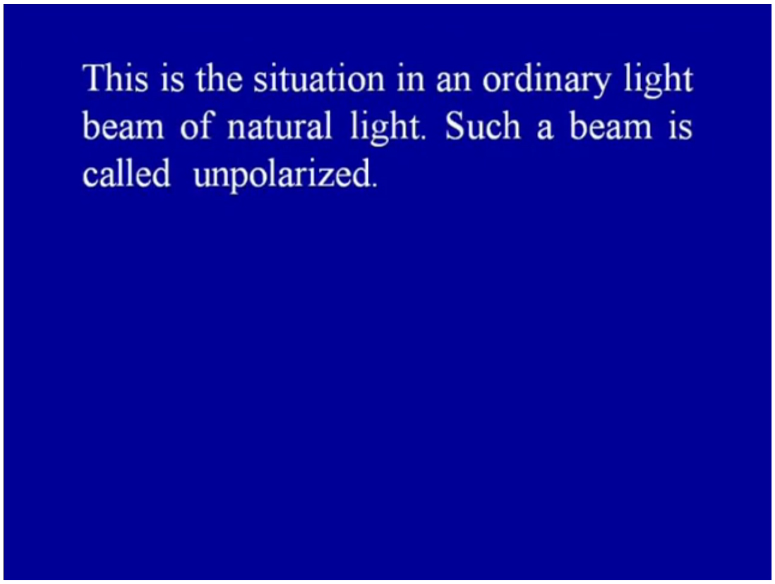

This is the situation in an ordinary light beam of natural light. Such a beam is called unpolarized.

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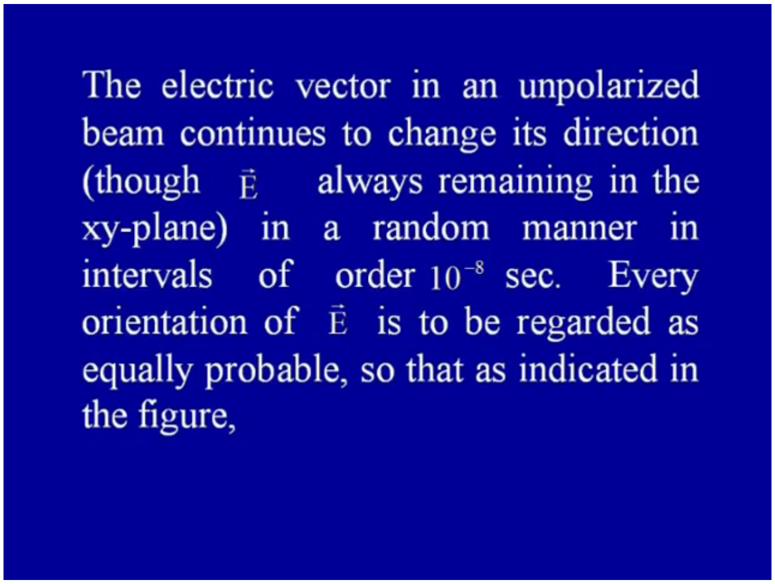

The electric vector in an unpolarized beam continues to change its direction although always remaining in the xy plane, so continues to change its direction in a random manner in intervals of the order of ten - 8 seconds. Every orientation of E is to be regarded as equally probable so that as indicated in the figure,

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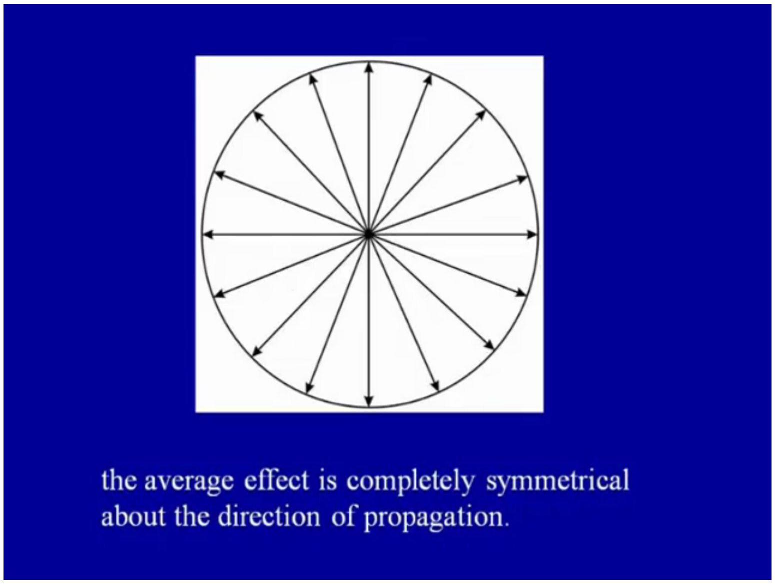

The average effect is completely symmetrical about the direction of propagation.

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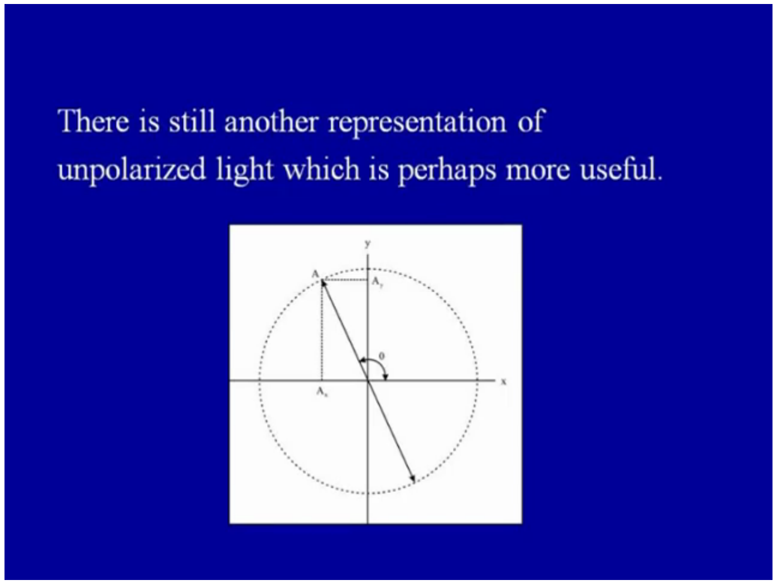

There is still another representation of unpolarized light which is perhaps more useful. If you resolve the vibration at any instant in the figure into components along the axes,

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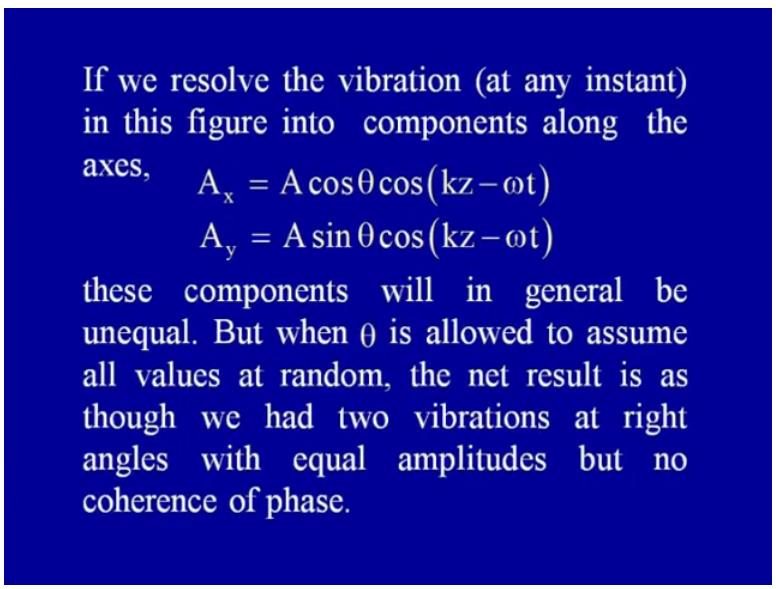

Ax = A cos theta cos of k z - Omega t and Ay = A sine theta again cos of kz - Omega t. Now these components will in general be unequal. But when theta is allowed to assume all values at random, the net result is as though we had two vibrations at right angles with equal amplitudes but no coherence of phase. Essentially each is the result of a large number of individual vibrations with random phase.

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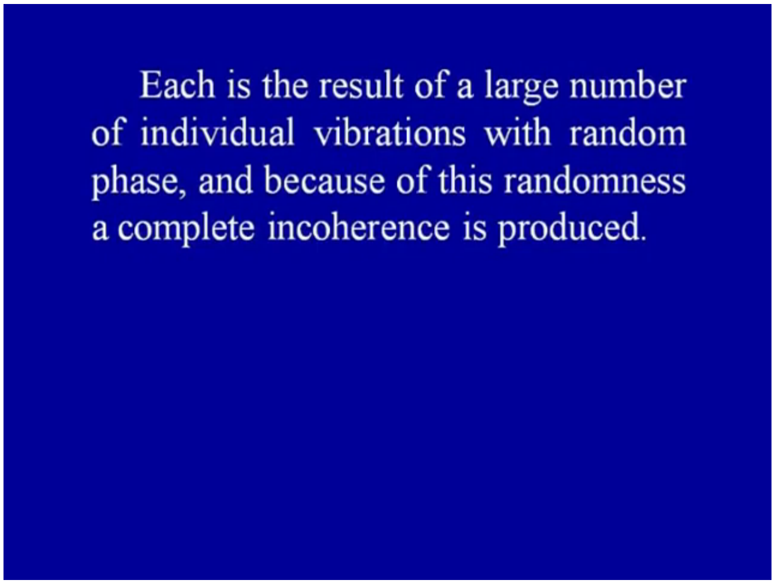

And because of this randomness, a complete incoherence is produced. But, if the direction of vibration continues to remain unchanged, we say that the light is plane polarized or linearly polarized,

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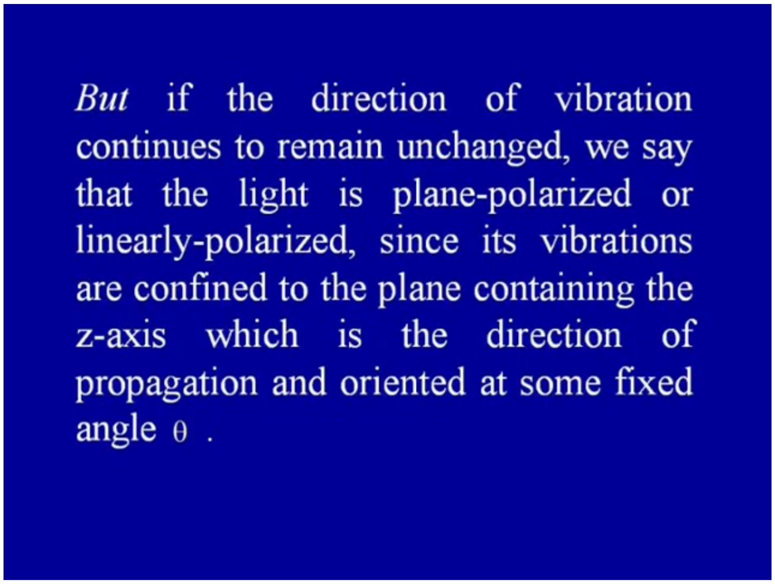

Since its vibrations are confined now to the plane containing the z axis which is the direction of application and oriented at some fixed angle theta.

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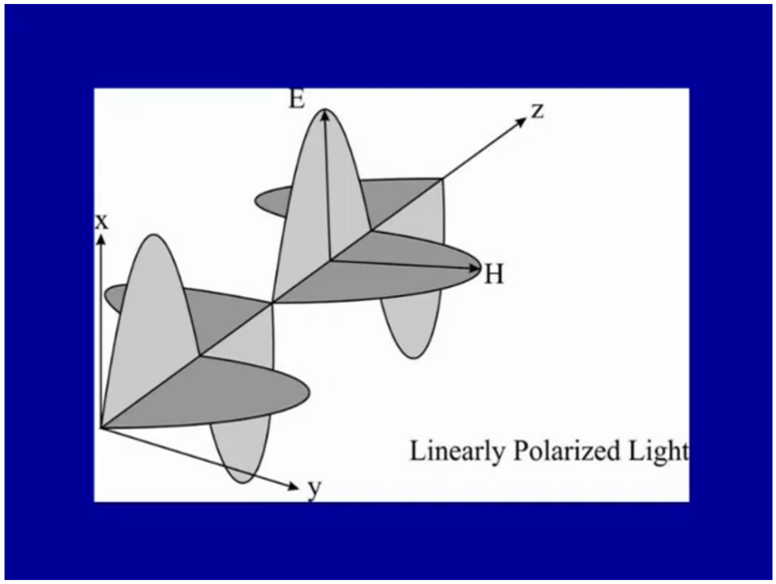

This picture shows the electric and magnetic fields of an x polarized light, propagating in the z direction. The light shaded region depicts oscillations of electric field along the x axis.

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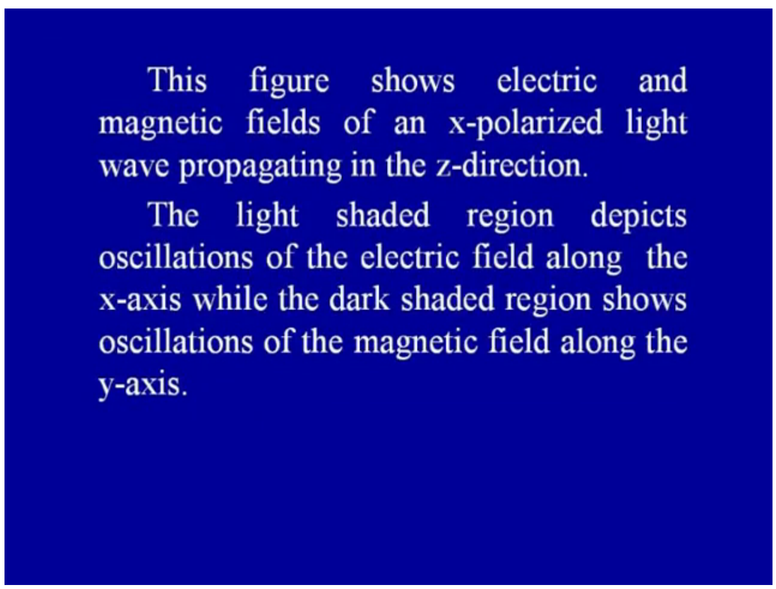

While the dark shaded region so the oscillations of the magnetic field along the y axis, if a polarized beam propagating along the z axis, this is not a convenient way of picturing these vibrations.

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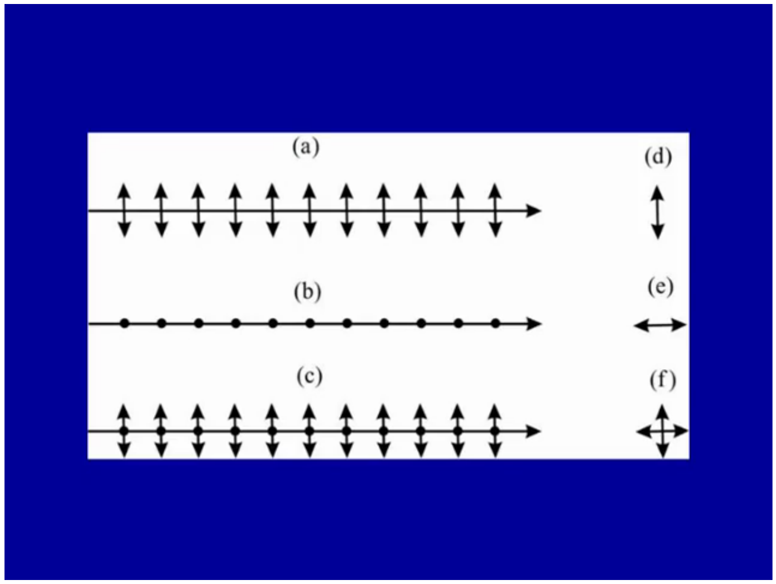

This figure shows a pictorial representation of side views a, b and c and end views d, e, f of being polarized and unpolarized ordinary light beams.

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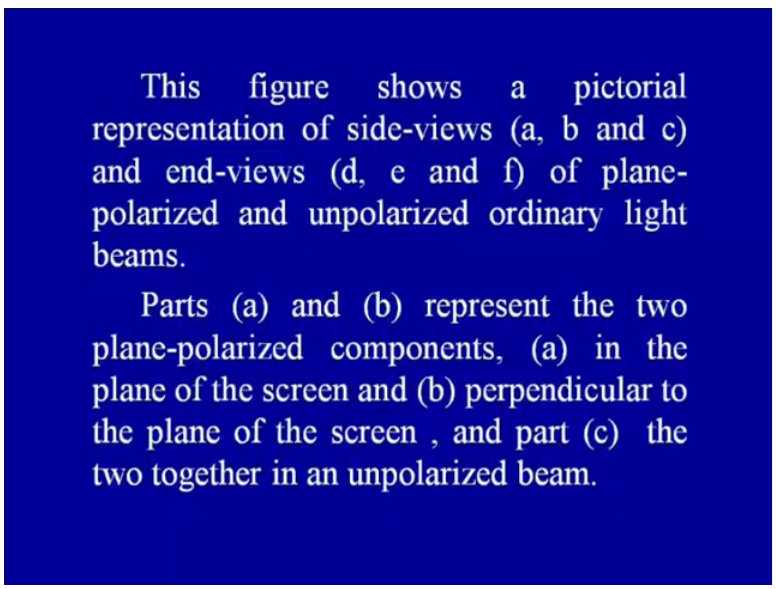

Part a and b represents the two plane polarized components, a in the plane of the screen and b perpendicular to the plane of the screen the part c, the two together in an unpolarized beam.

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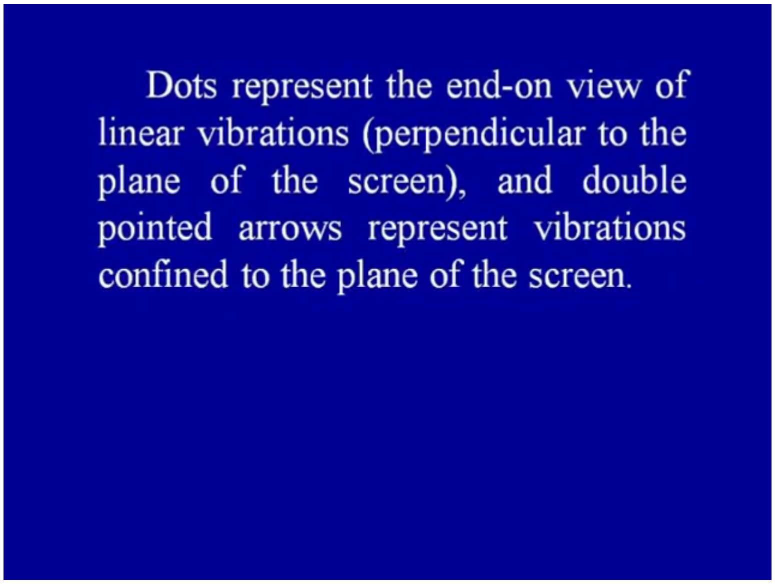

Dots repellent the end on view of linear vibrations perpendicular to the plane of the screen and double pointed arrows represent vibrations confined to the plane of the screen.

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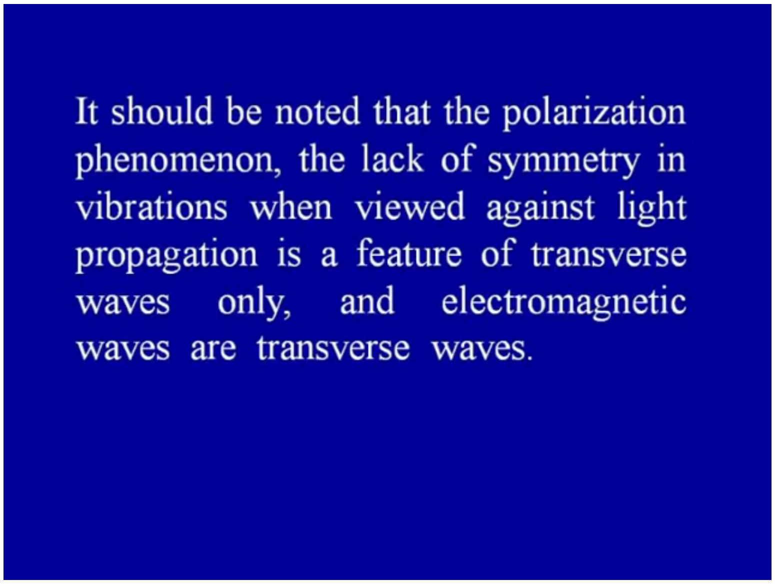

It should be noted that if an on the polarization phenomena its lack of symmetry in vibrations when viewed against light propagation is a feature of transverse waves only. And as we have seen electromagnetic waves are transverse waves. Now, we shall consider now polarization by reflection.

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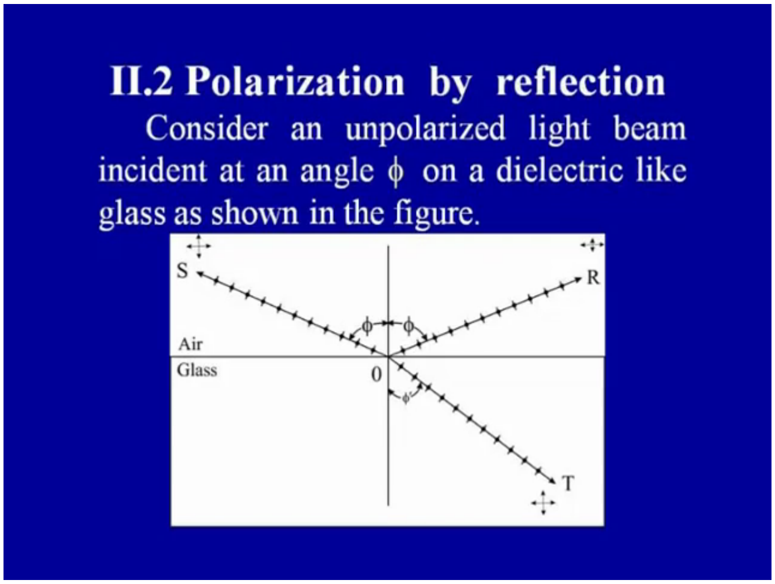

Consider an unpolarized light beam incident at an angle Pi, on a dielectric like glass as shown in the figure.

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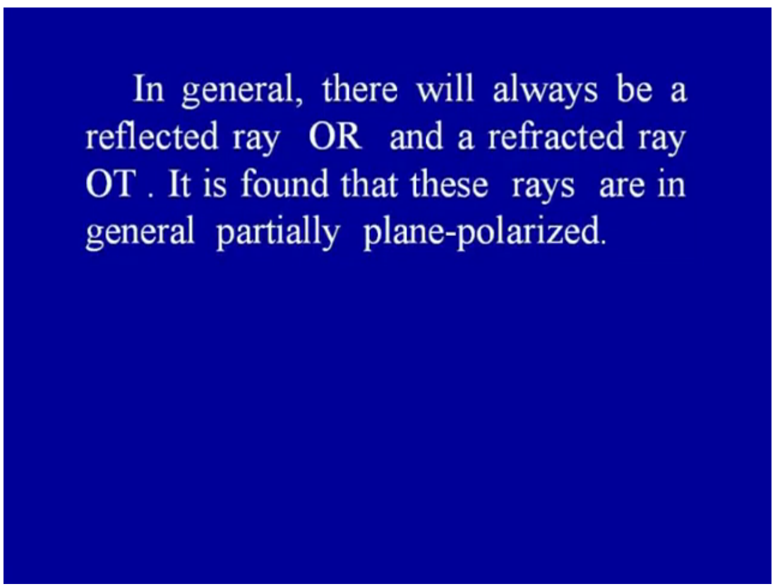

In general there will always be a reflected ray OR and a refracted ray OT. It is found that these raves reflected and refracted ones are in general, partially plane polarized.

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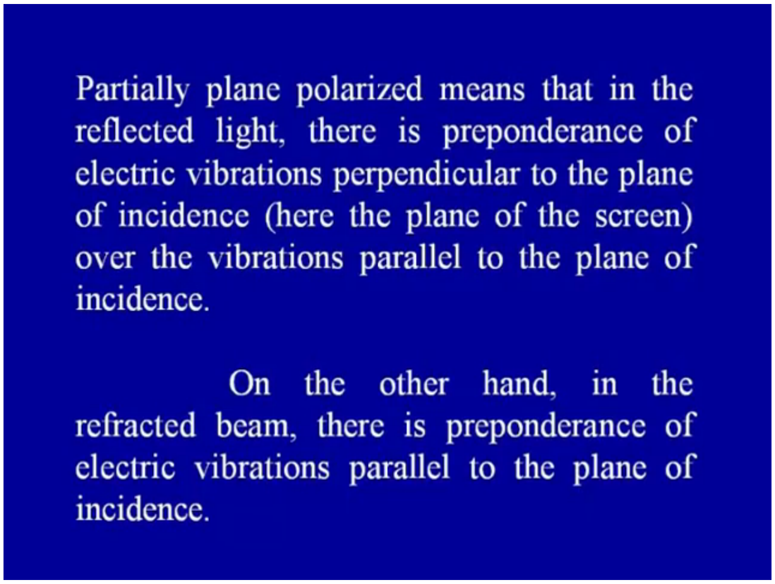

Partially plane polar light means that in the reflected light there is preponderance of electric vibrations perpendicular to the plane of incidence. Here the plane of the screen compared to the vibrations parallel to the plane of incidence. On the other hand, in the refracted beam, the preponderance of electric vibrations parallel to the plane of incidence.

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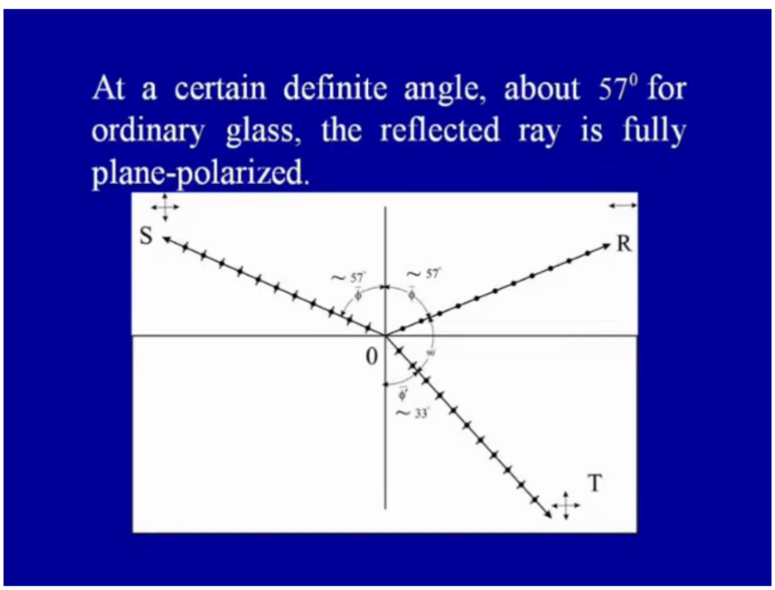

At a certain definite angle of about 57 degrees for ordinary glass, the reflected ray is fully plane-polarized. It was Brewster who first discovered that at the polarizing angle Phi bar.

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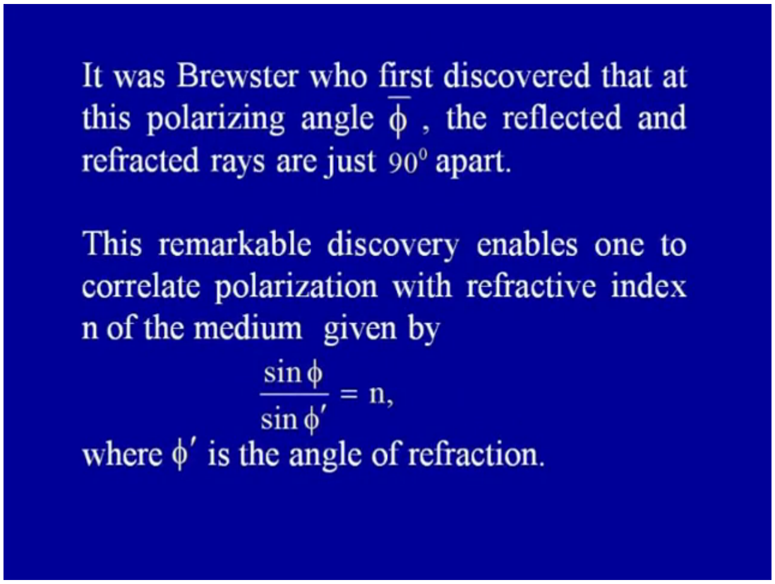

Reflected and refracted rays are just 90 degrees apart. This remarkable discovery enables one to correlate polarization with the refractive index n of the medium which is given by sine Phi divided by sine Phi prime = n.

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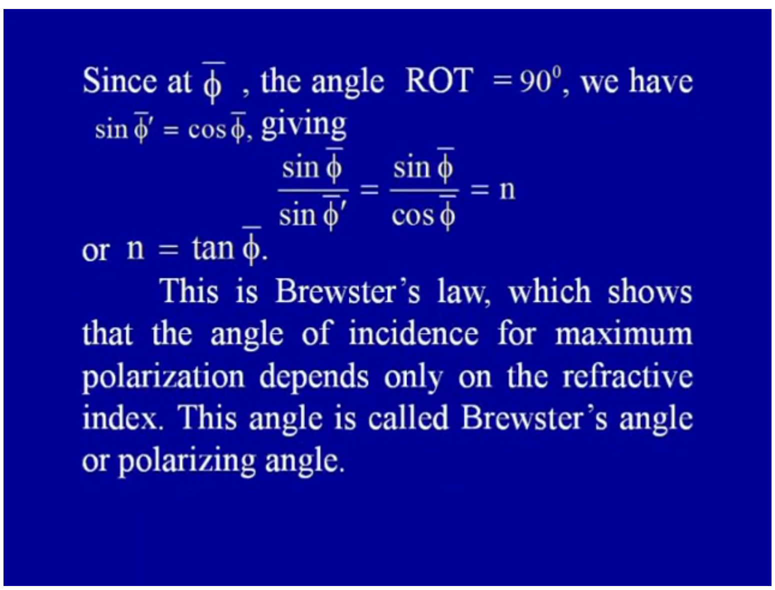

Where Phi prime is the angle of refraction, since at Phi bar, the angle ROT is 90 degrees, we have this sort of relation between Phi bar and Phi prime bar leading to the condition that the ratio of sine Phi bar and cos Phi bar becomes = n. That is n is = 10 of Phi bar, Phi bar is the polarizing angle. This is Brewster's law which shows that the angle of incidence for maximum polarization depends only on the refractive index through this relation n is = 10 Phi bar.

This angle is called Brewster's angle or polarizing angle because of its dependence on the refractive index this angle Phi bar vary somewhat with the wavelength.

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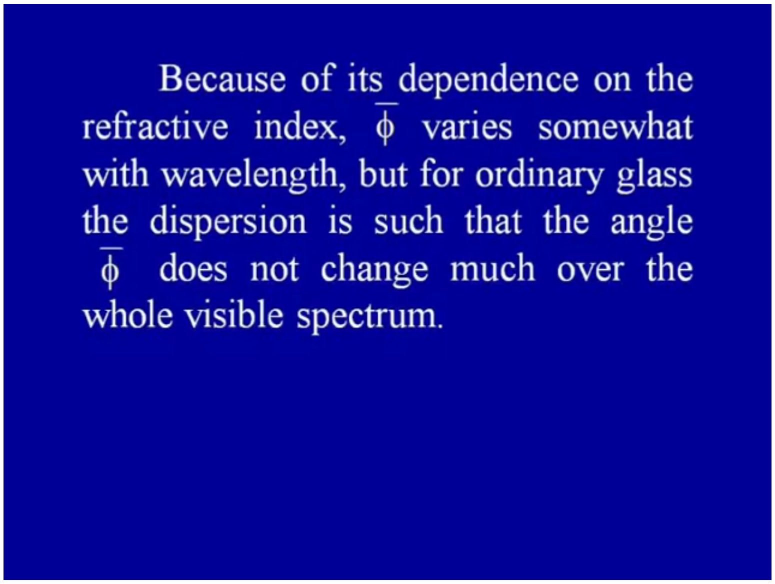

But for ordinary glass, the dispersion is such that the angle Phi bar does not change much or the whole of the visible spectrum. At this angle Phi bar of incidence, if the incident beam is plane polarized, electric vibrations in the plane of incidence, there will be no reflected ray.

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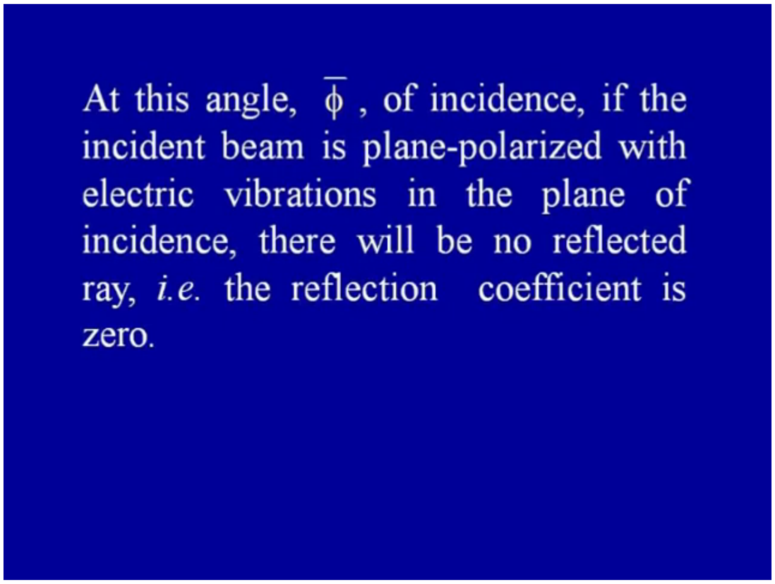

The reflected coefficient is 0 in this special situation. It is not difficult to understand.

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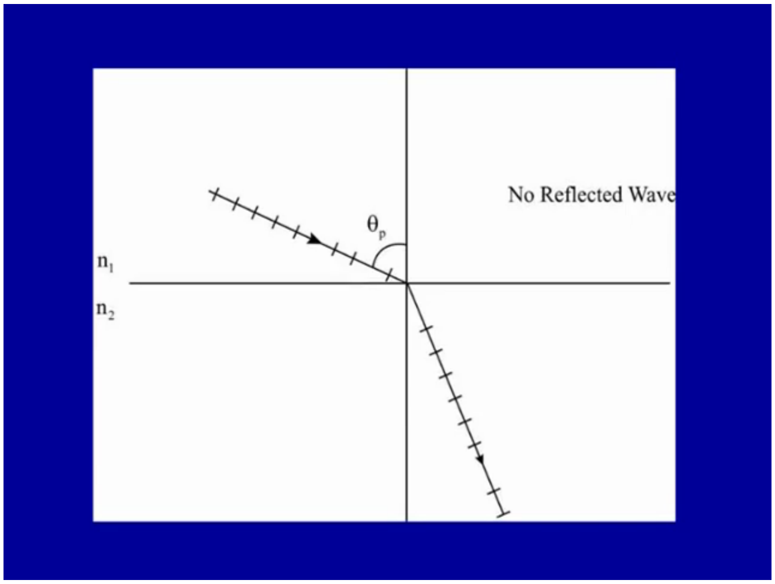

The physical reason why the light with vibrations in the plane of incidence is not reflected at Brewster's angle.

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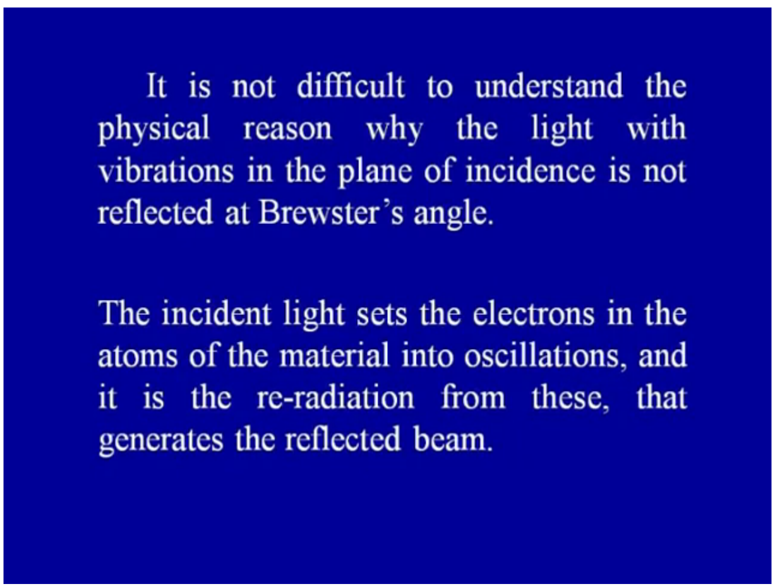

The incident light sets the electrons in the atoms of the material into oscillations and it is re-radiation from these electrons that generates the reflected beam.

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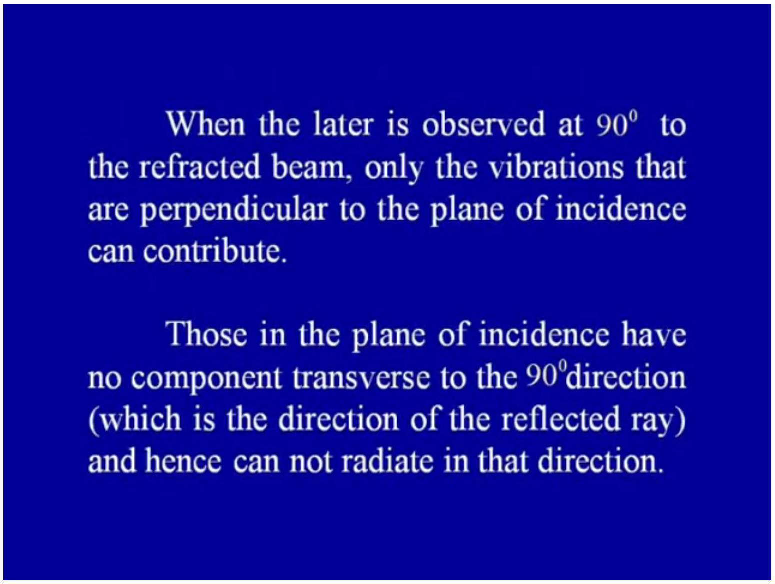

When the later is observed at 90 degrees to the refracted beam, only the vibrations that are perpendicular to the plane of incidence can contribute. Those in the plane of incidence have no component transverse to the 90 degree direction, which is the direction of the reflected ray and hence cannot radiate in that direction and there is no reflected ray. We shall now take a polarization by refraction.

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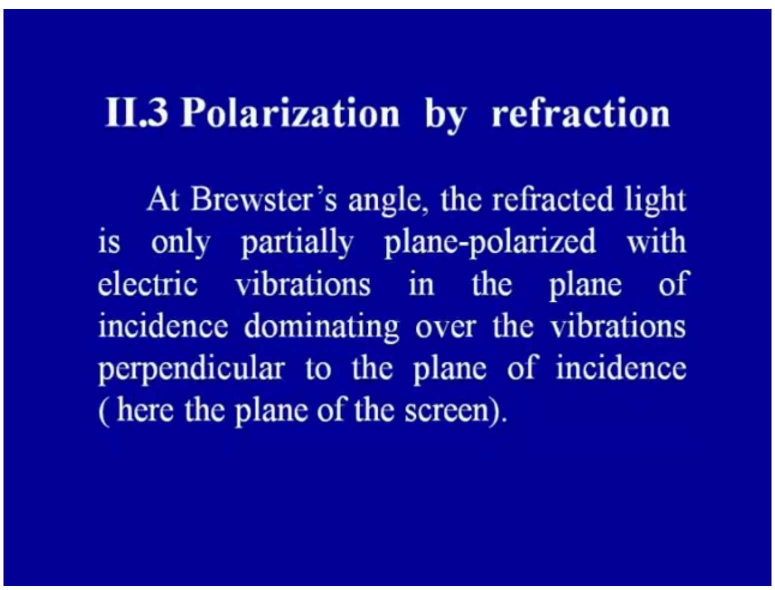

At Brewster's angle we have seen the reflected light is only partially plane polarized electric vibrations in the plane of incidence dominating over the vibrations perpendicular to the plane of incidence. Here that is the plane of this claim. One thing should be noted at no angle of incidence whatever the reflected light is fully plane polarized. It is always partially plane polarized.

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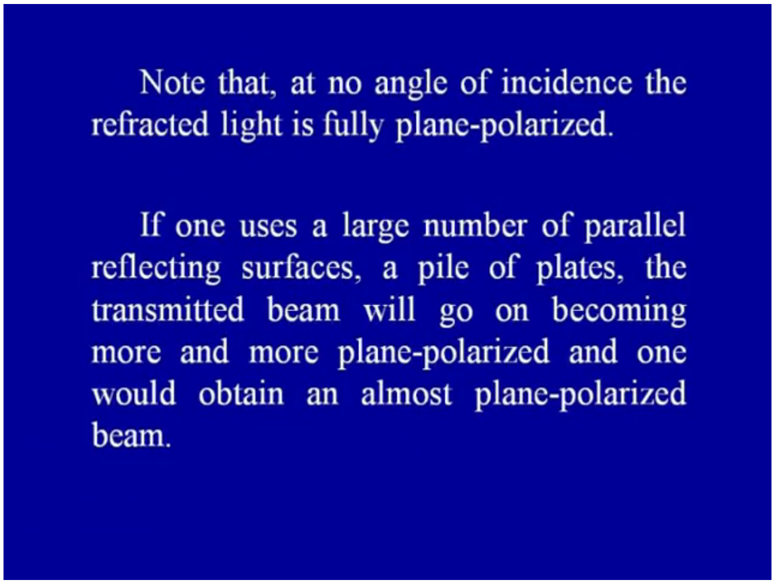

If one uses a large number of parallel reflecting surfaces that is a pile of plates the transmitted beam will go on becoming more and more plane polarized. And one would obtain an almost plane polarized beam in the end.

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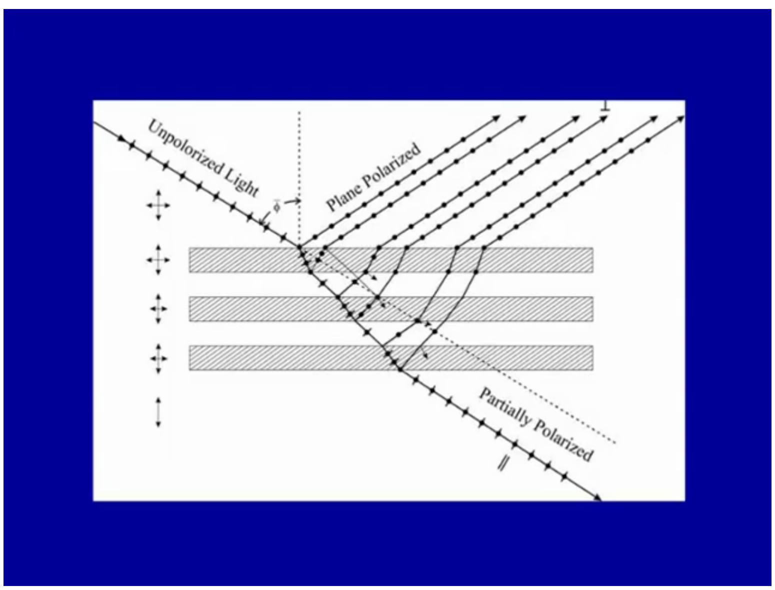

The figure shows the arrangement of pile of plates. The marking is given from the left of the figure with shortening horizontal arrows indicate that the transmitted beam is becoming more and more plane polarized.

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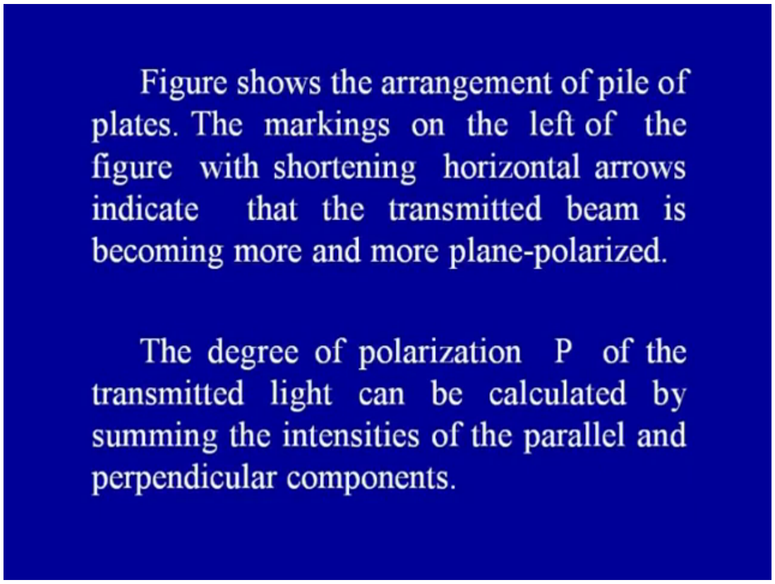

The degree of polarization P of the transmitted light can be calculated by summing the intensities of the parallel and perpendicular components.

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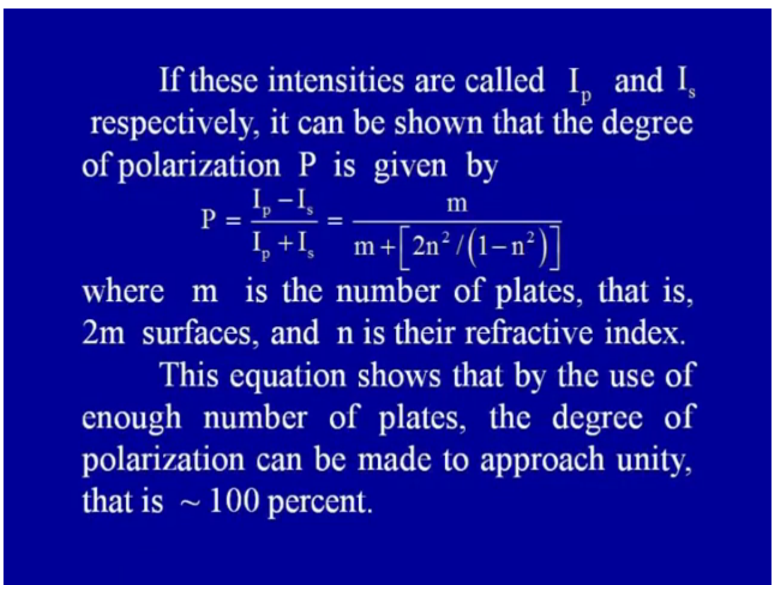

If these intensities are called Ip and Is respectively, it can be shown that the degree of polarization P is given by P is = Ip - Is divided by Ip + Is which is = m divided by m + 2n square upon 1 - n square. But m is the number of plates that is 2m refracting surfaces and n is their refractive index. This equation shows that by the use of it enough number of plates, by making them pretty large, the degree of polarization can be made to a pro unity that is almost hundred percent. Let us now consider polarization by scattering.

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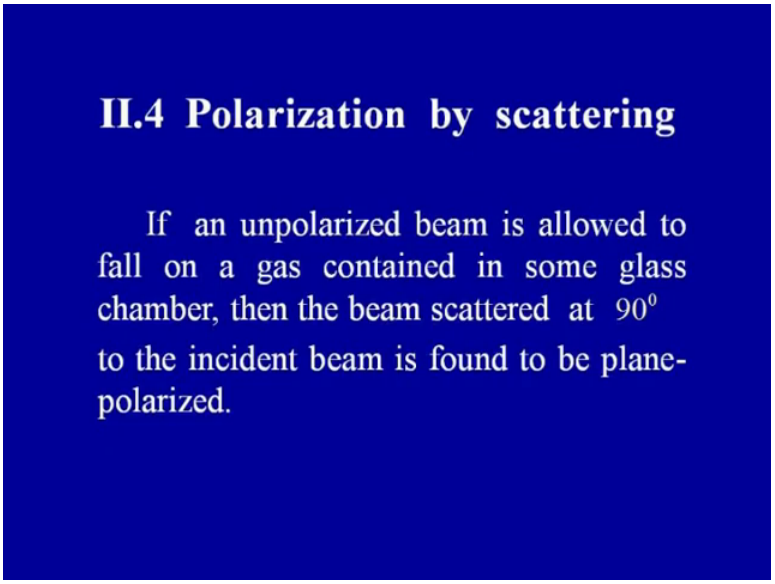

If an unpolarized beam is allowed to fall on a gas contained in some glass chamber, the glass container then the beam is scattered at 90 degrees to the incident beam is always found to be plane polarized.

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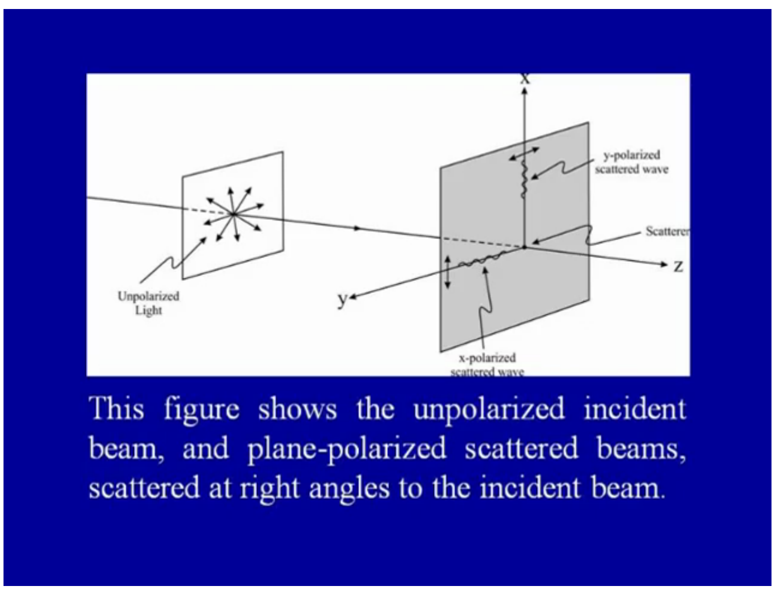

This figure shows the unpolarized incident beam and plane polarized is scattered beams is scattered at right angle to the incident beam. The incident wave is propagating along the z direction then the scattered wave along the y direction is x polarized.

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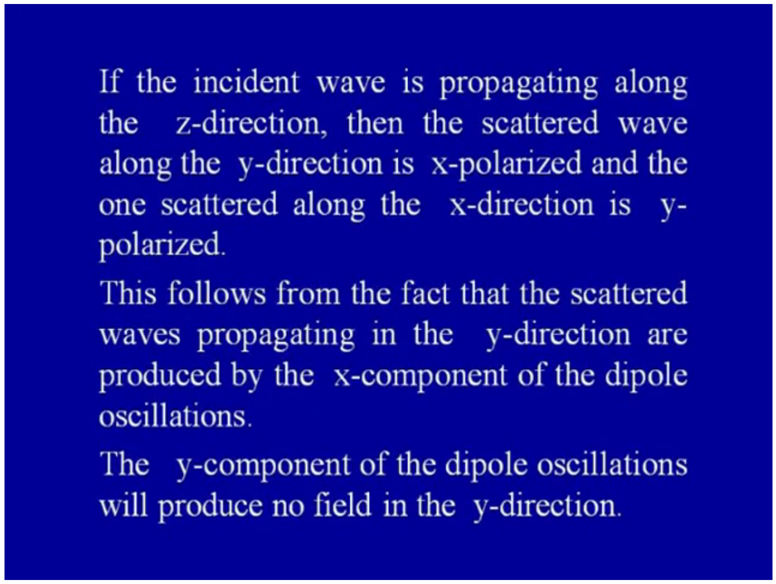

And the one scattered wave along the x direction is y polarized. This follows from the fact that the scattered waves propagating in the y direction are produced by the x component of dipole oscillations. The y component of the dipole oscillations they produce no field in the y direction. These y component losses no field in the y direction, x component produces no field in the x direction. That is the situation.

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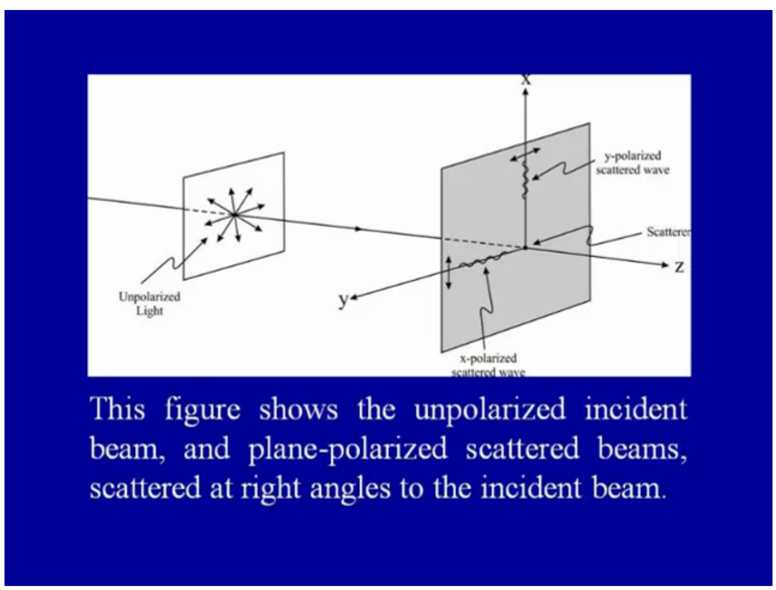

If the incident beam is plane polarized with its electric vector along the x direction, then, there will be no scattered light along the x axis.

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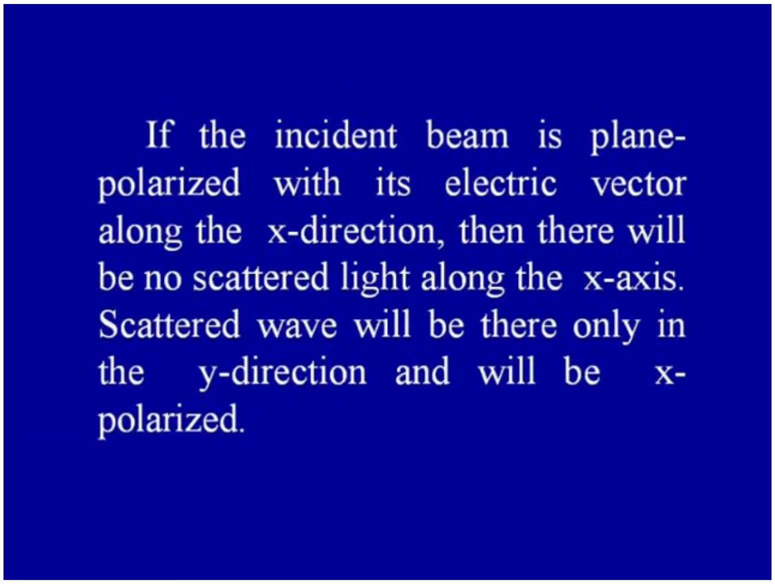

Scattered wave will be there only along the y direction and they will be x polarized. Let us now consider working of a Polaroid.

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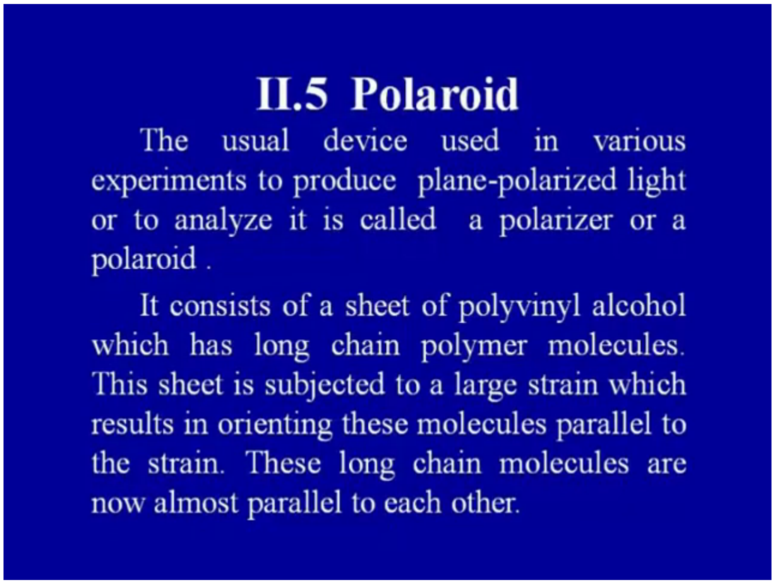

The usual device used in various experiments to produce plane polarized light or to analyze it is called a polarizer or a Polaroid. It consists of a sheet of polyvinyl alcohol which has long chain polymer molecules. This sheet is subjected to a large strain which results in orienting these molecules parallel to the strain. These long chain molecules are now almost parallel to each other. I mean, sort of arranged in a longitudinal fashion.

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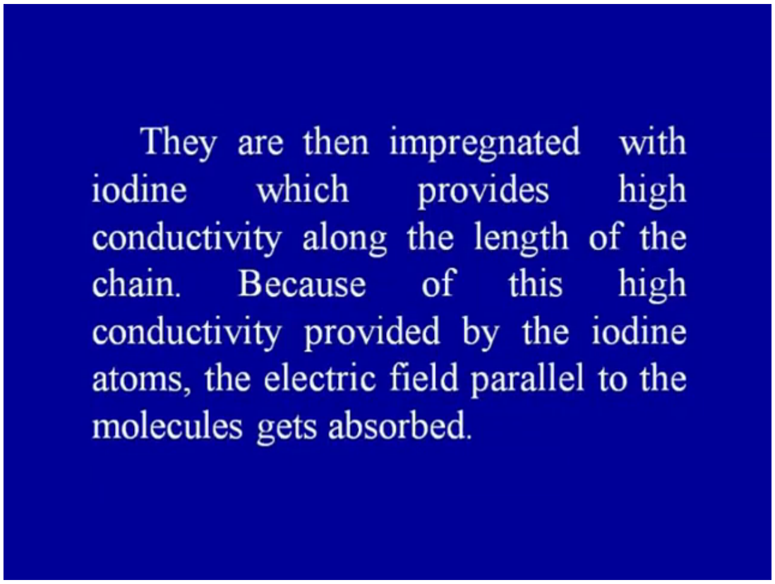

They are then impregnated with iodine which provides high conductivity along the length of the chain along the longitudinal direction. Because of this high conductivity provided by the iodine atoms, the electric field parallel to the molecule gets absorbed. Essentially along their direction, the substance will not sustain any electric field.

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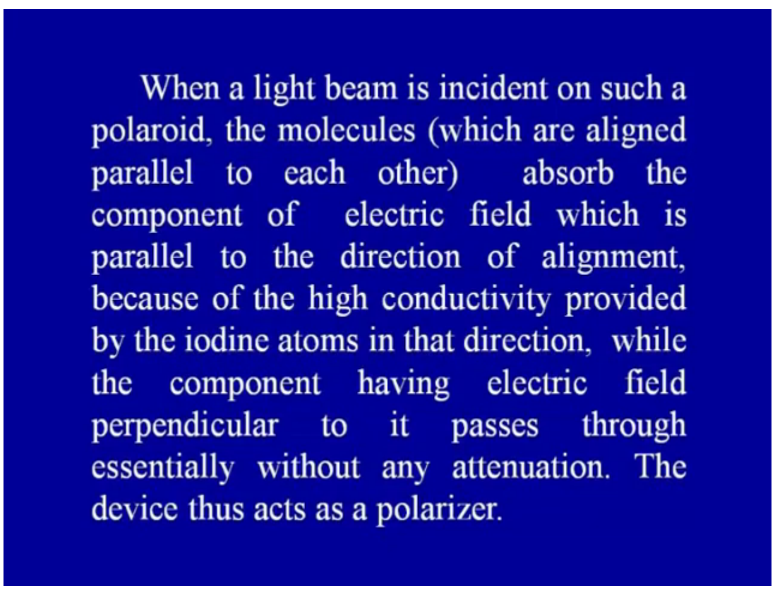

When a light beam is incident on such a Polaroid, the molecules which are aligned parallel to each other, we have seen, they absorb the component of electric field which is parallel to the direction of alignment because of the high conductivity provided by iodine atoms. While the components have an electric field perpendicular to it, passes through essentially, without any attenuation the device thus acts as a polarizer.

In actual practice this polymer sheet is then placed between two glass plates, so that it is a little protected from scratches etcetera, okay. This is all in the first lecture, thank you.