Applied Optics
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Lecture 49
Production of Polarized Light

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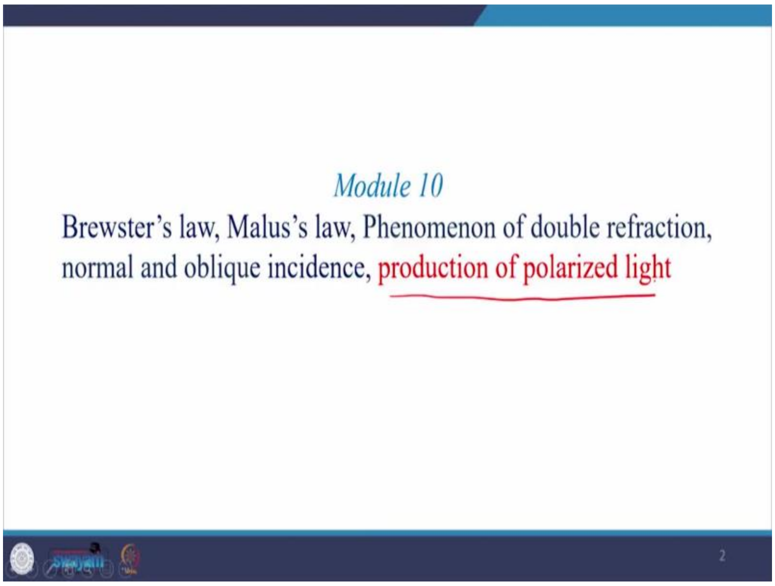

Hello everyone, welcome back to the class. Today we will hold the last lecture in module 10. And in this last lecture, we will talk about different techniques for producing polarized light.

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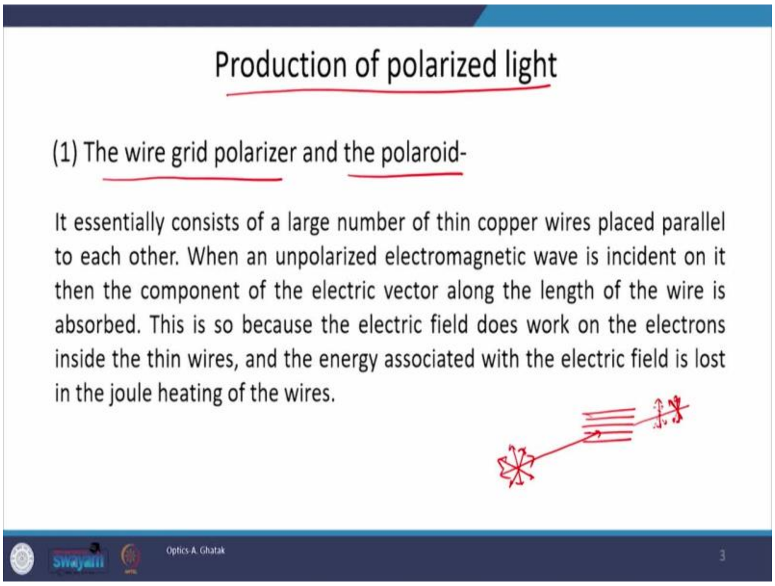

Now in this direction, we will first talk about the wire grid polarizer and then we will also talk about polaroid, this is a technique where in polarized light is produced using a very thin and long conducting wires. Now this wire grid polarizer essentially consists of a large number of thin wires and these wires are placed parallel to each other. Now suppose these are the wires which are very closely spaced, on these wires we launch a non-polarized light.

And what happens is that now since these are the wires and unpolarized light impinge on it then the component of the field which is along the length of the wire, what will it do is that it will make the electron oscillate and due to this electric field does work on the electron inside this thin wire and the energy associated with the electric field is lost in the joule heating of the wires and this is how the component which is parallel to the length of the wire it gets consumed, it gets absorbed and what is left is the perpendicular component and this is how we get a linearly polarized light using this wire grid polarizer, on the other side we will get a linearly polarized light.

As I said before, not all horizontal components are absorbed or it is not only that only vertical components are coming out of the wire grid polarizer, a component which is not perfectly vertical they also come out but the dominance is of vertical component therefore, we call it a vertically polarized or linearly polarized light.

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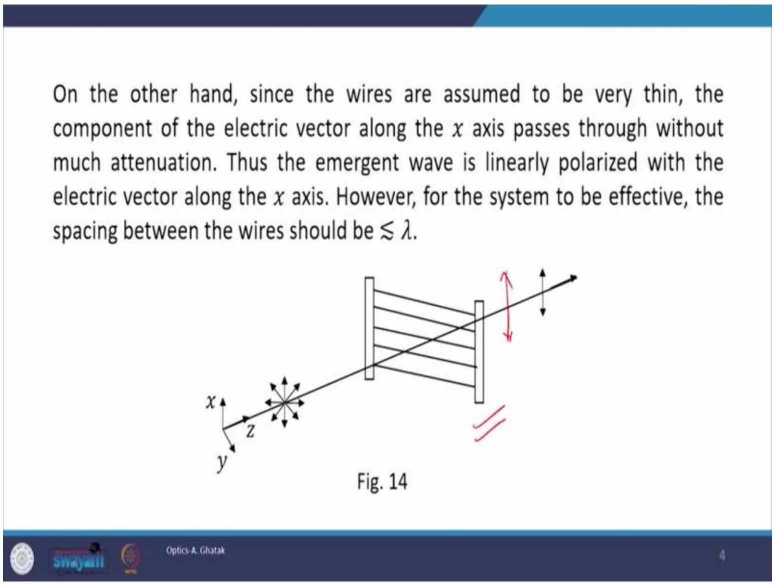

Now on the other hand since the wires are assumed to be very thin, the component of electric field vector along the x axis passes through without much attenuation, the x axis is vertical axis. Thus, the emergent wave is linearly polarized with the electric vector along the x axis and this is very nicely depicted in this figure number 14. But we know that spacing between the wires should be either equal to λ or much less than λ, the spacing between the wire must be smaller than the wavelength of the light, but this is not feasible because wavelength of light is very small and how to achieve this wire grid polarizer?

Now instead of this thin wire one may employ long chain polymer molecules that contains atoms which provide high conductivity. If we take polymer molecules which are of course very thin and very much conducting such as iodine then this wire grid polarizer can be replaced with this long chain polymer molecule and this long chain polymer molecules are aligned so that they are almost parallel to each other.

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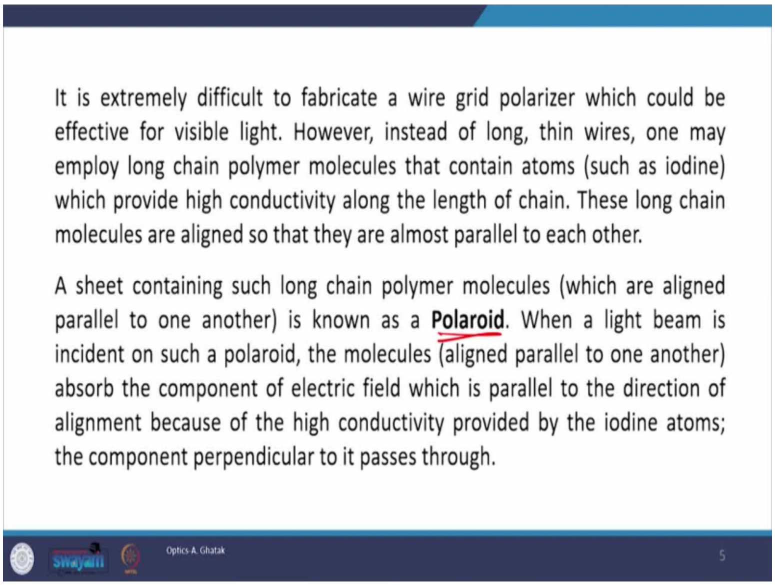

A sheet containing such long chain polymer molecules which are aligned parallel to one another is known as Polaroid. And when light is shined over such a polaroid then the parallel component of the field get absorbed while the perpendicular component is passed through, it get transmitted and this is how we get a linearly polarized light out of a polaroid.

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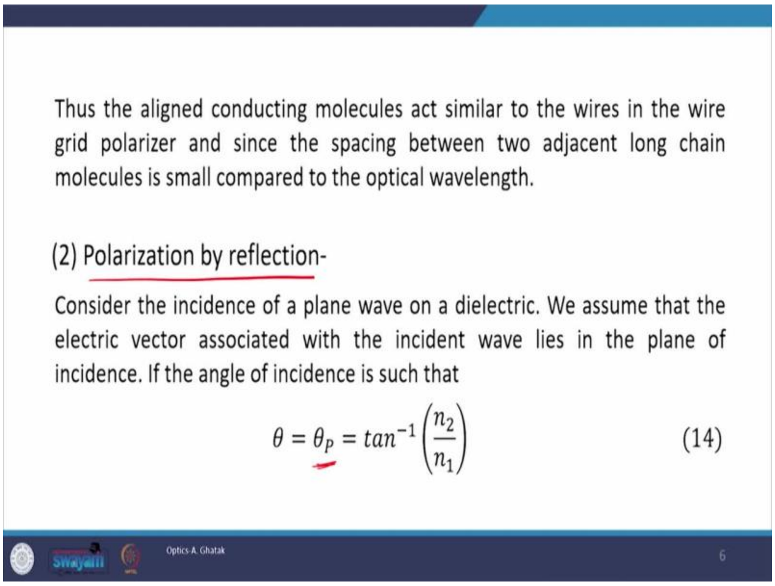

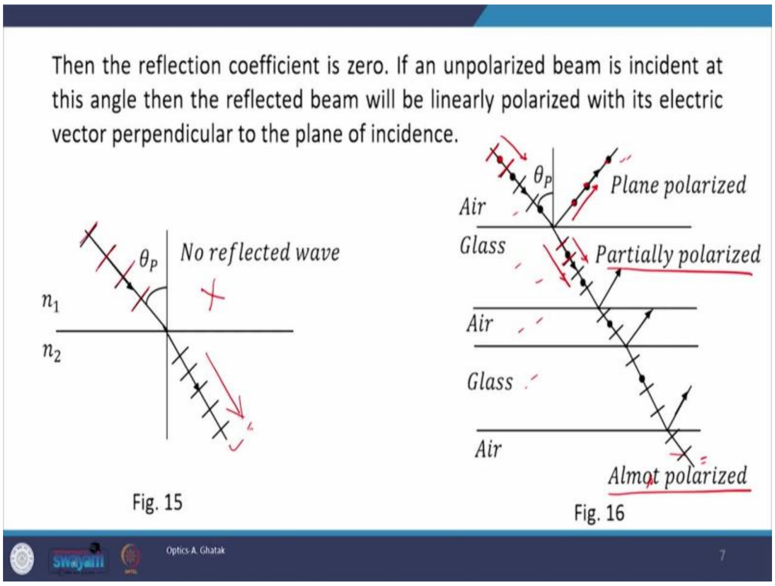

Now the second technique to produce polarized light is polarization by reflection, in this case we use Brewster's law. Here we assume that unpolarized plane wave is incident on a dielectric and we also assume that the electric field vector associated with the incident wave lies in the plane of the incidence and if the angle of incidence is equal to θ_p or θ_b the Brewster angle which is equal to $tan^{-1}(n_2/n_1)$, where n_2 is the refractive index of the second medium and n_1 is the refractive index of the first medium, then in this case we get no reflection because we have already studied that in if the angle of incidence is such that it is equal to Brewster angle then for in plane polarization the reflection is absent all the energy would be in the transmitted arm of the propagation.

But if an unpolarized beam is incident at this angle, then the reflected beam will be linearly polarized and with its electric vector perpendicular to the plane of incidence. Now here in this case we see that we are launching an unpolarized light which has perpendicular component as well as parallel component, in this case in the reflected arm there will not be any parallel component but only perpendicular component while the transmitted arm will have both parallel as well as perpendicular component and this transmitted arm is called partially polarized because most of the perpendicular component is there in the reflected arm. But if we use a stack of material in this case air glass air glass if we take a take such periodic arrangement, then due to multiple reflection and refraction, ultimately we get almost polarized light here at the output at the transmitted end.

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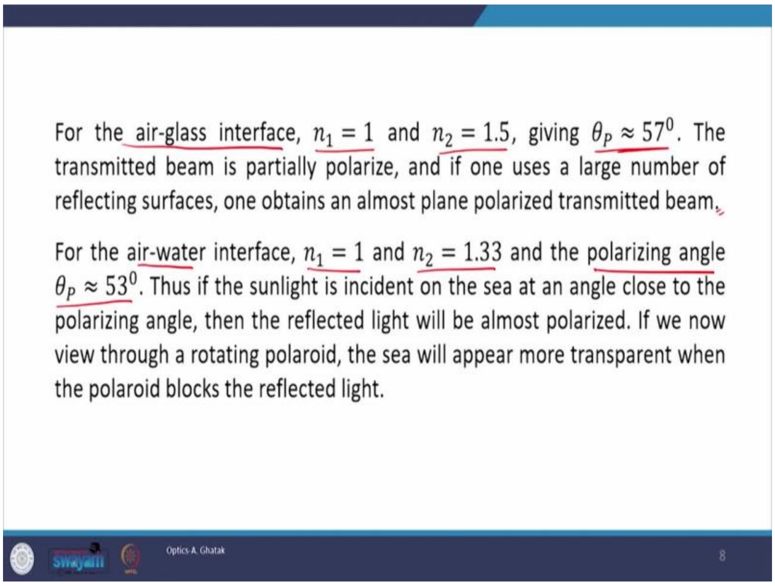

Now let us consider the case of air-glass interface and suppose the unpolarized light is falling at the glass interface from air therefore, in this case $n_1 = 1$, while $n_2 = 1.5$ and using these 2 values we can calculate the Brewster angle θ_p which is 57 degree. The transmitted beam is partially polarized and if one uses a large number of reflecting surfaces, one obtains an almost plane polarized transmitted beam.

Now instead of air glass interface if we consider air -water interface where $n_1 = 1$ and $n_2 = 1.33$ then the polarizing angle or the Brewster angle would be 53 degree. And thus, if the sunlight is incident on the sea which is of course water at an angle close to the polarizing angle, then the reflected light will be almost polarized. And now if you use rotating polaroid then the sea will appear more transparent when the polaroid blocks the reflected light and this polaroid, this phenomena, is used in sunglasses.

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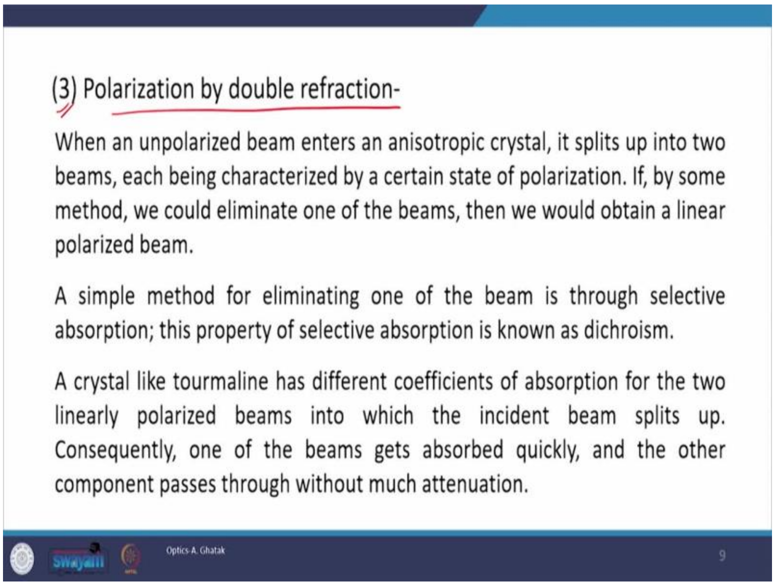

Now in this line, the third method to get polarized light is polarization by double refraction, here we use birefringent material and we know that when unpolarized light is incident in an isotropic crystal or birefringent material then it splits up into 2 beams, each beam characterized by a certain state of polarization. Now these 2 beams they both are linearly polarized and if we want only one beam to come out somehow from the material system then we will have to devise the technique to eliminate one of the beam. If we eliminate the one then the other one which is a linearly polarized wave, we will be left with the other one which would be a linearly polarized wave or linearly polarized beam.

Now how to do this? A simple method for eliminating one of the beam is through selective absorption. And this process of selective absorption is known as dichroism. There are few certain crystals and one of the example is tourmaline and this crystal has different absorption coefficients for different polarization. Now suppose we launch unpolarized beam in this crystal and due to its birefringent nature it splits the unpolarized light into 2 beams and one is in plane polarized, other is perpendicularly polarized and if there is a polarization dependent absorption, then one of the beam would be absorbed and we would be left with the other beam which is also a linearly polarized beam and we will get only one linearly polarized output through this Tourmaline crystal, which is schematically drawn here.

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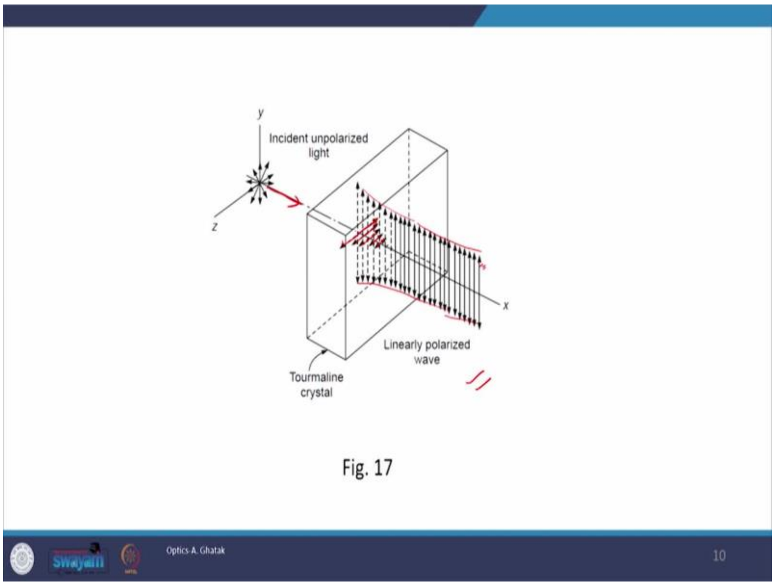

You see here in this crystal we launch an polarized light and this unpolarized light splits into 2, one has polarization direction which is in vertical direction, one beam is vibrating in a vertical direction while the other is vibrating in a horizontal direction. The properties of the crystal is such that this horizontal vibration is absorbed with propagation, it absorbed very rapidly while the other beam which has polarization direction in vertical direction, the vibration is in vertical direction, it has it sees a small value of attenuation and therefore, it comes out of the crystal and we get a linearly polarized light at the output.

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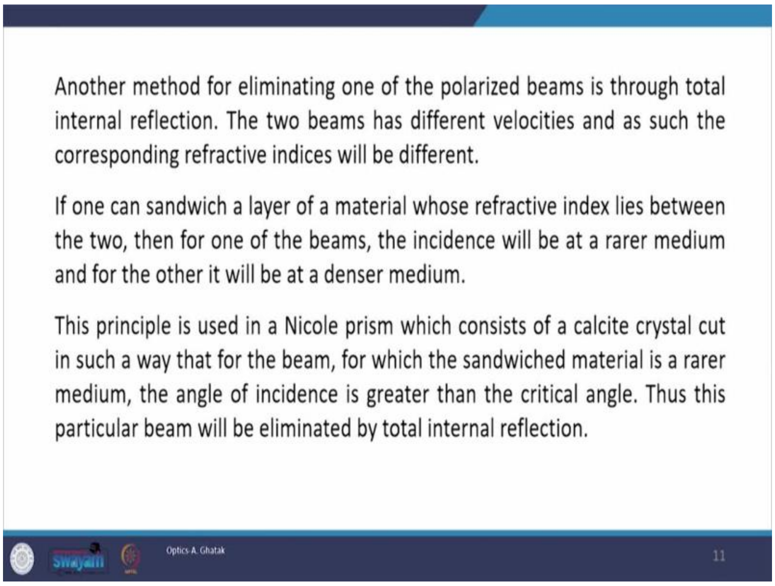

Now another method for eliminating one of the polaroid beam is through total internal reflection. Now what do we do here is that since the 2 beams has different velocities and as such the corresponding refractive indices will be different therefore. Now if one can sandwich a layer of material whose refractive index lies between the 2. We launched unpolarized light in birefringent material and then it splits into 2, the 2 rays are named as e ray and o ray and the 2 rays have different index indices of refraction. Now if we put a material whose refractive index is between that of n_o and n_e or that of e ray and o ray then the material which put externally it will behave as a rarer medium for one beam while denser medium for the other.

Now using this principle we can form a crystal wherein one ray falls at an angle which is larger than critical angle and if the angle of incidence is larger than the critical angle then out of the 2 rays one ray will be reflected total internally reflected and we will be left with the other ray which is again linearly polarized. And this principle is used in the Nicole prism which consists of a calcite crystal cut in such a way that one beam for which sandwich material is rarer medium, the angle of incidence is greater than the critical angle.

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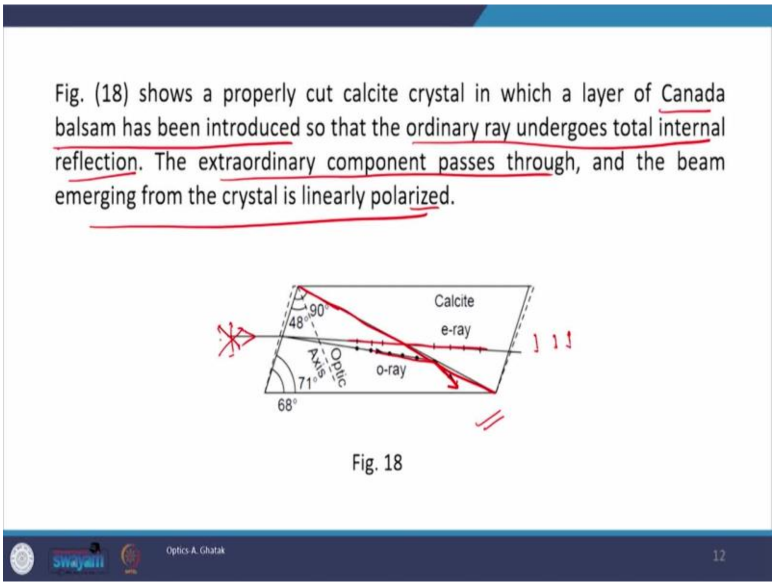

Thus, this particular beam will be eliminated by total internal reflection and this Tourmaline crystal is shown schematically here and the source the properly cut calcite crystal and here along this line a layer of Canada Balsam is introduced and the ordinary undergoes total internal reflection at this Canada balsam here. You see that we are launching unpolarized light and the o ray get totally internally reflected while the e rays passes through as it is. The e ray component passes through and the beam emerging from the crystal versus linearly polarized, here we get a linear polarized light at the output, while here we have launched a unpolarized light.

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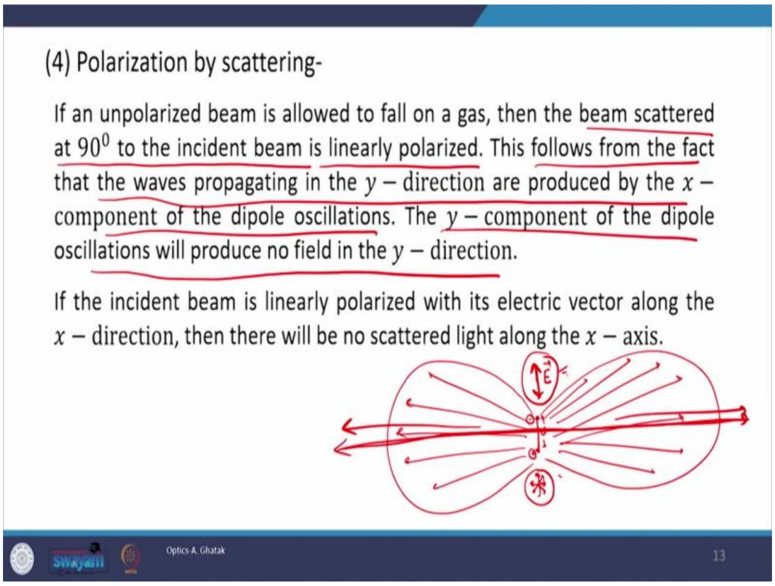

Now the fourth method of producing polarized light is polarization by scattering. We know that if we have a dipole, say it is a plus sign and it is a minus sign and this point charges are separated by a certain distance d. And if we somehow make this dipole oscillate with certain frequency, then we know that oscillating dipole emit electromagnetic radiation. And the radiation pattern would be in the form of butterfly wings and therefore, the pattern emitted would be in this form and this would be the direction of emission these lines represents arrows represent the direction of emission of electromagnetic waves.

Now you see that the dominant emission is perpendicular to the length of the dipole, this is the direction of dominant emission this horizontal arrow thick horizontal arrow and this is perpendicular to the length of the dipole. Therefore, if a dipole vibrates, the emission is perpendicular to the direction of vibration. Now using this we can also create polarized light, how? If an unpolarized beam is allowed to fall on a gas and gas consists of several molecules which are well separated from each other.

Now if unpolarized light is launched in this gas then the beam scattered at 90 degree to the incident beam is linearly polarized and this can be again understood from this figure. Suppose, we launched an unpolarized light on this dipole then out of the n number of direction of vibration, the field component which is along the length of the dipole, I mean this field component which is along the length of the dipole, this field component which is function of time it will make the dipole oscillate and therefore, it will get absorbed into the dipole and after the absorption the dipole will radiate in this direction and this emission would be in perpendicular to the vibration of initial field.

Therefore, the incident beam is scattered at 90 degree to the incident beam and this would be linearly polarized, this follows from the fact that the wave propagating in y direction are produced by x component of the dipole oscillations, the y component of the dipole oscillation will produce no field in the y direction. If the incident beam is linearly polarized with its electric vector along the x direction, then there will be no scattered light along the x direction and this is schematically shown here.

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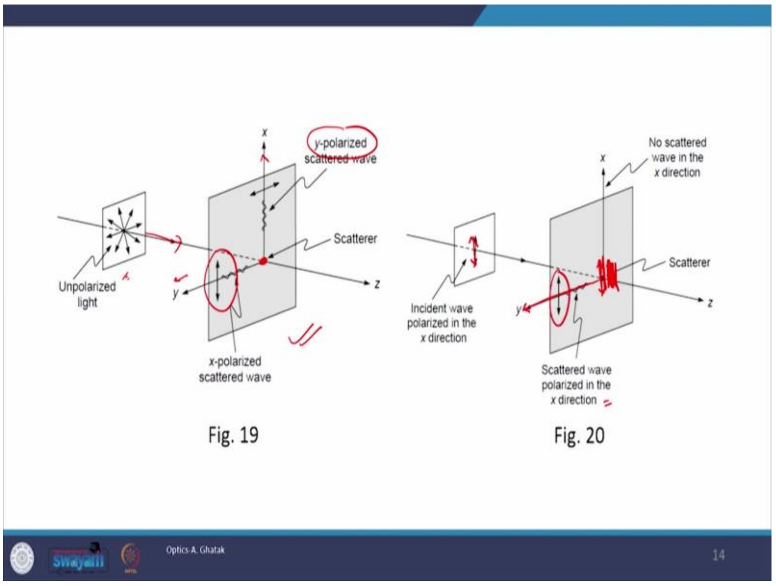

Now this is our scatter or the gas molecule on which we are launching an unpolarized light. Now in x direction we will receive a light which would be y polarized while in y direction we will receive a light which would be x polarized. Now suppose we have a scatter on which we have launched x polarized light, now due to the x polarization the dipole will vibrate in this vertical direction, the vibration would be like this and due to this vibration the emission would be in y direction and this emission would be x polarized.

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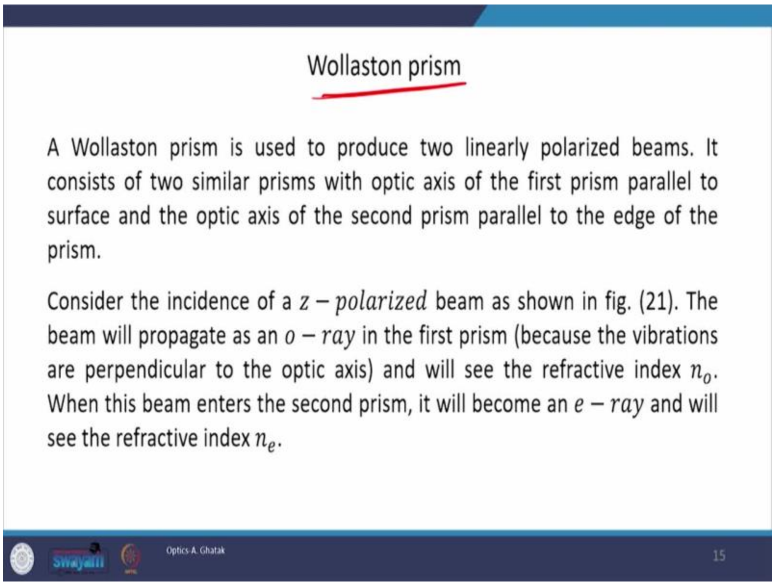

Now these were the few methods to generate polarized light. Now in this method we have also talked about polarization produced by birefringent material or double refracting material. Now using these birefringent materials, we can devise different type of devices and one of such device is Wollaston prism. A Wollaston prism is used to produce 2 linearly polarized beam and it consists of 2 similar prisms with optic axis of the first prism parallel to the surface and the optical axis of the second prism pilot to the edge of the prism, and this is shown here in this figure.

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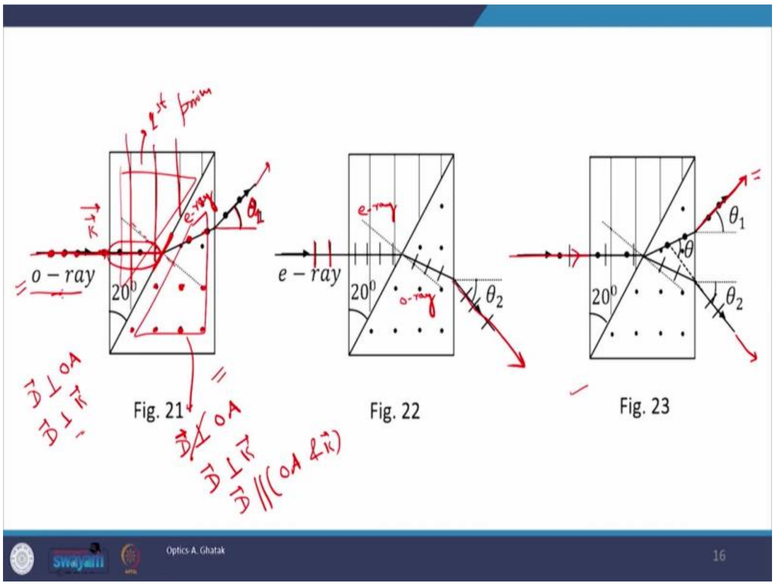

You see that this is the Wollaston prism consists of 2 prisms, this is the first one and this is our second one. In first one the optic axis is along this line, while in the second one the optic axis is perpendicular to the plane of the paper and the direction of that optic axis is shown by these dots. Now if you launch a ray whose direction of polarization is perpendicular to the plane of the paper, then for the first prism, this is our first prism, this ray will behave as o ray. Why? Because in the first for the first prism, the D of the incident beam is perpendicular to optic axis and since this is direction of propagation $\vec{k}$, $\vec{D}$ is also perpendicular to $\vec{k}$. And therefore, the incident beam will behave as o ray in the first prism and therefore, since the incidence is normal, it will propagate undeviated.

Now at the interface of second prism, we will have to draw a normal and then we will check the refraction of this o ray. Now in the second medium, the vibration the $\vec{D}$ in the second prism the vibration direction is not perpendicular to OA, although $\vec{D}$ is perpendicular to $\vec{k}$, $\vec{D}$ is perpendicular to $\vec{k}$, but $\vec{D}$ is not perpendicular to OA, instead $\vec{D}$ is in a plane which contains both OA and $\vec{k}$. Therefore, the same ray in the second prism it will behave as e ray therefore, for refraction we will use n_e as a refractive index for the same ray in the second prism. And using this n_o and n_e, we can calculate the angle of emergence that is θ_1 out of the prism.

Therefore, if we launch a beam with a polarization which is perpendicular to the plane of the paper, it will emerge out at angle θ_1 in this direction while launch a ray whose polarization is in the plane of this paper, then this ray will behave as e ray in the first prism while o ray in the second prism and the direction of emergence would be different, it would emerge at an angle θ_2 the opposite direction. Therefore, if we launch an unpolarized light in such a prism, then the perpendicularly polarized beam will emerge from here at angle θ_1, while in plane polarization will emerge at angle θ_2 in the other direction. And therefore, using this Wollaston prism we can generate 2 linearly polarized beams from an unpolarized light.

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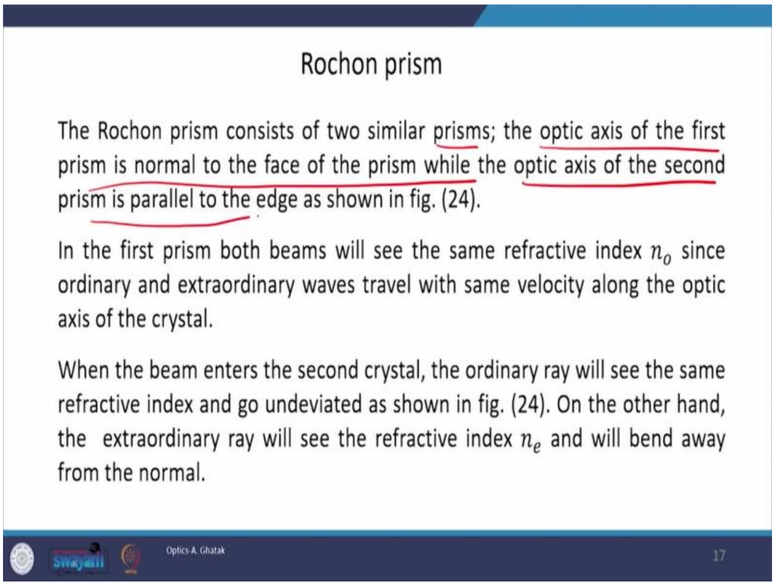

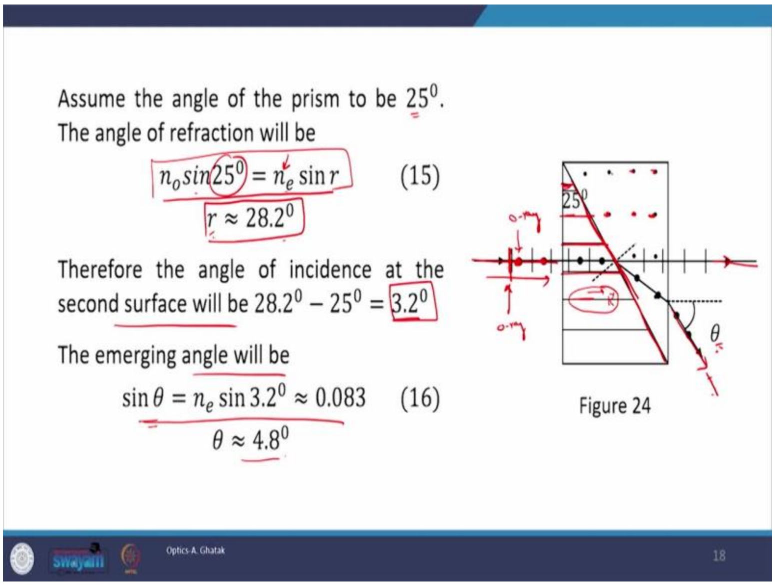

Similarly, there is another prism which is called Rochon prism. The Rochon prism consists of 2 similar prism, the optic axis of the first prism is normal to the face of the prism while the optic axis of the second prism is parallel to the edge of the prism as shown here in this figure. Here, this is the optic axis of the first prism, while this is the direction of optic axis of the second prism. Now here again if you launch and unpolarized light, the in plane polarization component will go straight and perpendicular polarization beam will go in other direction and which will emerge out an angle θ with respect to the horizontal. Now if the prism angle is 25 degree, for here you can easily calculate this deviation this angle of deviation θ, but we will have to do is that we are launching and unpolarized light. Now therefore, we can use Snell's law and it says that $n_o sini$ which is 25 degrees equal to $n_e sinr$ with this we can calculate the angle of refraction.

Now here this polarization, the dot polarization, you can see the dot polarization is perpendicular to the optic axis of the first prism and it is also perpendicular to the direction of propagation. Therefore, this dot polarization work as o ray in the first prism, while this plane in plane polarization it is perpendicular to the optic axis and as well as it is perpendicular to the direction of propagation $\vec{k}$. Therefore, you can also say that it is working as o ray, but the $\vec{k}$ vector is in this direction and optic axis is also in this direction and therefore, you can see that you cannot create a plane out of it. Therefore, both of these polarizations will work as an o ray.

Now once n_e is given using the Snell's law, we can calculate the angle of refraction. And once the angle of refraction is calculate and you know this slanted plane is making an angle of 25 degree with the vertical, the angle of incidence at the second interface will be 3.2 degree. And from here angle of emergence can easily be calculated using again Snell's law which is given by this relation. Now with this I end this lecture and thank you for joining me see you in the next class.