WAVE OPTICS

Prof. Samudra Roy
Department of Physics
Indian Institute of Technology Kharagpur

Lecture - 62 : Birefringent Crystal

Hello, student, welcome to the wave optics course. Today we have lecture number 62 and today we're going to discuss how the birefringent crystal works. So we have lecture number 62. So in the last class we discussed briefly about the birefringence property that means when the n refractive index is no longer same into direction then this kind of crystal is birefringent. So today we will extend this idea and try to understand a few things. So our topic is birefringent crystal. So we will start with a specific crystal, a well known crystal that is called the calcite crystal. So let us try to draw the crystal structure, this is a specific crystal structure. So we have a CA atom here and then this kind of structure is oxygens. So if I launch a light here along this direction, this is the plane where oxygen is present. Now I launch a light that goes through the crystal in this direction and comes out. So here two components of the electric field are there, one is perpendicular and another is parallel. So this is I write a parallel component because when this light is there and this is perpendicular, I will tell you why and if I launch the light from this direction to this direction, from the lower side, what happened that I have this electric field and this electric field. So this parallel and perpendicular is calculated . In terms of the structure and this plane where the three oxygens are there parallel to this plane we have something called the optical axis. So the optical axis is something which is making the symmetry of the system and that is perpendicular to this plane and this is my optical axis. Why is it called the optical axis? We are going to discuss it now. Along this direction if I launch an electric field you can see that both the electric fields will be perpendicular to the optic axis.

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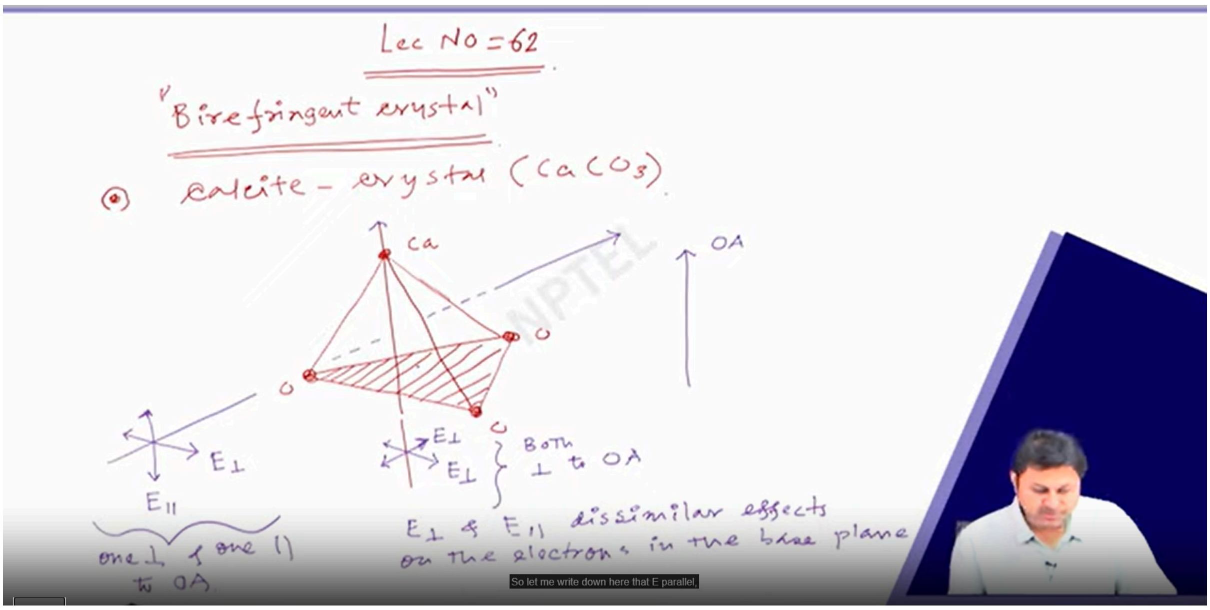

So that's why I write e perpendicular, e perpendicular so both of them are perpendicular to the optic axis which is a symmetry axis passing through this specific plane where the oxygens are contained. However, when I launch this stuff here then you can see that one is perpendicular to the optic axis but the other is this one is parallel to the optic axis. So here one perpendicular and one parallel to the optic axis. Now you can understand that E perpendicular and E parallel should have dissimilar effects on the electron on the base plane. So if you look at the base plane, you can see that when the light is perpendicular to the base plane, it will produce some effort on moving the electron perpendicular. And when it is parallel, so in that case, the electron will move in a parallel plane. So it is very difficult to move the electron in a perpendicular plane compared to the parallel plane. So let me write down here that E parallel, that is parallel to the optic axis. So let me draw the plane here. So that was the plane. If I only draw this plane one is parallel which is E perpendicular by name and another is perpendicular to this plane and by name it is E parallel because the optic axis is along this direction, so, this is the direction of the optic axis. So E parallel causes the electron to oscillate along the direction perpendicular to the base plane. So causes the electron to oscillate along a direction perpendicular to the base plane. On the other hand, the E perpendicular makes the electron vibrate and makes the electron oscillate in the plane. So in one case it is trying to vibrate along this direction. In another case it tries to vibrate along this direction so that in the plane the electron is confined due to the chemical bonding and this vibration takes place more easily compared to this one. So that means E perpendicular this field interacts more strongly to interact more strongly to electrons and because of that strongly to electrons and as a consequence what happened the velocity of this component reduces most that is the velocity. If I write the velocity of the E parallel component is v parallel and E perpendicular component is v perpendicular then from here I can write that v perpendicular component will be less than v parallel component. So when it moves through the system then if I go back and write that in this direction what happened, v parallel will be there and v perpendicular will be there but v parallel will be greater than v perpendicular along this direction. On the other hand in this case both the velocity will be the same and I simply write v perpendicular, that is the velocity we have along this direction. So in one direction we can see that the property of this crystal is such that in one direction we have the velocity same for two components but in the other direction the velocity differs and I mentioned why that it differs. So the refractive index is defined with the velocity. So now the refractive index I can write is C divided by V in general. So, I can write that refractive index parallel is equal to CV parallel and refractive index perpendicular is equal to CV perpendicular. If that is the case and V parallel is greater than, so our condition is V parallel was greater than V perpendicular. Let me draw the structure again. Then maybe it will be clear to you, then this is the base plane oxygen molecules are sitting here and this is the direction we call V perpendicular. This is the direction of velocity and this is the direction we call v parallel. So this corresponds to the refractive index n perpendicular and this corresponds to the refractive index n parallel. If v parallel is greater than v perpendicular, so, obviously e parallel will be less than e perpendicular n part. So n parallel should be less than n perpendicular. So for calcite crystal what happened, for $CaCO3$ what we have okay. So carbon was there in the middle exactly somewhere here I write, for $CaCO3$ what happened that in perpendicular for at lambda equal to 589.3 nanometer at this wavelength in parallel and in perpendicular the values are different. So in one case it is 1.486 and it is 1.658. So there is a huge difference between the refractive index for calcite crystal at that particular wavelength. So that means if I draw the refractive index in an n x and n y they will not go to n x or n y or in parallel with perpendicular they will not going to coincide rather there will be a gap between these two. So utilizing this idea, now we can say that, so, a birefringent crystal can be cut and polished to produce a polarizing effect and can be used as a polarizing element where the optic axis may have a desired orientation and be related to the incident light. So, we can make this kind of crystal and according to the crystal geometry, we can arrange the optic axis. So let me give a few examples or a few cases. So suppose this is a crystal I draw and light is propagating here along this direction and this is an unpolarized light that is allowed to pass through this crystal. Now the optic axis is along this direction. So this is the direction of optic axis OAM, this is case one. So this is another structure I can draw. A similar kind of crystal light is also passing through a polarized light and here the optic axis is along this direction. Suppose this is the direction of optic axis OA and this is second case and finally third case I can have a crystal structure like this, this is the direction light is passing also this polarize like this and optic axis is in this direction it is perpendicular to the plane of the paper. So it will be like this OA, this is the optic axis, the orientation of the optic axis. So three different orientations we have for the optic axis and see what happened. So here you can see both light component dot and arrow are perpendicular to OA. So both the component, both the component means e parallel or e perpendicular whatever I write is perpendicular to the optic axis because from here we can see the optic axis in these directions one is perpendicular this and another is moving this direction. So that is also perpendicular to o. So both e components are perpendicular to OA, if both components are perpendicular to OA then both the components will travel with the same speed. So V is the same, and refractive index n is the same for both. What about case two? In case two you can see that one component is perpendicular but another is parallel. So two components will travel at different speeds that are v perpendicular, that is the component perpendicular to OA, I mean here dot actually, dot component travel slower and V parallel travel faster.

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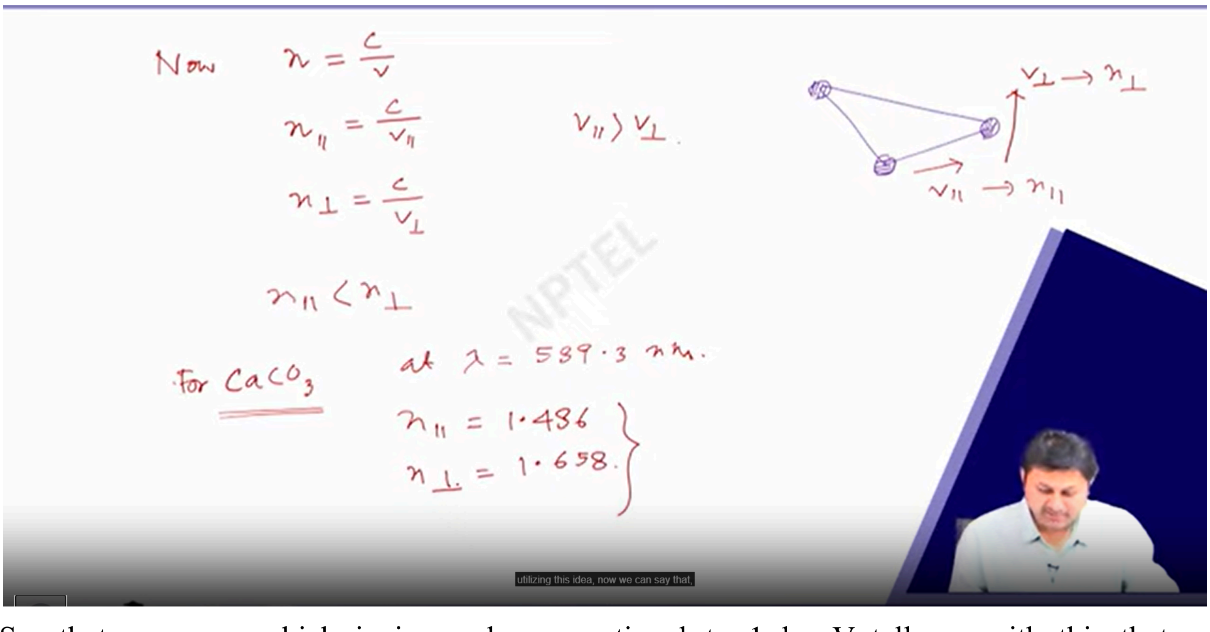

So, that means n which is inversely proportional to 1 by V tells us with this that n perpendicular is greater than n parallel. So if there is a change of n then what happened? When the wave is moving the path difference there will be a path difference occurring of two components, this path difference delta will be n perpendicular minus, n parallel multiplied by the length of these things say d okay. So d is the thickness of the crystal. Similarly here what happened is the v perpendicular component, so, the dot component is now parallel to that. So the dot component will be the perpendicular component. So here we will get the opposite thing. So the dot component is parallel to OA and the arrow component is perpendicular to OA. So it will happen in a different way. So now what happens is that n parallel will be greater than n perpendicular and the path difference will be simply n parallel minus n perpendicular multiplied by d. So, in general the path difference delta will be mod of n perpendicular minus n parallel multiplied by d that leads to a phase difference and that phase difference is delta phi and that phase difference will be 2 pi divided by lambda into path difference or equivalently 2 pi lambda into n mod of n perpendicular minus n parallel d mod sine close. So, by making this refractive index change we can introduce a phase difference between these two components and that is the essential thing to get a circularly polarized kind of light. Today, we don't have much time to discuss more about how this birefringence generates different polarized light. In the next class, I will discuss more about this issue. And show what kind of device one can make using these anisotropic properties of a crystal or birefringent crystal to generate different kinds of polarized light. With that note I would like to conclude today. Thank you very much and see you in the next class.

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