Modern Optics
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Lecture - 34
Electro-Optic Modulators and Devices

We were discussing Electro-Optics of Isotropic Media and we were talking about the electro-optic effect of the gallium arsenide crystal and now, we will be discussing a very important optical crystal electro-optic crystal that is KDP potassium dihydrogen phosphate.

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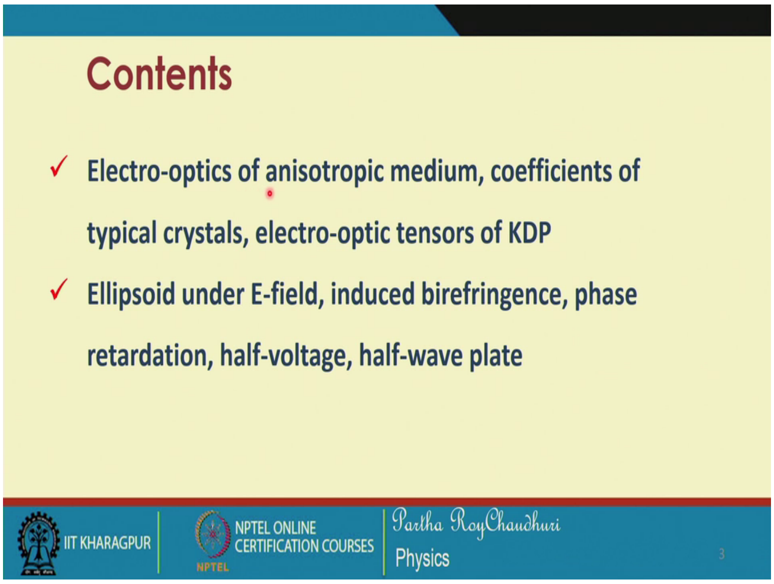

And for this purpose we have organized the discussion in this way; electr-optics of anisotropic medium, coefficients of the typical crystals, how we will provide a list of the typical crystals with their properties, refractive indices, electro-optic tensor coefficients. Then ellipsoid under electric field will look at the induced birefringence, then will try to evaluate the phase retardation half voltage and the action as a half wave plate and then will continue this a anisotropic crystal KDP a for longitudinal modulators as well as transverse modulators and the subsequent discussions.

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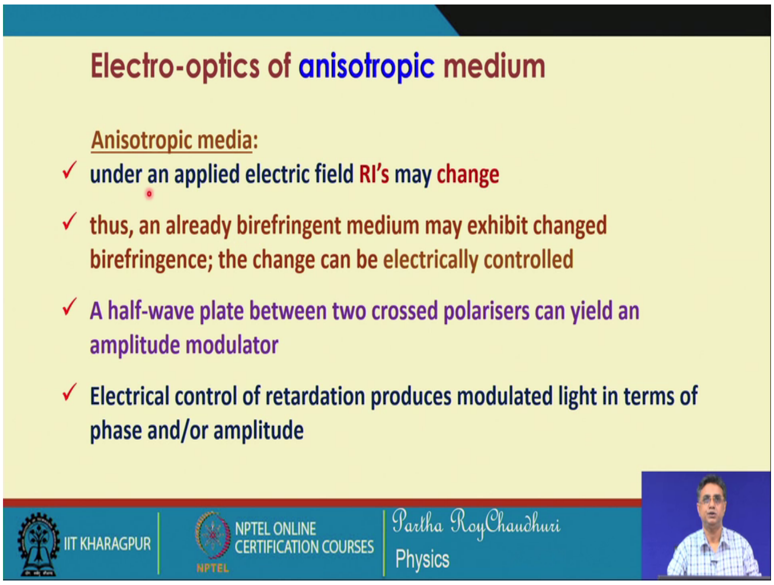

So, for anisotropic media under an applied external electric field the refractive indices may change it may change the lens of the semi axis of the ellipsoid or it can rotate the distort the ellipsoid in terms of the rotation. So, that we have to look for the principal axes system again under the action of the electric field. In general these all depends on how this crystal is configured. So, as a result an already existing birefringent medium and isotropic medium may exhibit changes in the birefringence and this change can be electrically controlled by external applied electric field.

Therefore a half wave plate between the two cross polarisers can yield an amplitude modulator this fact we have seen with all the details of the mechanism. If we place an anisotropic crystal with an applied voltage across it then controlling the electric field properties we can control the control the birefringence and as a result between the cross polarisers it can be used as an amplitude modulator. So, electrical control of retardation produces modulated light in terms of phase and amplitude and this fact we have seen earlier also.

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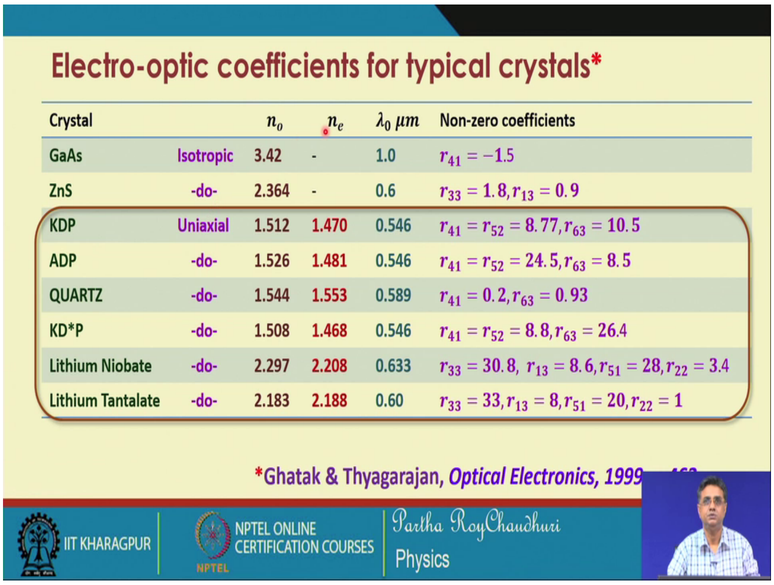

Now, provide a list of various crystals this we have already mentioned, but this time we are we are at this region that is uniaxial crystals KDP, ADP, quartz, KD P, then lithium niobate, lithium tantalite. Lithium niobate and lithium tantalite these two are a very important crystal crystals, and we will see the application of these two at the end and we can look at the refractive index properties ordinary refractive index, extraordinary refractive index at this operating wavelength 0.456 micrometer and these are the r 41 and r 52 they are equal in the case of KDP and also in the case of ADP. And these values are this into r 10 power of minus 12 or pico meter per volt and r 63 is 10.5. So, these values we will use to calculate the birefringence and retardation.

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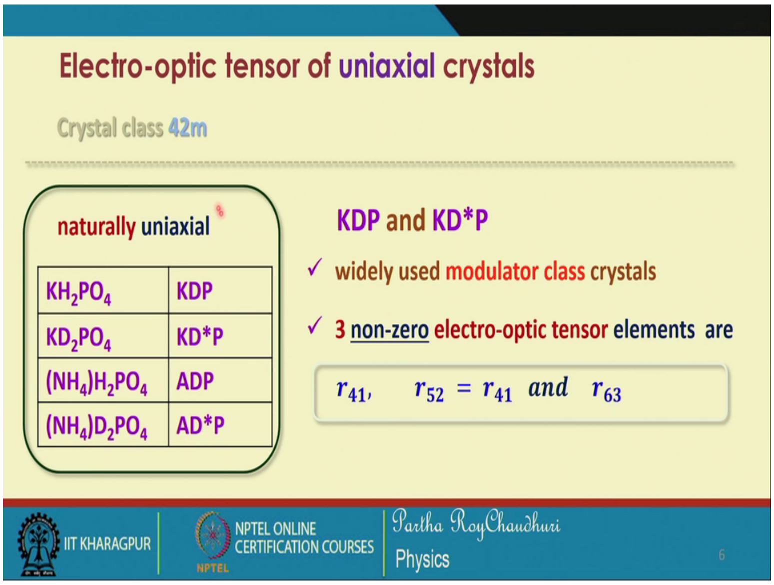

So, will first discuss this KDP and ADP the properties are like this their natural uniaxial KDP potassium dihydrogen phosphate, then ammonium dihydrogen phosphate these are very important crystals and these crystals are very widely very often used as a modulator class crystal a lot of commercially available devices made out of these crystals are already existing in the market 3. Nonzero electro-optic tensor elements of these crystals are r 41 and r 52 equal to r 42 this you have seen, and r 63 r 52 and 42 they have the same value as you can see from here 41 and 52 the values are 8.77 for KDP. Now, we will use this value for the estimation of birefringence.

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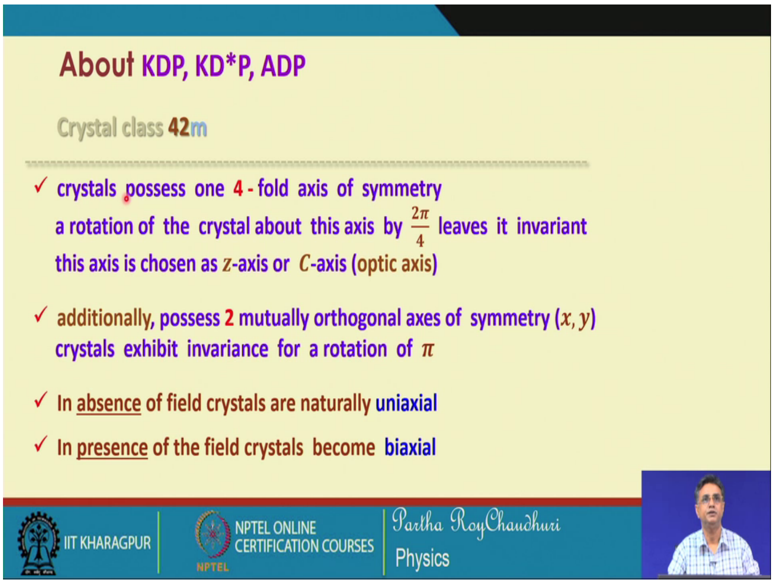

So, this group of crystal the class is 42 m crystals possess 4-fold axis of symmetry that is a rotation of the crystal about this axis by twice pi by 4 leaves it. So, you can you can go for 4 steps of rotation each one by twice pi by 4, and then the crystal will remain in variant and this axis the about which this rotation is given is chosen as the z-axis or C-axis the optic axis of the crystal. In addition to this so this is the 4-fold symmetry, in addition to this the crystals possesses two mutually orthogonal axis of symmetry about x and y this exhibit invariants for a rotation of pi. So, if you rotate by an amount pi then again it remains the same, in variant the crystal remains in variant.

So, that is why this class is 42 plus and in absence of any electric field that applied electric field the crystals are normally naturally birefringent and in presence of the field external field it becomes biaxial, in general it becomes biaxial.

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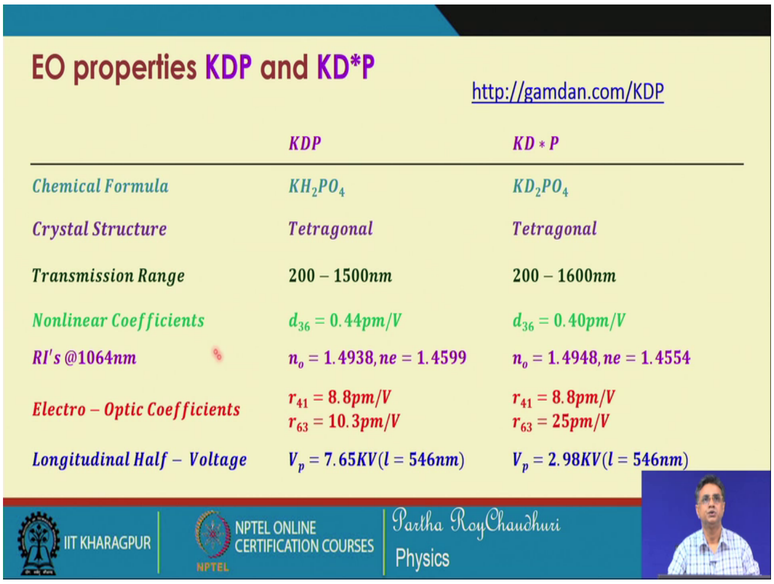

So, these are some important properties of these two crystals which are very well relevant for in terms of the design aspects and for calculation of various electro-optic properties these are taken from this reference. Crystal is tetragonal this one is also tetragonal operating range is from 200 to 1500 nanometer is slightly more 200 to 1600 nanometer, d 63 this will be d 63 this coefficients are this visible. Then not these are the non-linear coefficients and then the refractive indices ordinary refractive index and extraordinary refractive index these are given by these values.

Electro-optic coefficients the one which were talking about and which is relevant for this present discussion is this numbers will have to use this and then half voltage for this crystal is about 7.65 KV l as per these data. It may be different if you use different wavelength and different configuration. So, this is very useful for the estimation of the electro-optic properties.

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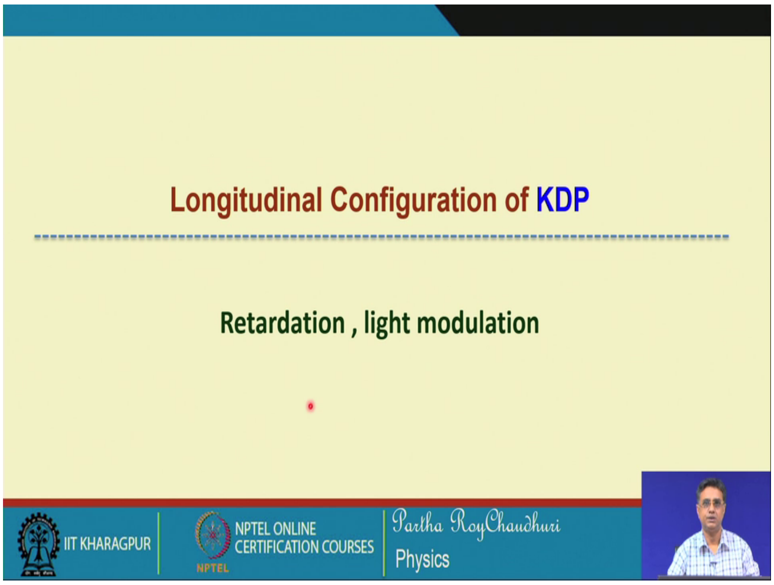

We will now, discuss the longitudinal configuration of the KDP crystal in terms of the retardation and then how this retardation can be used for modulation of light.

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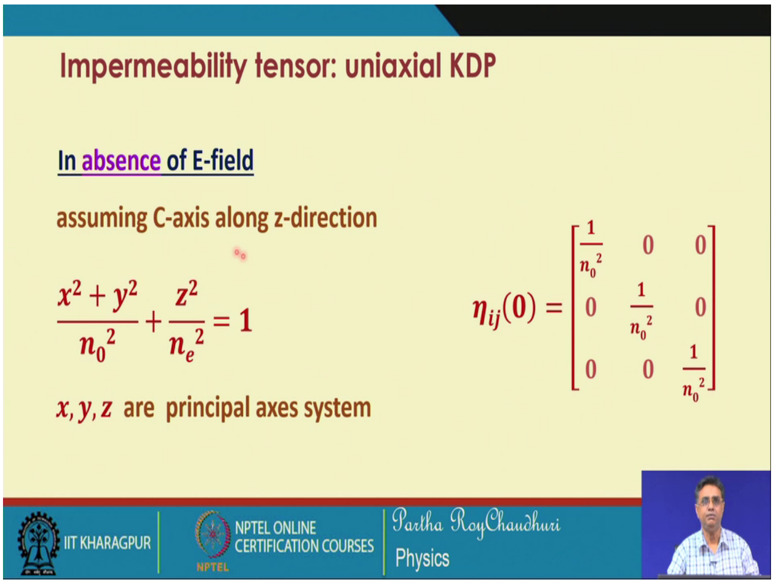

So, this is again very well known by. Now, we are very much conversion with this assuming the c-axis along the z-axis in absence of electric field that is the natural representation for the index ellipsoid of this crystal is refractive ordinary refractive index, extraordinary refractive index and you can write this ellipsoid in this form. This impermeability tensor in this case is n 0 square, n 0 square and this should be n e square is a mistake it should be n e square extraordinary refractive index.

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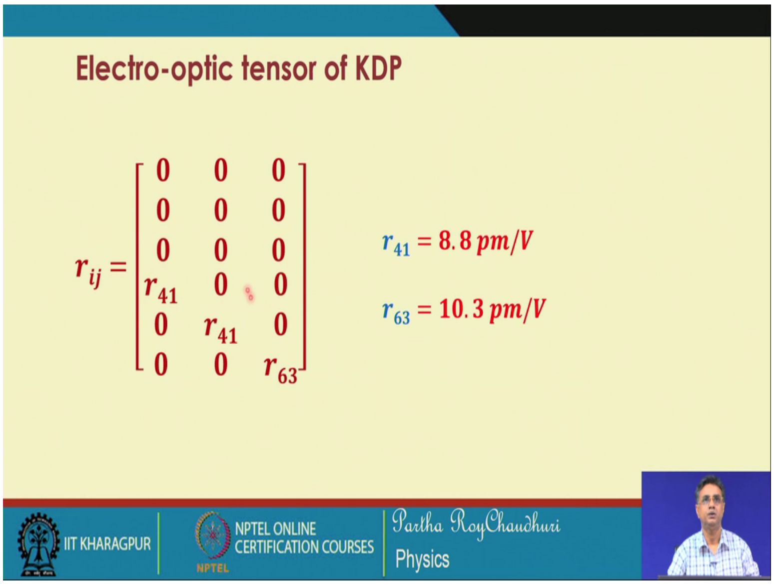

So, when you and the electro-optic coefficient that values we have already mentioned that r 41 is equal to 8.8 picometer per volt whereas, r 63 is so these two are the same value and this is different. And now these values will make the system different depending on the orientation of the electric field that is applied to the crystal.

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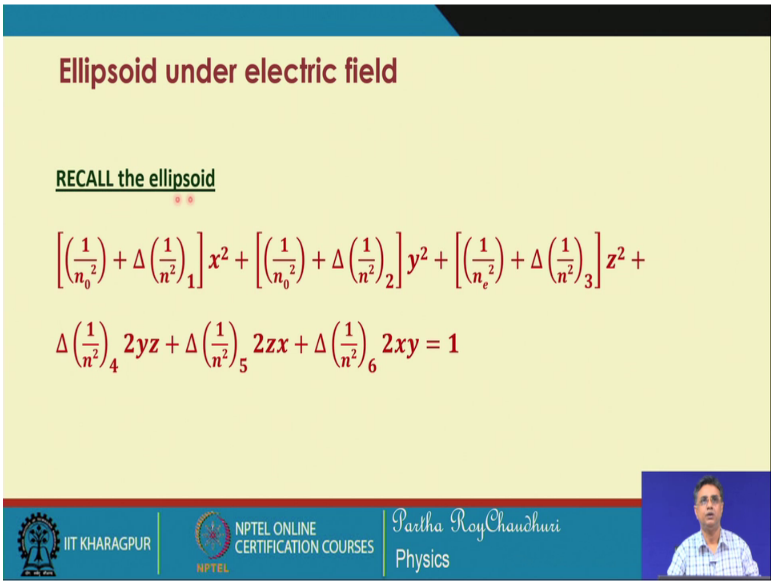

So, let us recall the ellipsoid when it is under electric field you have these incremental values of the refractive indices attached to the square components of the ellipsoid, and the these are the cross terms of which are also attached with this changes in the refractive indices.

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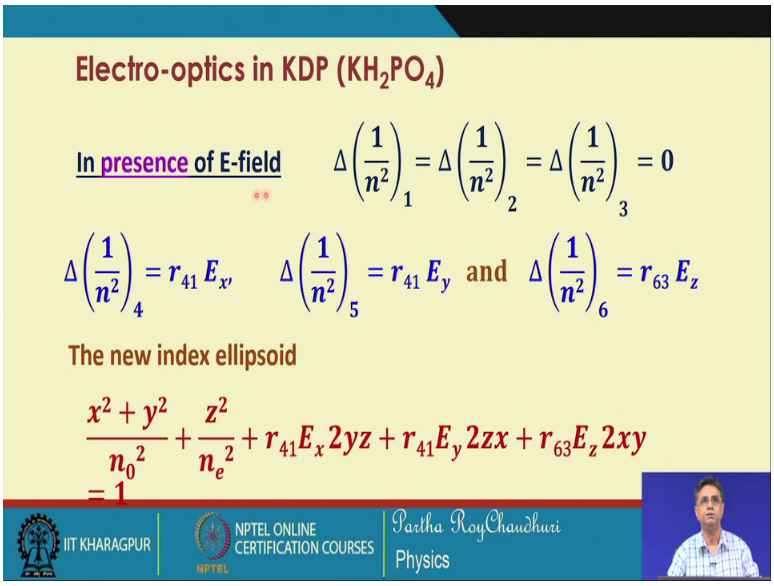

So, now, in presence of the field these quantities will be equal to 0 and these are because what we will do is that if we use that equation we will multiply this with e x, e y and e z, and e x will be attached to this, e y will be attached to this, and e z will be attached to r

63. So, and all other components being 0, so they are these components are all 0, but these cross terms will be nonzero and this is what we mentioned r 41 is attached to e x, e y and e z. Then the new index ellipsoid in this case will be represented; by this equation the this will be the ellipsoid under the electric field.

Now, we will have to diagnolize this equation or we can gives an other end will rotation looking at the equation who are the cross components etcetera.

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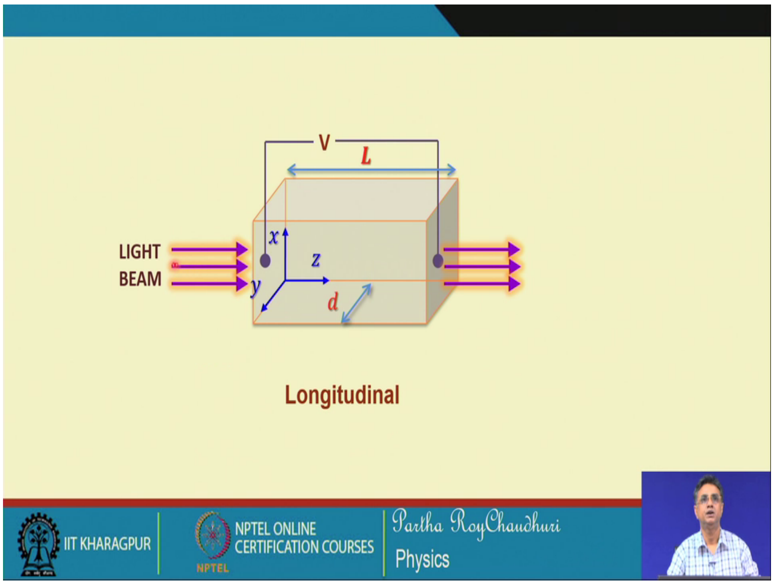

So, this is the longitudinal configuration of the KDP crystal you have taken your width d and the length L and these are the x, y and z-axis.

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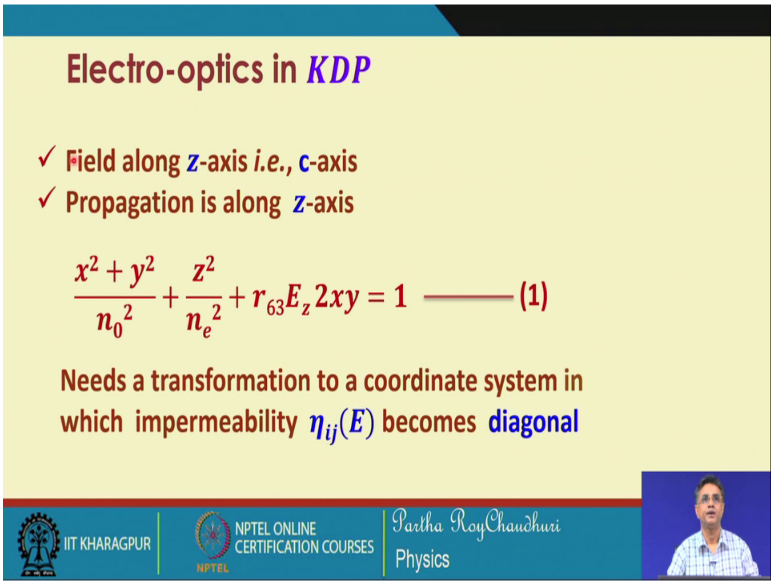

Now, if we assume that the electric field is along z-axis that is the C-axis of the crystal and the light is also propagating along z-axis that is this longitudinal mode of operation you have light which is travelling along x-axis and electric field is also applied along the z-axis.

So, along z-axis the light is propagating electric field is also along z-axis, therefore this in this longitudinal mode of operation we have because you have only one field e z. So, you retain only one cross term and then it needs a transformation of the coordinate system to look for the principal refractive indices. So, this impermeability becomes diagonal in the system after rotation that we are looking for.

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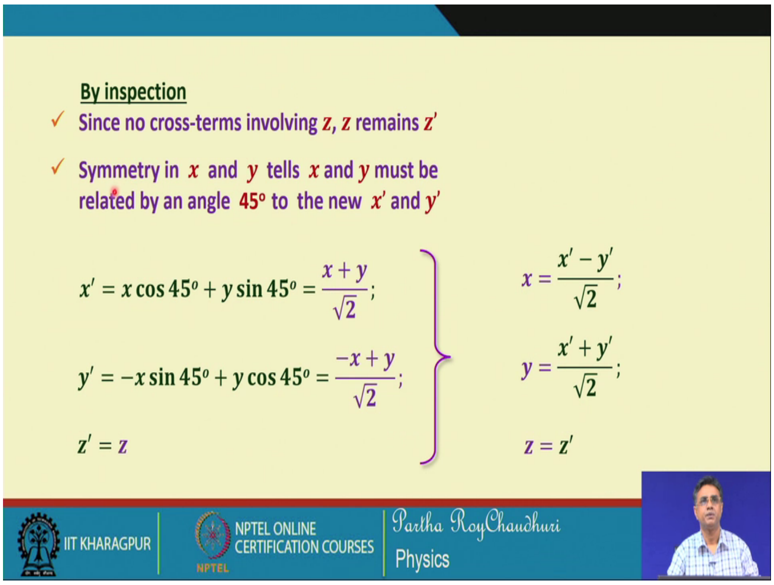

So, because this problem is very well known we have discussed quite a few number of times and we will give the Euler angle rotation of 45 degree about z-axis because x and y are interchangeable and it does not it leaves the equation unchanged. So, the we provide a rotation about 45 degree about the z-axis and this coordinate transformation this is again a very well known transformation equation, z prime is equal to z but because we need the reverse transformation because we will have to use this equation we have to replace x square x y z by x dash y dash and z dash. So, we will be using the reverse transformation that is in place of x will write x dash minus y dash under root 2 and y equal to y dash plus x dash plus y dash by under root 2, z remains z prime.

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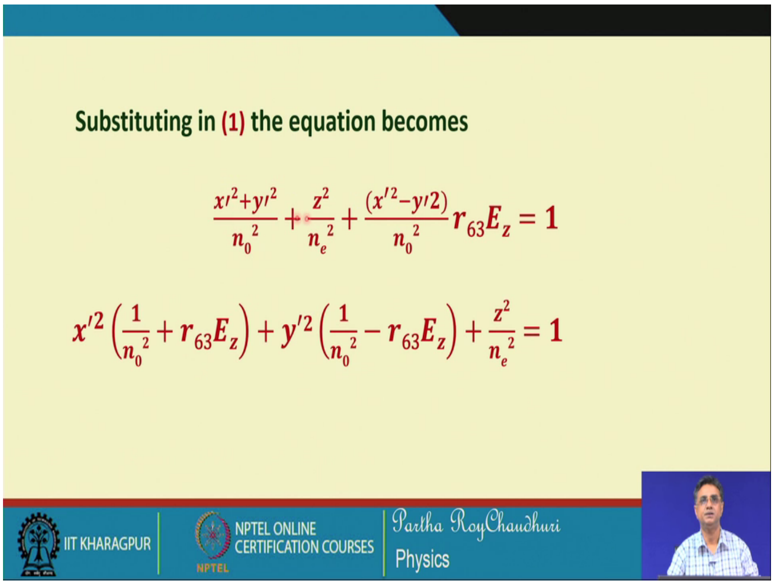

So, if we substitute this into this equation then we can we write this equation in this form, and then this equation becomes of this form x prime square 1 by n naught square plus. So, this is the additional quantity, additional term which has come along with 1 by n 0 square and similarly for the y square term is now associated with these two components. So, these are the new refractive indices in the principal axes system.

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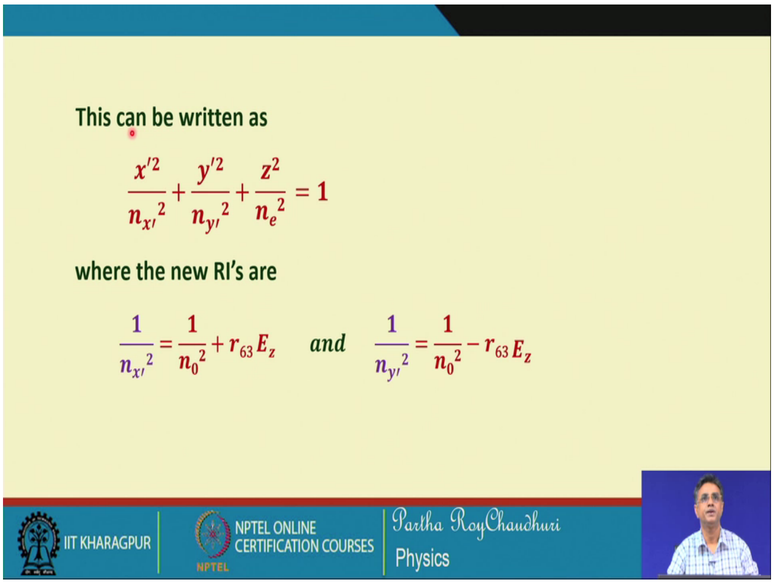

So, if we write this equation, if we write this equation in this form that x prime square by n x prime square like this and y prime square by n y prime square like this then the new refractive indices will be equal to this for x. It is this and for y there is a minus sign. So, it is by the equal amount it is increased and by the same amount it this quantities decreased.

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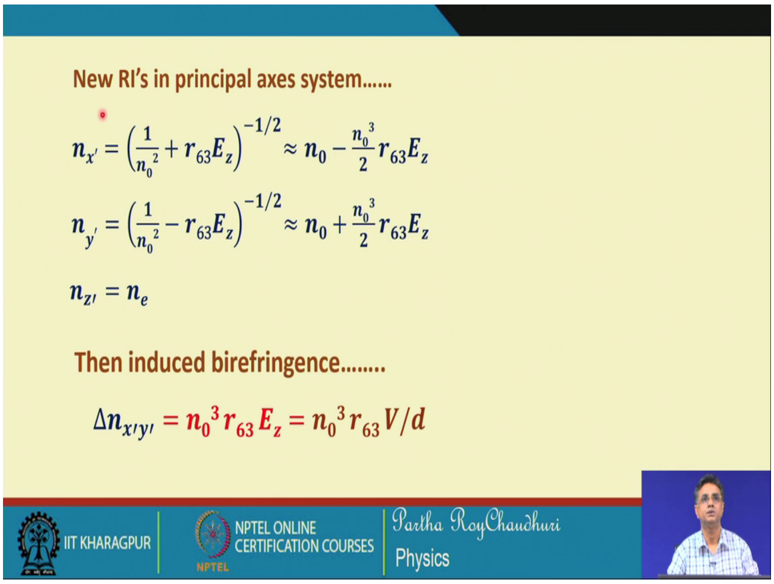

So, with respect to the new principal axes system under the electric field you have n x dash is equal to this which is with this approximation which can be written as this, and n y square with this approximation can be written in this form. Therefore, knowing this n x square and n y dash we can calculate the birefringence. So, the induced birefringence in this case when you have an electric field which is acting along z direction and the light is also propagating along the z direction then there will be changes in the n x, n y which will appear as n x dash and n y dash with the rotation by 45 degree and the induced birefringence I just have to take the difference of this.

So, this will become n 0 cube r 63 E z, but E z as E z is equal to V by d the voltage by the this should be L actually because it is longitudinal mode of operation. So, this will be L.

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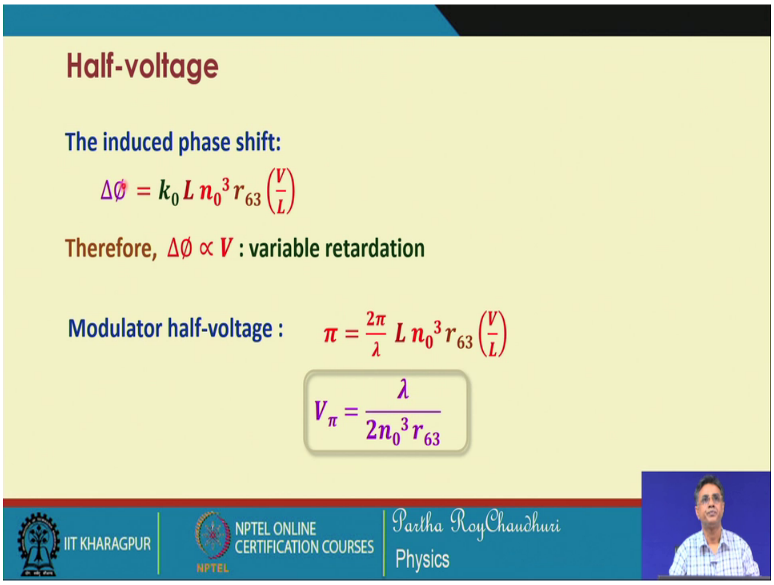

So, the induced phase shift will be equal to from here only because this is with the multiplied by k 0 that is twice pi by lambda times this will be the will be the induced phase shift which is equal to this. So, L cancels and you can see that this phase shift delta phi is proportional to the applied voltage. And by changing the applied voltage we can change the phase shift. So, this can be used as a variable retarder device just by controlling the electrical field in terms of the applied electric in terms of the applied voltage.

In this case, this is again the modulator half voltage which is a very important parameter that defines the quality of the electro-optic material. So, half voltage in this case is we can find by setting this phase shift is equal to pi and this pi cancels, L also cancels we get the half voltage expression lambda by twice n 0 cube r 63. These are all very similar to the ones which we have discussed in the case of gallium arsenide isotropic material, but the difference is that the coefficient r 63 is very high and then that makes additional either or other configurations which will be even more advantages for this KDP application.

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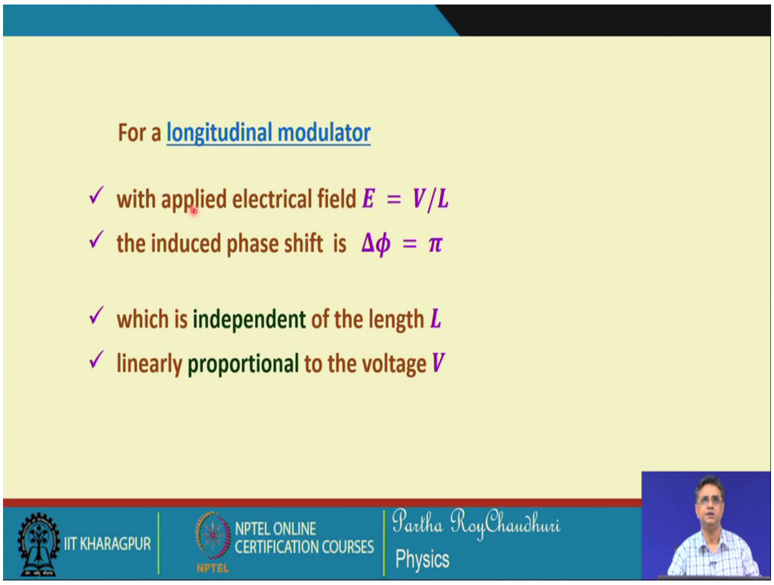

So, for a longitudinal modulation we see that the applied electric field e equal to V by L the induced phase shift del phi equal to pi and this is you can see that induced phase shift which is independent of the length of the modulator crystal. But it depends on the applied voltage depends on the applied voltage a phase shift is proportional to V, but it does not depend on the length of the crystal.

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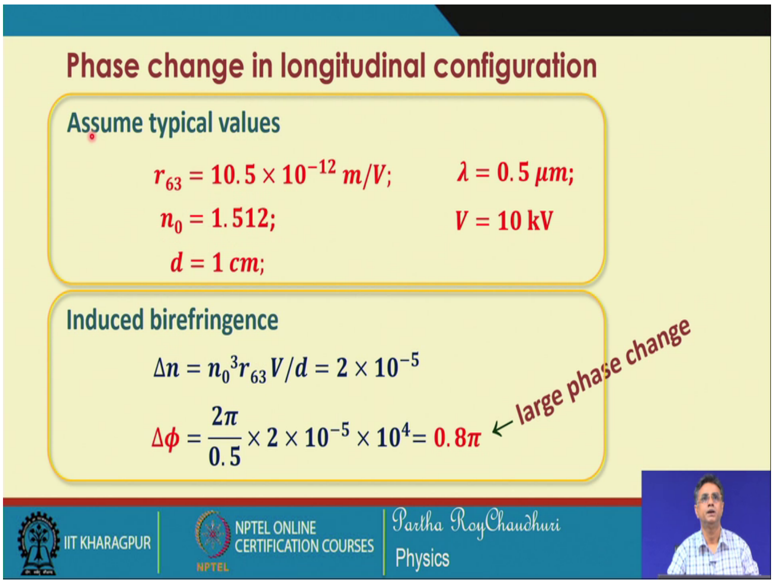

So, let us assume this typical values for r 63 which is 10 point that is at this wave length and V equal to let us suppose that it is 10 kilo volt if we apply this much have voltage across a crystal of this d should be L equal to 1 centimeter in that case then we can calculate the birefringence this will also this will be L. So, this birefringence will be equal to 0.8 pi which is a very large phase shift if you increase the voltage by some more amount you can reach almost pi. So, this phase shift is very large, but it also required reasonably very large voltage 10 kilo volt.

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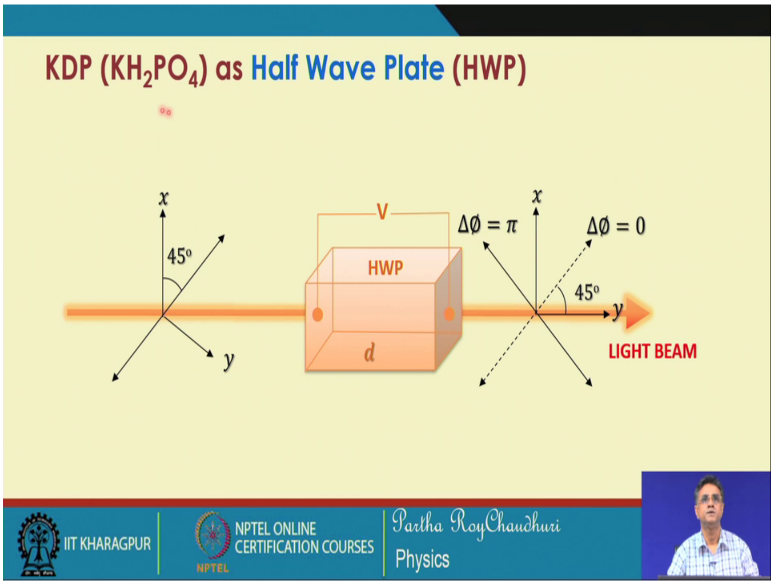

So, as a half wave plate this is the configuration you have your x, y and this is at 45 degree to x and y of the old coordinate system. In the voltage is applies in the and the longitudinal direction this should be again L, but if we call this is this d then this d, I think we should write this equal to L then there will be a phase shift will be 0 when it is oriented like this, but the phase shift will be equal to pi when it is oriented in this direction.

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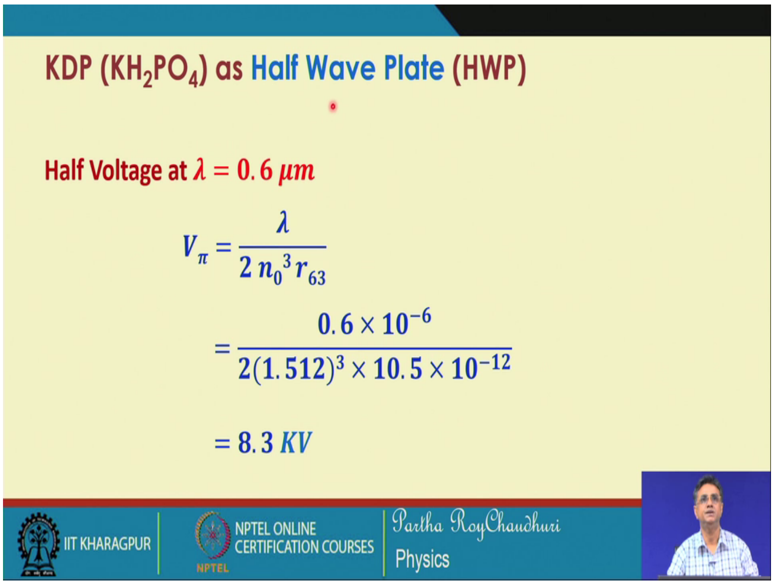

So, half voltage in this case for lambda equal to 0.6 we can calculate that 8.3 KV for this value of the electro-optic coefficient and this is your ordinary refractive index at the operating wavelength of 0.6, ok.

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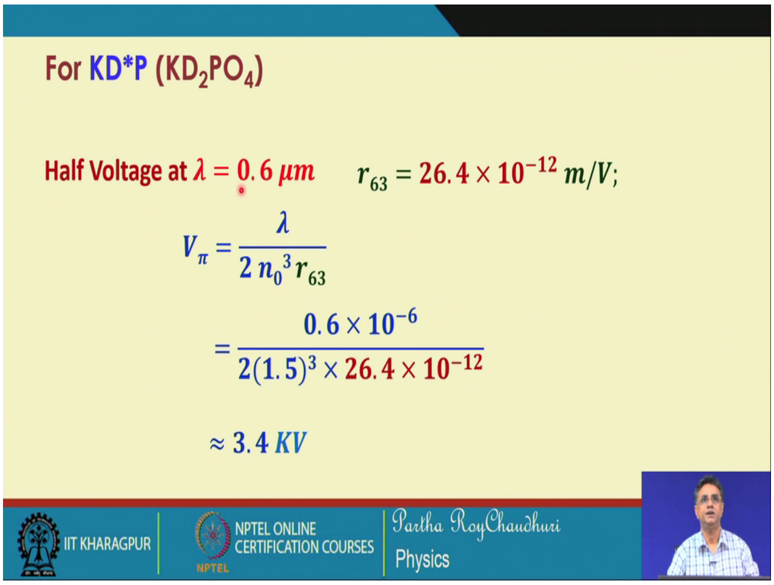

Half voltage for this KD star P dihydrogen phosphate this the coefficient is now more and as a result the half voltage reduces to 3.4 kilovolt which is as good as one-third times less than the half voltage of this one that is for the KDP crystal.

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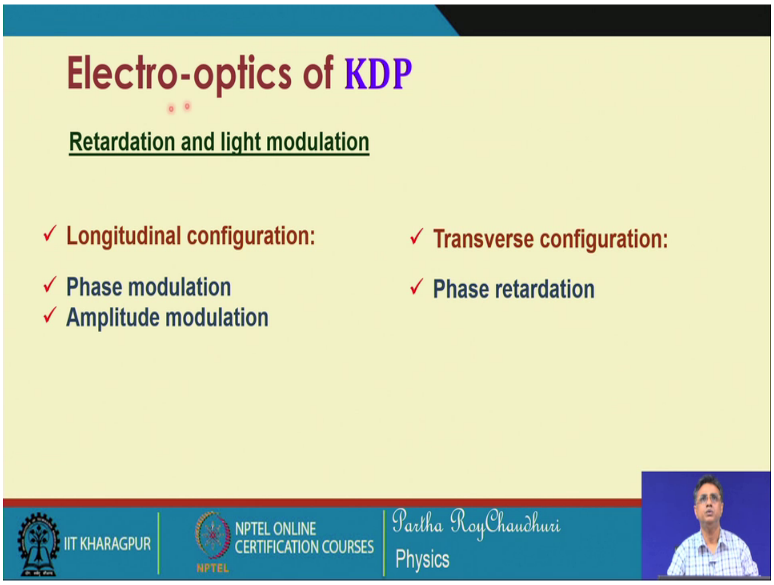

So, now we will continue KDP for this longitudinal mode of operation for phase modulation, amplitude modulation and transverse configuration.

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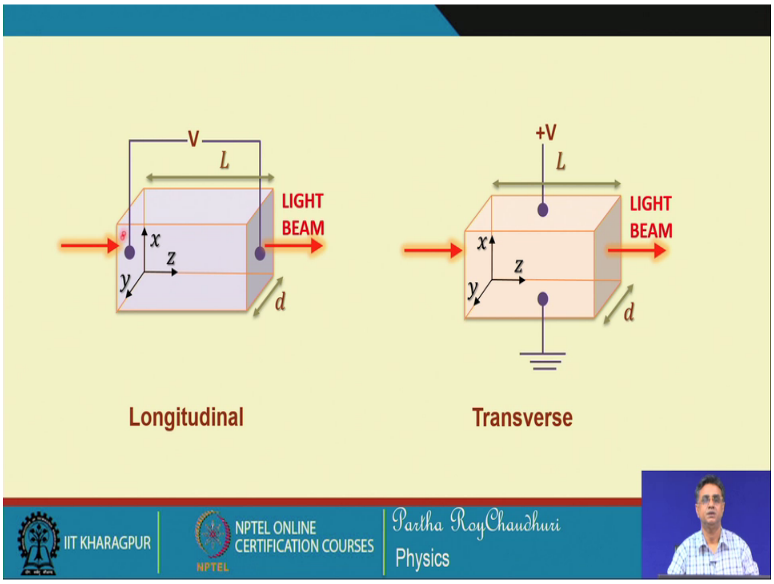

So, this is the configuration for a longitudinal mode of operation you can see this is your x, y and z you apply a voltage along the direction of propagation of the light beam. But in this case the voltage that is the electric field that we apply across the crystal a direction which is perpendicular to the direction of propagation of the light.

In the next section we will continue our discussion with this longitudinal and transverse mode of operation of this KDP crystal. And we will see how we can use both this configurations for light modulation and switching in terms of the amplitude modulation, phase modulation and also this transverse configuration to make use of this longitudinal and this amplitude and phase modulation.

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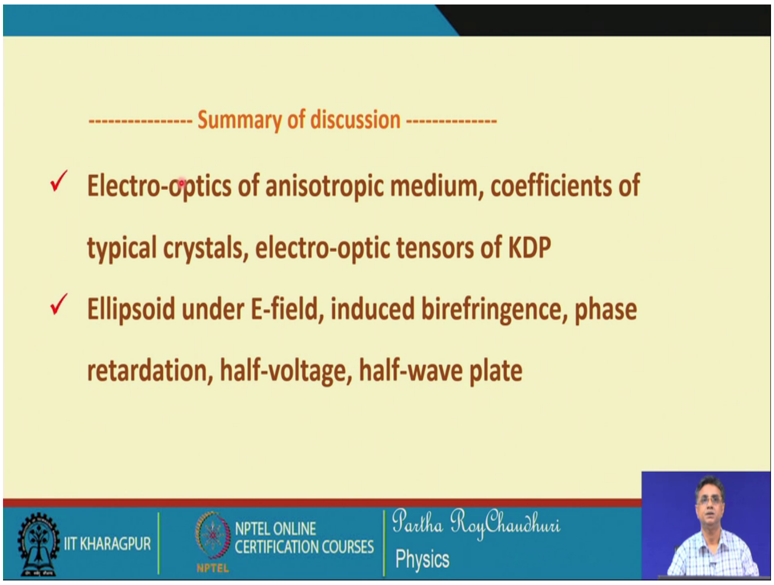

So, in this discussion we considered this electro-optics of isotropic medium, then we looked at the coefficients of the typical crystals, we provided a list of the crystals and then electro-optic tensor for KDP with the values of the nonzero coefficients that is r 41 and r 63. Then we looked at the ellipsoid without and with external electric field in the case of longitudinal mode of operation we estimated the induced birefringence, phase retardation, then half voltage, and use of this KDP as a half wave plate, also be compared the half voltage for KDP and KD star P. We saw that it is about one-third times less in the case of high electro-optic tensor coefficient for KD star P.

Thank you.