Experimental Physics - II
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Lecture - 49
Expt. for Verification of Malus law

today we will discuss about the polarization of light and we demonstrate some experiments on polarization.

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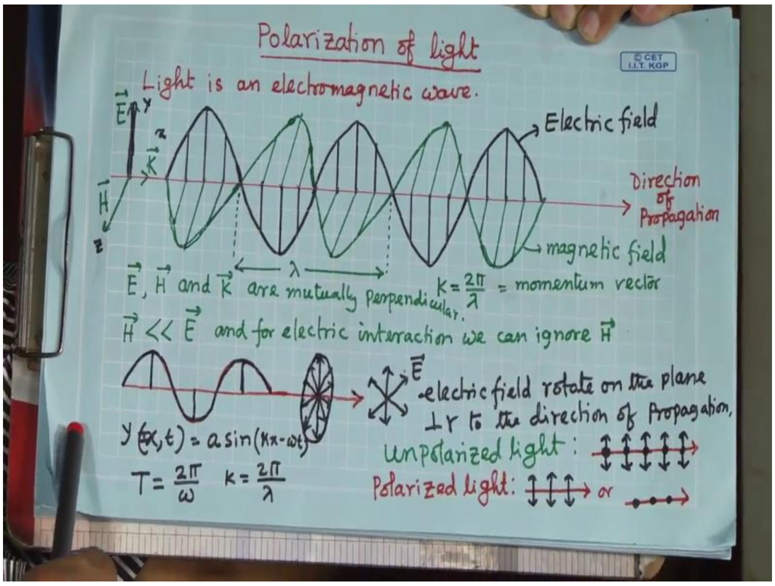

let me just tell you about the polarization of light. light is an electromagnetic wave. that is well known to all of us. this it has two component electric field component and magnetic field component. And, these two components are mutually perpendicular to each other and also these two components are perpendicular to the direction of propagation to the direction of propagation. That means, this electric field component, magnetic field component and direction of propagation they are mutually perpendicular.

this is the electric field component It is its amplitude this is the amplitude these are varying these are varying like waves and magnetic component also its varying like wave. So now, this magnetic component actually its strength is very weak compared to electric component for electric interaction with matter generally we neglect we ignore the magnetic component. So; that means, it is just like this light we can treat as a like this it has electric component and it is varying actually, magnetic component also varying in the same wave because they have to keep, they have to maintain the mutually perpendicular with each other. it is in perpendicular plane we are neglecting that part. we can think that light is propagating in this direction and it has electric components and its varying like this.

this electric component actually it's the its rotating you know it's the rotating. this its then is changing the direction again. it is this electric component is rotating on a plane perpendicular to the direction of propagation. electric component in as if in all directions on a plane perpendicular to the direction of propagation.

this light this type of light where electric component is the its vibrating in all directions vibrating in all direction on a plane perpendicular to the direction of propagation. this type of light is called unpolarized light, this type of light is called un polarized light these unpolarized light generally we represent like this.

this is the direction of propagation and so it is in all directions. these are vectors for any direction you can get two component, you can get two component mutually perpendicular to comfort you can reserve any vector into two components One is they are mutually perpendicular in a vector you will get two components; so, whatever the direction. we can think that they.

this we can represent with the component in two directions component in two direction in this direction and another is perpendicular to these papers because this is the direction of propagation. this line as well as dot here see dot means this electric component is perpendicular on the plane of the paper. this wave we represent the unpolarized light

Now, if only one component exists and other one is removed by some means, then we tell this is the polarized light if only; so if this direction is fixed of this electric component it is in this direction by some means if we can fix it, then we tell this is the polarized light or it can be. other component is there, and this component is removed by some means. we can represent this is the this either this or that one is polarized light. only it is an electric component will have a fixed direction then it is polarized light.

electromagnetic wave, so that wave we can represent this is the y is a function of x t this is the x direction, and this is the y direction electric component vibration in y direction, and this is the z direction for H. for electric component y is electric components. it will vary following this equation this a is 0 maximum amplitude

a sin kx minus omega it is a general equation of waves where this omega is the is related with the time. t equal to 2 pi by omega and this lambda this the lambda it is a k, k is wave vectors, or we tell momentum vector. this k is equal to two pi by lambda. here k and omega are actually they are related with the with the momentum vector at the time period now polarized unpolarized light by some means if you can make it polarized

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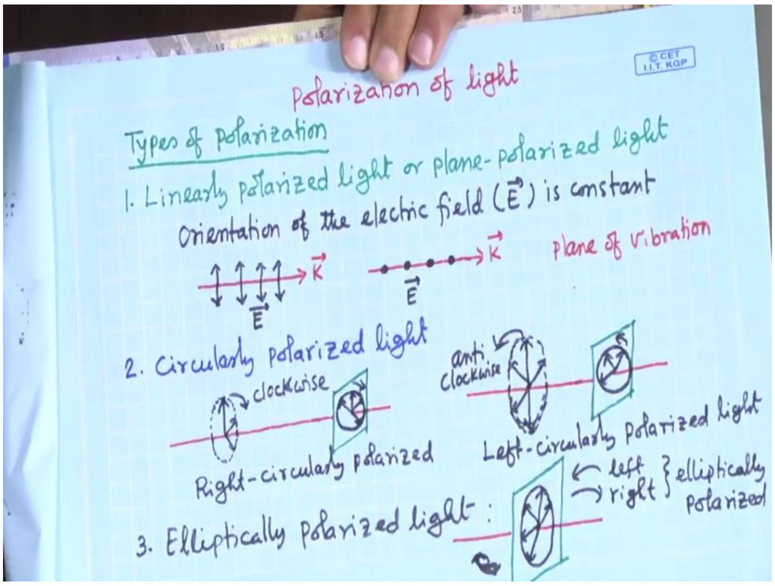

different types of polarization one can get. what are those these types? This one type is called the linearly polarized light or plain polarized light linearly polarized light or plain polarized light. these are it is the this is called linearly polarized light these or that its electric vector its vibrating in a particular direction with constant amplitude with constant temperature. then it’s the polarized light linearly polarized light. it can be this, so it can be this in this way or it can be any direction, but it will maintain that direction and it will maintain the amplitude

these called the linearly polarized light also there are other two types circularly polarized light and elliptically polarized light. When the tip of this; when the tip of this electric vector it will rotate; it will rotate on a circle ok, then we tell that this is the circularly polarized light. If it rotates; if it rotates on a ellipse tip of the; tip of the electric vectors if it if it rotates on a ellipse, then we tell that is the on ellipse this is the ellipse. then we tell them this is the elliptically polarized light. Now, rotation it can be clockwise it can be anti-clockwise

if it is clockwise; so, it is clockwise. this my hand; so, handed polarized light. If it is anti-clockwise its towards my left hand, so it’s called left handed polarized light Left circularly polarized light or left elliptically polarized light these are the type of polarization. here whatever the one can identify whether it is linearly polarized light, whether it is circularly polarized light, whether it is elliptical polarized light, how to distinguish them; experimental one can find out.

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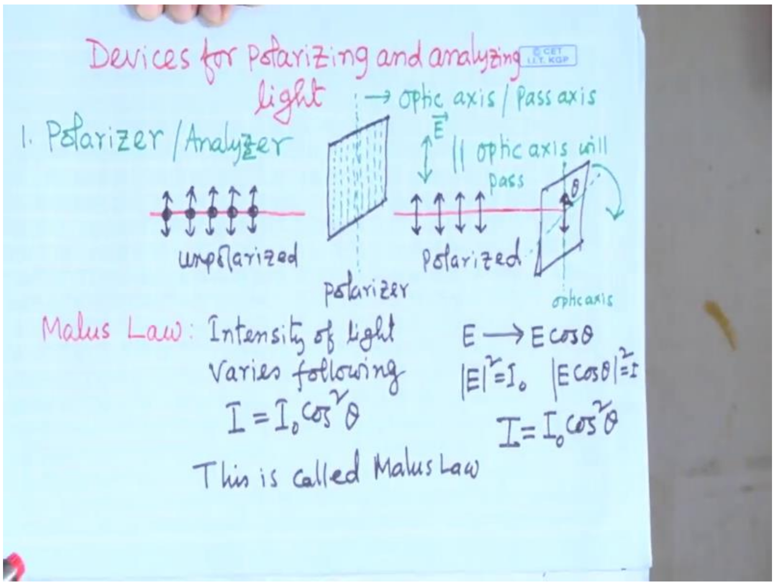

next; for polarization as I told this how to make a how to get the polarized light. generally natural light is unpolarized light; natural light is un polarized light and to get the polarized light you need device, you need some device, you need some arrangement. what are the devices for polarizing and analyzing light? you have to polarize the light and whether it is polarized or not that also you have to analyze. that is why we tell polarizing and analyzing of light.

so, device for that is we have very common device in laboratory we use that is called polarizer and analyzers. polarizer and analyzer both are same device ok, but depending on the use of that we tell them it’s a polarizer when it is polarizing the light and then it is polarize the light Then after polarization if we want to analyze whether it is polarized or not or whatever about the input, about the information of polarization; if you want to know; we use the same polarizer, but then we tell that is a its a analyzer.

what is polarizer? In simple way we can tell that it’s the it’s a made; it’s made in such a way; it’s made in such a way it’s the plate kind of things it is made in such a way that this it has it has an axis; it has an axis it’s called optics axis or pass axis. Electric component only passes through these pass when it is parallel to the optics axis.

electric component which is parallel to the optics axis that only will pass through this polarizer other components other components will not be able to pass through it electric component is a vector it’s the vectors. if I place a polarizer its optics axis is parallel to this component. other side of the polarizer I will get light only this component will be there, so then it is a polarized light.

Or if I put in such a way that these optics axis is parallel to these; optics axis is parallel to this then this component will not be there only these dot components will be there then also it is polarized light. now, this is the polarized light. electric component is along this direction and its magnitude is constant. Now, if I take another polarizer for analyzing this polarizing light. these you can tell this is a analyzer

if you put this polarizer or analyzer after this polarizing light. this light will enter into this polarizer or analyzer Now, optics axis of this polarizer’s of this analyzer if it is parallel to the optics axis of this of this polarizer’s ok; that means, this optics axis is parallel to the electric component.

then this electric component easily should pass through the polarizer’s this analyzer. I should get the same intensity of light on the other side. Now, if I rotate this polarizer, this analyzer with angle theta, then this component will make angle theta with this optics axis. only electric component parallel to the optics axis will pass through it.

we can say that if this is E, so E cos theta that component will be parallel to these optics axis; E cos theta will pass to it if I vary this angle when it will be 90 degree. E cos theta, E cos 90 degree will be 0; I should not get any light on the other side. whatever E here polarized light it is falling on the analyzers

Now, optics axis of the analyzer if we change this theta angle E cos theta, that will be a component which will be parallel to this optics axis and that will pass through. this is the electric component square of p t is intensity E square equal to say I 0. this E cos theta square is I; I equal to I 0 cos square theta.

other side intensity should; intensity should follow this relation intensity will change as a function of; as a function of cos square theta these intensity of light varies following, I equal to I 0 cos square theta. this is called Malus law ok; this is called Malus law. now, we will demonstrate this experiment verification of Malus law whether Malus law follows or not.

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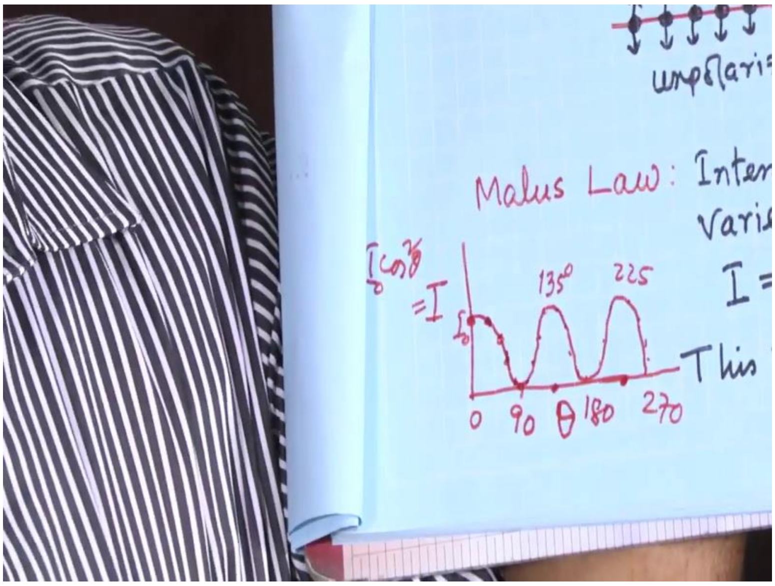

what we will do? We will measure the intensity will measure the intensity I of light from this arrangement and if I plot, I will change the angle I verses theta. cos theta you know this change like this cos square theta. this it will change like this; it will change like this cos square theta this I it’s a cos square theta and some initial I 0 will be there when theta equal to 0 when theta equal to 0. this value is I 0.

Now, it’s the its a 90 degree this is 0 degree, then this will be 180, 270 and this will be at 45. 135; 135 this angle will be 135, then this will be for 180, 45, 225 write 225. I should get maximum light at 0 degree parallel to the optics axis and then 90 degree it should be 0. what we will do this experiment. we will change the angle by 10 degree or 20 degree

10 degree I should change by 10 degree then you will get you will get this point and if you plot then this type of curve, we should get you should get

let us do the experiment, let us let me show you the experimental setup. this is the simple experimental setup to verify the Malus law.

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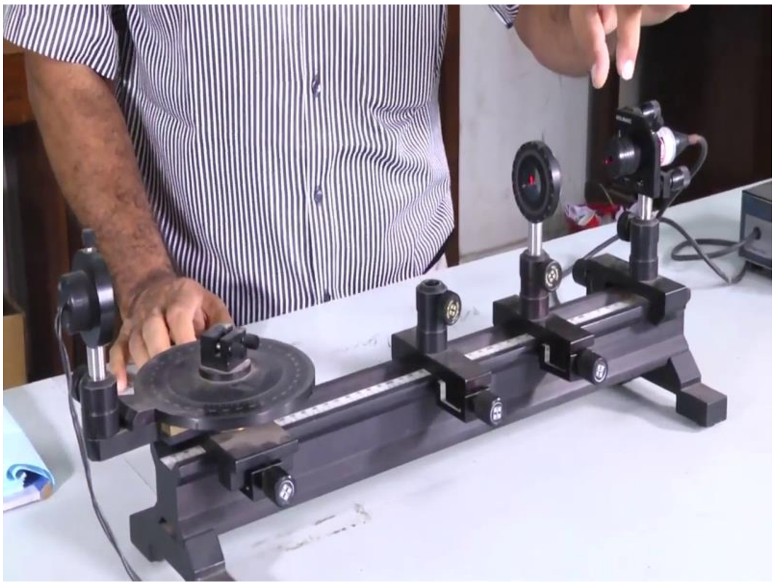

here actually this laser is diode laser this is the diode laser this is the power supply of the laser this is the power supply of this laser it is on. light is coming out from this laser point light Now, this light generally from laser light are polarized light Laser light is polarized light, so I do not need to polarize it

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as I told this polarizer or analyzer. this is the polarizer, so inside you are seeing these on circular plate. this is the polarizer and outside your ceiling the circular scale this is you see one mark is here; one mark is here now, it is at 0 now it is at 0 Now I am changing, so it is at 0. this is the polarizer means it has a optics axis now optic axis I do not know in which direction it can be in this direction or it can be in this direction whatever it is fixed

Now, I am rotating the polarizers I am rotating the polarizer means I am rotating the optic axis. it’s the ins it was 0 now I am changing to 20, then it is going 30, then 40, 50, 60. that way I can change; that way I can change up to 360 degree. Now, it is one 180 degree; now it is at 180

this way I can I can get a one complete rotation I have come back to; that means, I have arrangement here to rotate the optics axis and that angle I can measure. the same thing we have put here. I am not going to disturb this one. same this thing, so we have put here. this light is coming if it is not polarized light. what I could do.

it’s a light source and then I could put this polarizer here ok; I could put this polarizer here then it will be polarized light but that is not necessary since we are using the laser light it is a polarized light linearly polarized light this linearly polarized light is falling on the on the polarizer. this will use as a analyzer polarized light linearly polarized light is falling on these polarizer.

we have set optics axis parallel to this; parallel to this electric component of this polarized light ok; how I will know this is it’s a parallel and how I will measure the intensity of light. light is coming and falling on it. it’s the its the photo detector it can detect it can I think I can show you the spot of the light.

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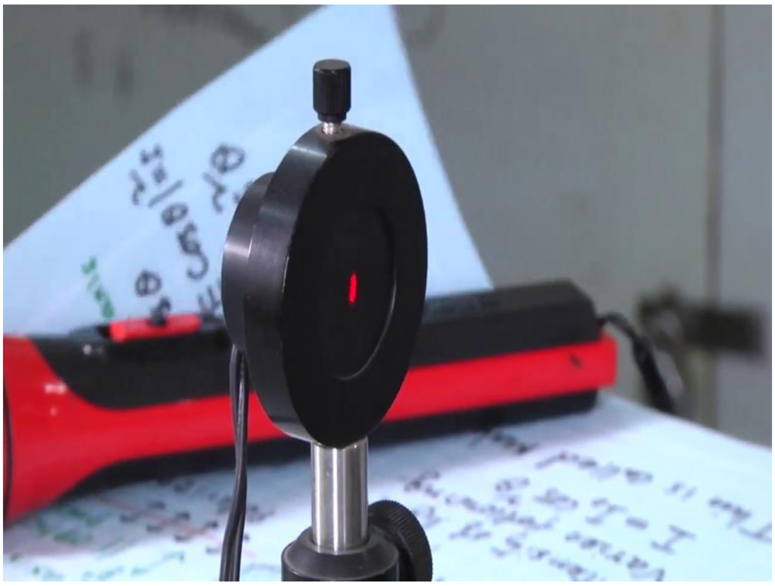

Yes, spot of the light you can see. inside there is a detector and one I do not know whether you can see or not, inside here is a small hole. through that hole this light is falling on the detectors what do you what is that detector its very simple it’s a its a its the photo diode. I can explain you the; I can explain you the principle of this of this photo diode actually you know diode this P n junction say P n junctions ok

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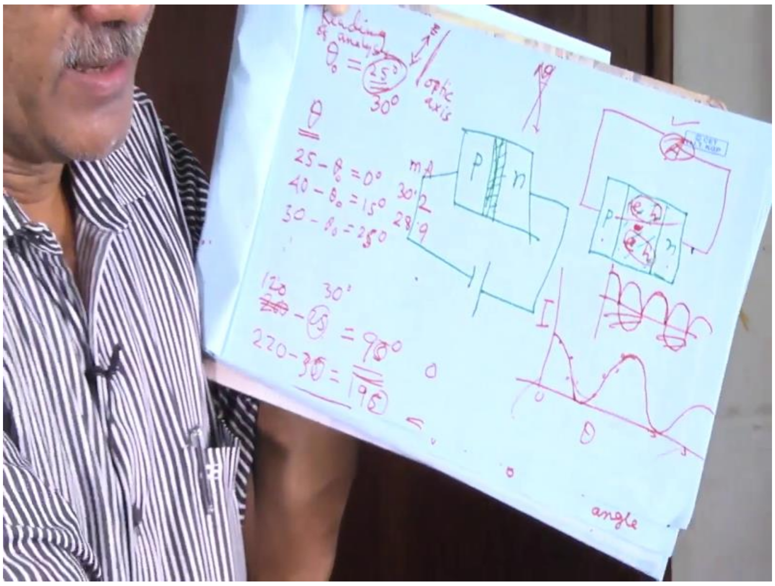

this is P and this is n P n junction diode; P n junction diode. Now, there is a depletion layers there is a depletion layer between this at the junction at the junction these are depression layer Now, if you apply reverse bias, if we apply reverse bias reverse bias means so this P will be connected to the negative terminal of the battery and n will be connected to the positive terminal of the battery .

Now, if you apply this reverse bias, so what will happen? this depletion layer this width will be bigger. it will be like this it will be like this. this is P this is n, and this is the depletion layer this is the depletion layer So now, depletion layer it is the larger area.

when this light is falling on this diode it will fall on this on this diode let me. light is falling on this on this diode it will generate electrode and hole electrode and hole ok; it will generate electrode and hole. How many electron and hole it will produce that, is proportional to the; that is proportional to the intensity of light Now this electron; so from here if you measure the current; if you measure the current if you measure the current this current, so this electron and hole they will they will move they will move they will travel. it will give current

that current will be proportional to the concentration of the pair generated production of the electron hole pair in this depletion layer. If it is produced in other design what will happen there will be recombination you know. you will not get current for this for that pair. that is why we increase the depletion layers, so there; there is no hole and electron whatever hole and electron will produce they will they will not recombine they will move in opposite direction as we call it. this current will be proportional to this pair density of pair, concentration of pair and concentration of pair is proportional to the intensity of light falling on it.

this current whatever you will get that is proportional to the intensity of light this current we can take as an intensity of light fine. that is the principal working principle of this of this photo diode this photo diode we are using as a for measuring the intensity of light in terms of current

now what I will do? this polarizer this is analyzer. I will change now we can see. I have to take reading I have to take reading here itself I can tell you. I have to see the reading of the I think we can show the reading. here you can see this my marker is at 20 I think it is 25 it is at 25 yes, each division is 2 degree, so it is at 25 I.

now; so, this I have set. this angle theta; angle theta this is the initial angle, or this is the reading this is not angle theta is the reading of analyzer reading of analyzer; reading of analyzers yes reading of analyzers initial reading, so it's a we are writing that is the theta 0 it is a 25 degree

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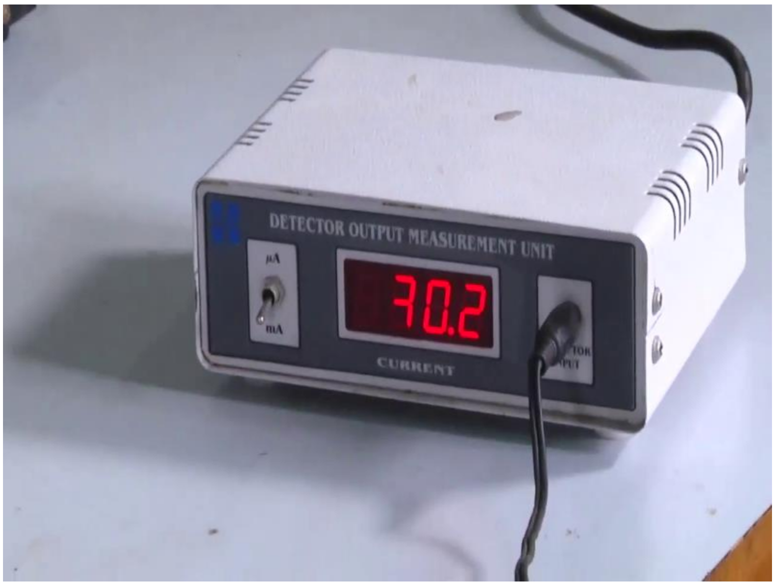

And you can see this meters; you can see this meter it is the current meter. connection you can see; connection you can see it is coming from the from this photo diode; it is coming from photo diode this current. it is giving the reading it's the 30.2

actually, I have said it at a highest current; that means, whatever the light passing through this analyzer that is the highest intensity of light and that is coming at 25 degrees. you can say that this axis optics axis the reading this optics axis which is parallel to the electric component; electric component this is optics axis; optics axis optics axis, this optics axis this optics axis parallel to the electric component

at this position, so this theta 0 we are telling theta 0 it's the 25 degree. So; that means, from other angles, so this we can take as a 0 angle it's the parallel. whatever in formula I have showed you this angle between the optics axis and the electric component, so this angle is theta

this angle theta I can tell this angle theta is whatever reading you are taking; that whatever reading you will get. that from there, so now, it is 25 minus theta 0 theta 0 is 25, so it is the 0 degree. at 0 degree what is the reading of the current? 30.2; 30.2, it is in milli ampere there you can see there are two option micro ampere and milli ampere, so we have kept it at milli ampere. current is 30.2

Now, I will change the angle; I will change the angle by 10 or 20 degree it is at 25. now, you can look at this when I rotate it you can look at this current how intensity is varying means current is varying. I put at now say it is 25 let me put at 40 its now at 40 degrees and 28.9.

I have to note down; I have to note down its a 40 degree; 40 degree minus your theta 0. it is a 15 degree, so our theta is 15 degree for that you are getting reading 28.9 next I will change; I will change to; I will change to 42 say 50; I will change 40 to 40. now, it is 26.2 26.2; so, it is a 25 degree because reading is 50 minus 25 it's the 25 degree.

this way I will show this way I will vary, this way I will vary the; I will vary. now, it is a 50 minus theta 0 means 25 degree 25 degree. this way and you vary and note down the reading. I am not going to note down the reading just let me show you that now it is at it is at it is at 50, then I am going to 60 take reading 23.8 note down, then I am going to 70 19.1 that reading should note down, then I am going to 90 this 13.0.

here reading 90 means 90 minus 25 ok; 90 minus 25 ok, so that is the theta; if I go 100; if I go 100, so it's the 4.6 now I am going 110; 110 its a 0.9, now I am going to 115; 115 yes it's a its not 115 slightly higher than that its around yeah around 200 around 200 I am getting the around 200 this reading it's a 200. you take reading at 200 minus theta 0 means 25 around not 200 it's a sorry it's the 120, yes 120 not 200, 120; 120 minus, so this is the 95 degree it should come that 0 intensity, 0 current we are getting an 95, so there is a some error once you repeat the experiment

is its 95, so it's supposed to be 90. one has to do very carefully, so then should come. I will continue I will continue by I will continue by again I am going 120 to 130 now started to increase is 0.5, 140 2.6 reading is 2.6, 150 6.5 and at 160 12.2, 170 16.9, 180 22.2, 100 200 it is a 28.7, then 200. I am getting maximum at this point now again this started to decrease, so let me maximize it I am getting around this 220 220. 220 am getting again minus 25. it will be 195; 195 ok, so I am getting again maximum

it's supposed to be at 180 degree; it's supposed to be 180 degree it may happen that when initial reading I was taking their maybe mistake it will be maybe not 25 I will check when I will come back, I will check it. this way; so, hope all the time I am getting positive current you know. this is the current equivalent intensity of light this is the theta. is varying 0 degree maximum and then I am getting at 95 it's supposed to be 90 0 and then it is changing again I am getting maximum here I am up to this. I can continue 36 degrees and let me come back to the 0 initial position.

now I am at I am at 240 decreasing again 260 decreasing, 280 more or less 4.5, then it is two 300 I guess is the 300. Yes, it's almost 0, 300 is almost 0 again 320 increasing, 340 increasing 260 I mean 0, then 220 sorry 360, then; that means, 0; that means, repeated again this are 20.

then I am changing it is; it is yes, it is around 30 yes, it is its a 30 around thirty. that again you take this one. actually these 25 whatever I took, so you say to be 30; it will be 30 degree. initial reading probably, I took wrong. now, its I can see that maximum we are getting when it is at 30. instead of instead of instead of 25 you can you can subtract 30; 30

then it will be 90 ok, it is 30, then it will be 190. some slight error will be that is why we draw graph. there be graph will not be, so there is there should be an average curve, then you will see that it is following the cos square graph you know cos this is the cos; cos graph ok, this is the cos theta graph when you will square it. this part come up this come up square of it. negative part will not be there, so it will you will get this type of curve

in density of light polarized light intensity of polarized light making angle with the optics axis of the polarizer or analyzer if it is theta; this intensity is varying following the cos square theta formula following the cos square theta and that is the Malus law and this is the verification of Malus law this is a very simple experiment of polarization and hopefully I was able to explain it properly only here since it is polarized.

I do not need to polarize it from the natural light. if necessary, you use natural light, so here difficulties are that we need higher intensity for doing this experiment otherwise you will not get current there sufficient current. that is why we have used the laser beam I will stop here.

Thank you.