welcome to all of you for the second lecture in the series of what is broadly called as modern physics

so in the last lecture i gave you a broad outline of what i am going to discuss and also gave you an equally broad outline of what you have supposed to have studied in mechanics thermodynamics and also in electricity and magnetism the birth of modern physics especially quantum physics depends on all the three subjects some of the concepts were imported as i told you like for example the principle of equipartition of energy which we do not give up but some of the concepts we would have to reject them like for example the concept of a trajectory is allowed in quantum mechanics but it is not allowed in bohr model of atom for instance

so we took a broad overview of whatever we have learnt today what i wish to do is to start a discussion of photoelectric effect but before that it is good for us to actually ask what exactly is the evidence for wave nature of light now there are two aspects that are involved in discussion of the wave nature of light one is to find general characteristics which are common to all kinds of waves we have sound waves we have water waves we have waves propagating along for example a string when you shake it all of them share some common properties they are collective modes in some sense and they all exhibit interference diffraction etcetera etcetera but then they all differ from each other for example sound waves in air are longitudinal vibrations waves in solids can be transfers or longitudinal deep c waves are quite different from the surface waves

so they will all have different characteristics and when we say we verify the wave nature we should actually verify every single aspect of that particular wave whatever way we are considering and then convince ourselves that we have indeed settled the matter

so when it comes to electromagnetic waves maxwell identified in what we call as light to be nothing but a small part of the spectrum of electromagnetic waves

so if that be true then we should be able to verify that light exhibits all electromagnetic properties as a wave that is the important thing

so let us see how we can figure that out the standard procedure is to look at the template

so to say for all wave determination experiments and that is the double slit interference

so what we have to do is to now look at the peculiarity of electromagnetic waves in the double slit experiment at the end at some time actually i am going to go beyond double state experiment because the standard double slit experiment will not be able to show all the properties that we expect to verify but let us start with a recall of the double slit experiment

so here is a schematic view which is based on the higgins construction and this is common to all waves

so you have the primary source s naught which you can see at the left most side it emits waves there are two slates s1 and s2

so these two slates act as secondary sources both the secondary sources are related to whatever the primary source is therefore they are phase correlated

so each secondary source produces its own circular waves the circular waves superpose on each other and they produce maxima and minima patterns

so they are short the superposition is shown there wherever there is a destructive interference you have minima wherever there is constructive interference you have maxima

so this is the overall picture of what happens in a double slit experiment now what we want to do is to go beyond this and see what exactly we want to verify in the case of light

so if we go back and look at interference
so let me go back there are many many important parameters that we have to pay attention to one is the distance between the two slits s1 and d2 that is important for us the next is the distance between the slits and the screen that you have put along the perpendicular that distance is also very important for us and third of course what we need is the wavelength or the frequency of light in general the difference the relation between the wave number and frequency can be wave number and frequency or wave number and velocity can be quite complicated but here we know what the relation is
so what we want to do is to treat all these parameters but when it comes to light not only do we worry about those three parameters we also have to worry about the polarization of the two beams this is very very important remember polarization was something that was known to newton and newton was also the first person to observe the dispersion of light
so he took the prism the light passed through it and he was able to resolve all the seven colors and yet in spite of what he had observed he had very strong reasons to believe in the corpuscular theory of light although higgins proposed the wave theory of light because of the enormous influence and the stature of newton people continue to believe in corpuscle or theory of light there were many many different predictions made by the corpus color theory and the wave theory for example according to the corpuscular theory the speed of light in a medium should be greater than the speed of light in free space what we call as vacuum of course during newton's time there was no way to measure the speed of light in fact newton performed a crude experiment by taking two lanterns which were separated maybe a few hundred meters and their grit one of them agreed to switch on the light and the other person was supposed to record and obviously did not measure the speed of flight the speed of light was too enormous
so it was only young's double slit experiment that actually decisively clinched to the issue
so what we want to do is to add one more ingredient namely the polarization
so because i am including the polarization it is good for me to repeat the derivation of your double slit experiment the phenomenon in a slightly different fashion i will not simply add amplitudes i will actually add electric fields
so that is what we would like to do
so at this point i will have to do a little bit of algebra and describe the experiment to you and let me start with it
so let us recall what is happening in the case of electromagnetic wave and then proceed to describe the experiment light
so in your study of electricity and magnetism in the very last chapter you people studied about the displacement current faraday's law of induction maxwell's equations in free space and you observed that the parameter 1 over root mu naught epsilon naught has the dimension of speed this is l t inverse and numerically 1 over root mu naught epsilon naught is nothing but speed of light this is numerical observation based on this observation maxwell speculated that what we call as light is nothing but an electromagnetic phenomenon and if you people remember there are two parameters that are sitting here this is my permittivity free space permittivity which corresponds to the electric field and this is my permeability this is my permeability
so the speed of light depends on what we can crudely call as the magnetic properties of the free space which is characterized by mu naught and the magnetic properties of electric properties of the free space which we call as epsilon not
so it is very tempting and it is exactly what maxwell did and that is what led him to speculate and predict that what we call as light is nothing but as part

of the electromagnetic spectrum however we should be careful in drawing such a conclusion because in physics we proclaim not often but always that we introduce only those quantities that are measurable if you look at your textbook carefully what the textbook does is to say that mu naught is a definition nobody says that mu naught is defined is measured in fact it is given as a definition and then of course once you give mu naught as a definition you can always determine epsilon naught this is not exactly a course on units and dimensions and what is measurable and what is not measurable but i would invite all of you students to think a little bit about it and ponder over what is happening here but for our purposes we do not have to worry about that what matters to us is the speed of light and speed of light is an imminently measurable quantity because it is nothing but distance divided by the time taken by the signal

so that is something which is measurable but please do think about it but there is a lesson in this even if i cannot measure mu naught and epsilon naught namely my electromagnetic field is a complicated field in the sense that there are two amplitudes the electric field which is a function of time and space and the magnetic field what is the beauty of this they do not need any external source they act as sources for each other

so thanks to faraday's law which tells you that my magnetic field can actually give rise to an electric field i can also put a spatial dependence and again if you make use of the concept of displacement current which is nothing but the derivative of the electric field it can actually give rise to magnetic field they feed on each other and that is the characteristic of the electromagnetic wave there are two vector fields which act as sources for each other therefore they are not independent of each other

so how do we then understand what their mutual dependence is the way to do that is to observe that if you give me the frequency and the direction of propagation

so these are the two parameters that is it is a plane monochromatic wave monochromatic plane wave then everything is known if you give me the electric field

so i will write for example a equal to e naught cos k n dot r minus omega t that is what i will write

so n is the direction of propagation r is wherever the location is t is your time k is your wave number

so let me write expression for k 2 pi by lambda and omega is your angular frequency which is nothing but 2 pi nu and they satisfy the relation omega equal to kc

so the wisdom that we learn is although that there are two vectors at every point in space which keep on varying in time they are not independent of each other because my magnetic field is nothing but the magnitude of the electric field divided by c that is what i have and the direction of the magnetic field is such that e cross b is parallel to n

so the direction fixes the direction of the magnetic field the direction of propagation because i have given the direction of the electric field and the first relation fixes its magnitude of course we should also remember that elect they are perpendicular to each other they are perpendicular to each other and finally e dot n is also equal to 0 meaning if my wave is propagating in this particular direction i am going to look at a plane which is perpendicular to that if my electric field for example is in this direction my magnetic field would be perpendicular to that

so let us say along this particular direction b cross e equal to n okay along this particular direction and the wave continues to propagate therefore if i wish to verify the wave property of light and identify that with the light i should also be able to factor in the polarization

so that is what we intend to do
so let us therefore repeat our analysis of the double slit experiment
so the double slit experiment is a fairly well understood the geometry is well understood
so let me write the slit here since there are lines here it is easy for me to this is the slit this is my source
so two light beams come here
so there will be coherent
so let me write this screen here and i am going to look at a point let us say somewhere here this is my p and the light ray that comes here is going to propagate at this particular point this slide is ok this line is also going to come at this particular point this is my midpoint
so this is the distance d this is d by 2 this is d by 2 that is what i have and this distance i will call as y i will call this distance as y therefore what i am going to do is to move my traveling microscope or any detector that i want along the y direction and see how the intensity varies as a function of y
so please notice what are all the parameters that i have here these parameters are all standard the distance between the two slits s1 and s2 is d and this is along the y-axis that is what i have and then the distance between these slits and the screen is capital d this is along the x axis and then you have the two rays which are propagating this direction is n1 this direction is n2 this figure is highly exaggerated in the sense that the distance between the two slits is quite comparable to the distance between the slits and the screen and also the distance y but in reality that is not what is going to happen please remember that that this capital d is much much greater than small d in fact this is a very important thing for us because it is going to create some problems later when we try to verify it is convenient to draw a line from the center of the two slates here and i will call it as n
so this is the diagram this is a common diagram to all waves
so what is it i want to do now i want to write a polarization vector here under polarization vector here
so what do i mean by polarization by polarization i mean the direction of the electric field it is a convention the word german books for example were using magnetic field as the direction of polarization the great book by bond at one point had magnetic field as the direction of polarization but it does not matter because we know how to go from the electric field to the magnetic field
so i need a few more things for my analysis
so what i am going to do is to draw a line here and i will call this angle beta and i am going to draw a line here and i am going to call this angle alpha
so this will be pi by 2 pi by 2 minus alpha this will be pi by 2 minus beta i need not write that now what i will do is to write down the expressions for the electric field and the magnetic field corresponding to this
so what do we have electric fields
so i will write e 1 equal to e 1 0 cos k n1 dot r minus omega t at any given point and e 2 is e 2 0 cos k n 2 dot r minus omega t that is what we are going to write at any given point
so what will i do i will resolve n1 and n2 along in the xy plane remember i took the direction x to be when i move from the slits to the screen and i took the direction y to b when i move along the screen
so please remember that and have defined angles alpha and beta with respect to the x axis that is what i have to remember
so what are we going to write now what we are going to write is to resolve and call this cos alpha i plus sine alpha j i is the unit vector along the x direction j is the unit vector along the y direction and n 2 is nothing but cos

beta i plus sine beta that is what i have
so if i define the quantities in this particular manner the difference between e 1 and d 2 would be known at any two points let us say this is evaluated at r 1 this is evaluated at r 2 by finding out the expressions for cos alpha sine alpha cos beta sine beta and that is what we are going to do
so how are we going to write that we are going to look at this sheet again
so this is my angle beta
so cos beta will come from this cos and cos beta will come from this there is a distance d by 2 here there is a distance minus d by 2 here if you feel like
so let me keep it at the side and let me write down the expression for cos alpha
so that is nothing but the adjacent side divided by the hypotenuse that is what i have
so i will put my d here
so the hypotenuse is nothing but y minus d by 2 whole square plus d squared and i have to put a square root
so all that we have done is to make use of the pythagoras theorem
so by the same token my sine alpha will be what it is nothing but the opposite side divided by the hypotenuse
so the opposite side is y minus d by 2 because i am measuring everything with respect to the center of the two slits that is my origin that is what i am writing
so i am going to divide it by that and my denominator is of course the same d square plus g squared to the power of half what happens in the case of cos beta sin beta this y minus d d by 2 will become y plus d by 2 because you have come further downwards
so you have increased the distance that is what you are going to see
so this is at a distance d by 2 therefore it is y minus d by 2 this will be y plus d by 2 i am going to write that but now if you people remember the approximation that i made and what is the approximation that i am going to ignore quantities small d by d this is much much less than 1 sorry this is not an approximation this is the physical situation small d by capital t is very very large small d may be of the order of a few millimeters and capital d could be a few centimeters tons of centimeters or even more therefore there is a large factor associated with them therefore if you look at this this y minus d by 2y is also relatively small quantity you cannot go to very very large values of y because intensity will start decreasing your pattern will start becoming poorer therefore you restrict to small values of y
so what happens is that this first term becomes quite small compared to capital d
so for all practical purposes this is of the order one that is what we have d by d plus some correction terms
so all of you are familiar with binomial expansion
so binomial corrections please work it out let me not waste your time here however when it comes to sine alpha we want to keep the lowest order non-vanishing term again the denominator is completely dominated by capital d the distance between the slits and the screen but in the numerator we have y and y is of course larger than d because you are going to move it therefore i will write it as y by d that is what i am going to write and interestingly you should know this is exactly what you would get if you had computed the tan alpha also y by d
so this approximation corresponds to writing sine alpha roughly equal to tan alpha that is what your text books tell you that is what you are going to do but what is the beauty of this the beauty of this is that i never made use of the

fact that there is a y minus d by 2 that is sitting here
so for example if i were to write down the expression for beta this y minus d by 2 would go to y plus d by 2 and this would correspond to cos beta and again this would go to y plus d by 2 and this would correspond to sine beta and in my approximation whether you write y minus d by 2 or y plus d by 2 it does not matter
so i will get exactly the same expression therefore your books tell you that we are discussing the two slit interference phenomenon in the parallel ray approximation
so that is the reason why i wrote this highly exaggerated picture by no stretch of imagination are these two parallel
so what are we saying we are saying that we can treat them as parallel when where do two parallel lines meet the two parallel lines will meet only at infinity
so for all practical purposes this capital d is as good as infinity which means to say that small d by d is very very small 10 to the power of minus 3 10 to the power of minus 4 because in physics we never deal either with absolute zero or absolute infinity infinity is not a number 0 is not a measurable quantity but this is the approximation that we are going to do
so if we did that my n1 and n2 will become the same therefore the only difference will be the magnitudes of the electric field at this point and this point
so that is all what i have to worry about and i will start writing down the expression
so now i will write my expression my e one is nothing but e one zero cos now i can write simply k dot r minus d by 2 minus omega t and e 2 will be e 2 naught cos k dot r plus d by 2 minus omega t where this r is measured here from the distance i am doing a vectorial addition that is all what i am doing this is my r
so this is r1 this is r2 and this is my r
so that is what i have done and this is our expression in this experiment again i have to go back to this diagram there is a common source which is emitting radiation and if the source is unpolarized the two secondary sources will also be producing unpolarized beams
so to say unpolarized rays and if the source is polarized the polarization here and the polarization here will be the same therefore this setup is not good enough for me to probe polarization effects i have to do something more i will come to that later
so at this point i am mathematically keeping indirect e1 naught and d2 naught but we should appreciate that for our purpose as far as this setup is concerned e1 naught is parallel to e2 not there is no escaping that
so if we did that my total electric field my e t is nothing but the superposition of e one plus e two e one plus e two and we know that energy depends on the total electric field the magnitude of the total electric field at any given point the energy density and therefore when i calculate the magnitude of the total electric field not only do i add the squares of the magnitude of e 1 and d 2 i have to worry about their cross term the energy density manifests as the intensity of the radiation that you see on the screen greater the energy density greater the intensity greater the amplitude greater the energy that is what we have to remember therefore the pattern whatever we are going to see depends on whatever is in the cause in the argument of the cost function whereas the intensity depends on the magnitude of the electric field that is something that we have to remember they play a complementary role
so if you remember that my e t squared is nothing but mod even square plus mod

e2 squared plus twice even dot e2 this is what i have
so one thing that we learn from this is that the minute you look at a radiation at a given time whatever light is coming not only to have the addition of the two intensities i always have an interference term however we demand coherence for the simple reason that we cannot take a instantaneous snapshot that is something that we should always remember because whether it is young's double state experiment or the experiments that you are going to do either near 12 standard or in your higher classes we deal with light in the visible spectrum where the frequencies of the order of 10 to the power of 14 10 to the power of 15 let us say 10 to the power of 14 that means light wave is oscillating 10 to the power of 14 times per second and our eye does not have that resolution there is something called persistence of vision which says that all images persist in our eyes for one twentieth of a second that is point one ten to the power of minus one is an enormously large number compared to ten to the power of minus thirteen or 14
so we do not have a photographic plate that is going to record we are going to say an average picture if the sources are incoherent then of course what is going to happen is that all those images will be superposed and this will be washed out and you will have addition of intensities therefore this is called incoherent addition of intensity but if they are face correlated if they come from a common source for example they keep on matching each other whatever may be happening in the primary source you will continue to see this inter see the effects of this cross term and we should be able to see the interference pattern
so that is what we wish to do
so that means that i have to average over the time period corresponding to
so many oscillations but then it is sufficient of average over one period and everyone knows that cos square average over one period will simply give you a factor of half that is something that we always know therefore my e t squared will be nothing but
so i will put an average sign here half e 1 square plus half e 2 squared e 1 squared i am sorry this is a wrong expression e t squared half e one zero square plus half e two zero squared plus we will keep this even dot e to average therefore my task is to evaluate the time average of e one dot e two and we already have this expression we are almost home all that we need to do is to do a little bit of trigonometric exercise
so evaluation of the cross term also called the interference term
so this interference term can work either in favor or work at cross purposes it can increase the intensity in fact it can make the intensity to zero
so this is one of the counterintuitive things where light plus light can give rise to darkness that is what is happening and maybe that was the reason why the great newton was wary of imagining that light you know when everyone wants to say give me light he did not want that to be a phenomenon i mean a wave phenomenon of course people had not seen the double slit experiment
so remember my even is even 0 cos k dot r minus d by 2 minus omega t e 2 is e 2 naught cos k dot r plus d by 2 minus omega t i want to take their dot product because i have already added them up and squared them therefore i want to evaluate e1 dot e2
so what is this quantity this is nothing but e 1 0 dot e 2 0 this is a term which not you would not encounter with sound waves for example
so this is the term that is going to be important for us and i am going to write the expression for the two causes if you assume that the polarizations are fixed in time like plane polarization you do not have to worry about that
so this time average will be nothing but the time average of the product of the two cost functions

so this cost function will come here this argument will come here i am not going to write that therefore basically what i need is a formula for the product of the two cos functions we will evaluate that and find the conditions for interference therefore i have cos k dot r plus d by 2 minus omega t it does not matter in which order i write into cos k dot r minus d by 2 minus omega t the two electric fields are different at the point p we are evaluating at the point p

so now we make use of the expression that you people are all familiar with cos a cos b is half of cos a minus b plus cos a plus b this will give me cos a cos b plus sine a sine b this will give me cos a cos b minus sin a sin b the two cancels they do gives this

so what we want to write is lhs in terms of these forms

so i am going to get a factor of half i am going to add the arguments and i am going to subtract the arguments

so if i first add the arguments what am i going to get i am going to get cos a plus b is going to give me k dot r minus omega t with a factor of 2

so that is what i am going to get the k dot d by 2 will cancel minus k dot d by 2

so cos 2 k dot r minus omega t that is what i am going to get the next term is important for us when i subtract the two terms

so this corresponds to this when i subtract the two terms k dot or minus omega t and the k dot or minus omega t they cancel each other that means all spatial dependence will go away that is something that we have to remember

so i get the neat expression cos d by 2 plus d by 2 is d k dot d this is what my expression is i am supposed to calculate the time average of this which is nothing but the time average of this now look at the first expression it is oscillating with a frequency 2 pi by omega period 2 power 2 pi by omega when an average cost function over a period or a sine function over a period it goes to 0

so this is going to 0 therefore i am left with the term half cos k dot d that is what i am left with

so now at last we have an expression for the intensity for us and what is it given by the expression for the intensity is simply given by mod e1 square plus mod e2 square plus 2 e 1 dot e 2 and this we wrote as half e 1 0 square plus half e two zero square half cos dot d

so where is the information on the point p that we were looking at

so let me come back to this picture we are interested in the point p at a distance y from along from the y axis that is what i have done where is the information on that that information is here you people can see

so if this term were not there you would simply get a uniform intensity even not square plus e2 not squared you are sending a monochromatic plane wave that is what would happen

so what is this k dot d remember that the d or the distance vector is along the y axis therefore this k dot d you can if you want rate alpha or beta it really doesn't matter this is nothing but kd

so let me call it as sine alpha or whatever you want to call it as you could have written written sine beta and this is nothing but kd and sine alpha is roughly the same as tan alpha and we got an expression for sine alpha and that was nothing but y by t i remember that

so please remember y is the perpendicular distance d is the horizontal distance sine alpha is the same as tan alpha therefore y divided by d is tan alpha that is what we have and this is my expression therefore i have now got a final expression of the intensity as a function of y which is given by the two constant terms half e 1 0 squared plus half e to 0 square

so we left out even 0 dot e 2 0 and presumably there is a factor of 2 because this was a 2 e 1 dot e 2 therefore i supply a factor of 2 here 1 into 2 that is what we are going to supply and now that is my full expression

so you have essentially e squared if they have the same intensity plus e1 dot e2 the intensity is the same but the angle can be different into the cos k dot theta

so e 1 0 dot e 2 0 which multiplies cos k d y by d this is the classic derivation which is made in wave theory and what i have learnt here is not only to analyze interference experiment with some ordinary waves we also know how to analyze and understand interference experiment with light waves which can be called as vector waves in fact there are transfers they are vector waves because they involve two fields electric and magnetic fields now the rest of the analysis is very simple for you to do all that you have to do is to find conditions for minima or maxima i am not going to write that because it is really not required by us

so you demand that it will be a maxima whenever k d y by d is a integer multiple of 2 pi because cos is a maximum at 0 2 pi

so on and

so forth cos is a minimum at pi 3 pi

so on and

so forth because it takes the value minus 1 and cos of course is 0 when it is a multiple of pi by 2 that is what we have

so depending on how you as you keep on changing your y you are essentially keep on changing the value of your cost function

so depending on how we are going to move you are going to get a maxima which will be nothing but e 1 0 square plus c 2 square 0 square plus this quantity

so which will essentially that many times twice the intensity that is what we are going to find or if you are looking at the minima this e 1 0 dot e 2 0 will exactly cancel the contribution coming from these two terms that is the standard analysis but all this will work if and only if my e 1 0 is parallel to e two zero now what i can do is to play around with polarization play around with polarization

so e 1 0 dot e 2 0 is equal to e one zero e two zero magnitude parallel implies standard interference condition now suppose i perform the following experiment and we will worry about how to do such an experiment

so i have a slit here i have a slit here i am again exaggerating and suppose rays are coming here now what i will do is i will put a contraption which rotates your plane of polarization i will put a contraption here or even better let us say that unpolarized light is coming here unpolarized now i will put a polarizer which let us say polarizes my electric field in this direction and here it will be cross polarized and here my electric field will be in the opposite direction suppose i did that now the two polarizations are not parallel they are in fact anti-parallel

so what will happen to the cross product term now even 0 dot e 2 0 will become minus e 1 0 e 2 0 magnitude now that means what is happening is instead of getting a plus term i am getting a minus term

so where will the intensity maxima appear intensity will be maximum a maximum if cos that argument is minus 1 because this minus 1 will cancel this minus 1 it is the opposite

so if i did this then i know that i am looking at a phenomenon which is coming from light

so all of you might have heard of the discovery of this particle called hicks the god particle

so if you go and ask a serious experimentalist the experimental will tell you

that look here i have seen a higgs i do not know if i have seen the higgs you have to study every single property to convince yourself that it is indeed the phenomenon it is quite true that when you see the interference pattern coming from the young double slit experiment it could be nothing other than that of light but it is still a matter of faith and it is not a matter of complete demonstration that is what physics has taught us repeatedly and many times because we make that assumption there are many pitfalls in which you get trapped now suppose we start playing around

so what i will do is i will look at this double slit again i will start with a source here which produces unpolarized light and i will put two polarizers through which light rays will propagate and they will fall on the screen and these two polarizers can be rotated independently aligned independently

so they can produce polarization in the same direction

so even zero parallel to e two zero or they can make even zero antiparallel to even zero

so even zero is minus e two zero i am writing the unit vector to emphasize the direction anyway since they are coming from the same source slit width will be the same the intensity will be the same the magnitude will be the same or the third option for example is even 0 dot e20 is identically equal to 0 they are perpendicular

so if this is the propagation direction one of them will be in one direction perpendicular in the plane that is perpendicular whereas the other electric field will be in the exactly opposite direction but in the same plane now you see the conclusions that we draw on the interference pattern will change interference conditions get modified

so e one zero parallel to e two zero standard conditions what are the standard conditions maxima at even multiples of 2 pi minima at mod multiples of 2 pi if even 0 antiparallel to e 2 naught exactly opposite conditions now the conditions for the maxima and the minima will change that is what is going to happen and of course if even 0 perpendicular to e20 the pattern vanishes completely

so in other words study of the standard double slit interference experiment which is almost beaten to death actually offers us gives us an opportunity to explore additional properties of light and this is required please remember each one of these statements is going to acquire a different meaning when we do photoelectric effect or the bohr model therefore it is very important for us to pay attention to these things therefore what should you do you should go to your classroom ask your teacher to please perform an experiment and demonstrate to you that actually this can be done or if you cannot do that go to your nearby college come to iit and ask them to do that and you will see that it is not such an easy thing why is that

so because it goes back to the fact that that this distance d is small fraction of a centimeter and it is not going to be an easy task for you to put a polarizer or an analyzer

so that may be one of the reasons why these experiments were not done in the double slit configuration but if you think a little bit and go back and see what is it that caused interference it is not

so very much the double slit as the fact that there is a phase difference this phase difference is produced by what the path difference

so if you can somehow produce a path difference which does not depend on the two slits then we have done our job smart experimentalists have actually produced such interferometers where things can be controlled very well one of them is very very famous michaelson interferometer

so this great experimentalist was actually able to measure the speed of light with enormous accuracy and not only that he undertook the mission to measure the

speed of the earth with respect to ether
so that was a great great experiment which was a null result and there is a modification of that which is called maxender interferometer where what you essentially do is to manipulate the system in such a way that these large the arms are far far away
so that you can actually put a polarizer
so that is what we want to show here this is a max gender polarizer
so you see you have a system of prisms
so there is a light beam that comes here there is a beam splitter half of it goes here half of it goes there it gets reflected and you see the reflected pattern because they have traversed two different paths there is going to be a path difference because there is a path difference there is going to be a phase difference and that is what you are going to look at cos square delta phi by 2 sine square delta phi by 2
so you put your detector and you will when you superpose these two waves this wave coming here and the wave coming here and what you do in order to create a path difference is to make it go through a medium or change the arm length one of the two things that is what you are going to do and you ask for the interference pattern now this is a much larger system and therefore now you can put your analyzer you can put your polarizer and you should be able to verify whether whatever we have predicted in this sheet of paper namely parallel standard condition antiparallel is opposite condition and the interference pattern vanishes exactly
so this is something that has been verified only very very recently and here are the results the interference pattern that is produced here is quite complicated and it is beyond our scope to discuss that
so all that i can ask you is to look at them carefully and see that there is a difference in the interference pattern this is the normal configuration when the two are parallel to each other you see those fringes that are superposed over each other circular fringes now when it make it 45 degrees you get beautiful straight lines that is what you are going to do and then when i make it 90 degrees you see it is almost completely different the pattern is completely different and minus 45 degrees is again going to produce the straight lens
so although in this experiment i have not been able to correlate exactly what is happening between the polarizer analyzer system and the equations that i wrote because the patterns are different you can at least see that there is a sensitivity to the dot product term e1.
e2
so what is the lesson that we have learnt this is a paper that has been published in american journal of physics there will hopefully be a supplementary material where we will provide you with all the references there is no reason to clutter up our lecture with those things we will certainly do that that means we can be secure in our belief in our understanding that the wave theory of electromagnetic radiation and in particular light rests on very very solid foundations reflection refraction total internal reflection diffraction interference every one of these phenomena and interference depending on the polarization surely points out that light can be understood in no way other than what as a wave but still we are going to encounter experiments which tell us no that is not the truth there is something beyond that and that is the reason why i spent a considerable time explaining the well known things now what we shall do is to go beyond what is well known
so let us start with the experiments
so the conclusion has already been stated but let me repeat we can alter conditions on minima and maxima energy is proportional to e squared that is the

next condition because as you keep on varying the intensity or the amplitude the intensity on the of the fringes also changes the condition for maxima and minima will not change but how intense will be the brightest that will certainly depend on the value of e square therefore wave theory of light rests on secure experimental foundations

so now we come to photoelectric effect and it is good to give a certain timeline of what kind of developments took place in the experiments this timeline has actually been picked up by me from your 12th standard book let me read that leave you today

so that from the next lecture onwards i can actually start discussing the experiment and einstein's explanation

so 1887 was the year when hertz discovered follow it photoelectric emission maxwell's equations were just being written around that time and in 1897 jj thomson discovered the electron and he put a capacitor plate saw the deflection and concluded that they are negatively charged hertz experiment was not very refined or conclusive but between 1888 and 1902 halawak and lenard performed a series of experiments that is where they saw that famous linear behavior between the stopping potential and the frequency which you are going to study which i have already studied and then came 1905 1905 is known as anus mirabilis the miraculous year because einstein wrote three great papers photoelectric paper is one one of them

so einstein gave his theory in terms of the photons and in 1915 millikan repeated this experiment with enormous accuracy and actually determined the planck's constant in an independent fashion

so i am going to stop at this particular point but i would like to repeat a statement of what millikan said in 1915 millikan said that in spite of the great agreement between the theory of mr einstein and what we have seen experimentally it is impossible to believe in photoelectric effect because that cannot be a theory and it is against all our understanding and in 1951 all that you have to do is to invert one five to five one the same great man said that we have no option but to believe in photoelectric effect and quantum mechanics the rest of the world had moved on great developments took place between 1920 and 1950 but robert milliken took 45 years to accept einstein's explanation and we will continue you