WAVE OPTICS

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Week - 01
Lecture - 01

Hello student so today we have the first class of our course wave optics. so today it will be an introductory class where we briefly describe about what is optics and how optics can be understood with three different aspects with three different processes or three different methodologies Let us start with the topic. So, today we have lecture number one. So, generally, there are three different ways to understand optics or rather three different approaches to studying optics. what are those optics? optics can be understood in three different ways. What are those? First is ray optics. In ray optics what we have is that we consider the ray optics We consider the light source and from this light source what happens when light is emitting, we consider this to be a ray and describe all the phenomena by using this ray geometry.

Then the next thing that we have is wave optics, which is the topic that we are going to cover in detail in this particular course. Finally, we have another approach which is the most advanced and most modern approach and that is quantum optics. So, as I mentioned in the ray optics. what we have the propagation of light is represented by rays the propagation of light here is represented by ray what is ray here? so ray is basically a light path along which the optical energy flows. So, this is along a line through which the optical energy flows and that is what we call the light path. or in general, we call these optical rays or rays. So, if I have a figure it should be like this. So, this is generally the representation of a ray or a ray part. In a homogeneous medium in a homogeneous medium. What is a homogeneous medium? A medium where the refractive index is uniform because the refractive index is one of the major parameters that one can deal with or one needs to understand in the context of this ray path.

So, the homogeneous medium here essentially means that the medium with uniform is a refractive index that means inside the medium if I go in any direction the refractive index will remain the same so the refractive index is uniform if we have this kind of medium

then what happens is the ray path will be simply a straight line in a homogeneous medium that means where the refractive index doesn't change along the direction in any x y z direction suppose then that a medium is such that the refractive index doesn't change then this ray path whatever we are talking about will not go to change its direction it will be simply a straight line so the ray path will be a simply straight line. okay, but there might be a possibility that the ray can spread over. A simple example is this I am drawing a simple light source most common light source is a torch so if I illuminate a torch what happened we will see that the rays are coming out like this but they can spread there will be spreading of this ray and we know that this spreading is called diffraction that we will discuss in detail in our course. This is one kind of light source that looks from where we can have the light ray that is coming like this and here we have spread as I mentioned but we also have another kind of source which is a very specific kind of source very special kind of source called laser I believe many of you who are taking this course are aware of this name laser. In laser what happens is we will have the light and the light can be represented by this so-called path or straight line but in that case, the spreading is much less there are many other properties also we have and this the property we will discuss in detail in a later section of this course like coherence and they have monochromaticity etc but the directionality property that means the direction along which the ray is moving is very straight the spreading on the other hand that is here is coming through a torch is a bit more compared to this kind of source which we call laser apart from this source we have The most general source that we are aware of is the sun. And from the sun also we have a light that is coming and this light also follows a ray kind of path if I study the light in terms of this ray approach. So, here is what happened. Light goes in all directions. But the important thing is everything here is considered as a ray. All the light that is coming through these sources is in general forming a ray. so let us do let us understand more about this ray so that we are already aware of so let me do that once again and that is ray path tracing what is ray path tracing that if I have a block for example say glass block with refractive index n 2 and it is placed in the air say refractive index n 1 and n 2 then if the light falls here and we consider this light to be a following a path ray path which is a straight line and it falls on the surface of these blocks like this then what happened it will experience a change in refractive index as I mentioned in the earlier slide if the ray is

passing through a homogeneous medium the light the path does not change. So, whatever light I have the path will be a straight line. Here we find that from here to the medium is homogeneous it does not change its direction, but as soon as it enters another medium with another a refractive index which means it is experiencing different refractive indexes there will be a change in its path and we know that it follows a certain rule and it will move like this inside this glass block and then again it experiences a refractive index change and it moves out in this way We know that it will follow certain rules and if this angle is I, this angle is r, then this light ray will follow simply a rule that n1 sin i is equal to n2 sin r. And that in general called Snell's law. Well, if however, there is a gradient. So, here is what happened. The refractive index is n1 here and the refractive index is n2 here and then again refractive index is n1 here. But there is a possibility that we have a system or a medium where the refractive index change is not like n1, or n2 rather there is a continuous change in the refractive index. We call generally this kind of medium a graded-index medium. In that case, also, the ray path, if I allow the ray to move in such kind of system where the index is not changing like n1, and n2 in a discrete manner, rather there is a continuous change of refractive index, the ray will move not strictly in a straight line, but there wi ll bea sinusoidal kind of movement or a curve there will be a curve curvy structure one can have so here for example I have a medium where the refractive index changes if I plot the refractive index change it is not discrete but it changes with a gradient, normally in optical fiber, we have a different kinds of fiber One is called step-index fiber another is called is graded index fiber. So, suppose this is a graded index fiber or a graded index system where the refractive index is gradually varying and has a maximum value if I plot this refractive index n as a function of r. So, we have a maximum value here and if I go away from this central axis then it gradually goes down. In that case, if I launch a light here. inside this system, there is a possibility that it follows a path like this so even though we are talking that the path will be a straight line here it will not follow strictly a straight line but a sinusoidal kind of path Here the refractive index change is continuous which is the reason it follows this kind of path and If I go to a very micro, a very amplified, or a magnified version of these things, we can see that if I make this as a small section where the refractive index gradually increases or decreases like n1, n2, n3, etc., in each section it follows a straight line path.

Altogether, even if it looks like it is following a sinusoidal kind of path, at the end of the day, it is following a straight line path if I divide this refractive index section into different small sections like n1, n2, n3, which is gradually changing. Okay, that is roughly the way concept of the light that we discuss here very very briefly now in the same way we are going to discuss what happened in wave optics. In wave optics which is our course, in wave optics instead of considering light to be a ray here, the light is considered to be a wave so light is considered as a wave that is a very interesting approach and we will going to discuss it in detail why from ray optics one needs to go to this wave optics approach so what is this wave whatever the wave I mentioned this wave is essentially an electromagnetic wave So if I want to understand the picture in the same way that we did in the earlier case suppose I have a torch and I switch on the torch how the light will come out from this torch under this approach in the wave optics approach it will be like this if I draw a schematic kind of figure instead of drawing a straight line I should draw in this way So this is a torch and the ray that is coming out is simply a bunch of propagating waves. this propagating wave is essentially the electromagnetic wave that we already mentioned is okay. So this a beam of light, this beam of light comprise a large number of the propagating wave So, we will have a light beam and this light beam essentially comprises a large number of propagating waves as I mentioned this wave is essentially an electromagnetic wave. Now, we will discuss electromagnetic waves in detail, but here I just quickly like to show that what should be the structure of this kind of electromagnetic wave that we are talking about so mathematically if I want to write the electromagnetic wave the an electric and magnetic field will be there it will be a function of space and time so this is an electric field which is a vector quantity it should be a function of space and time and if I simply write it as in a one-dimensional case say it is going along the z-direction so z and t, or okay I should write r here in general so it should be like E0 x vector and sine of kz minus omega t I am writing a very specific form why I am writing this form I am going to discuss but for the time being, let us consider that this is the mathematical form through which the electric field can be described in a similar way the magnetic field in general should be a function of the position and time it is also, a sinusoidal function having an amplitude b0 polarized perpendicular to the electric field if it is polarized along y x should be polarized along if it is polarized along x it should be

polarized along y it is sine k z minus omega t well if I draw the electromagnetic wave should be like this so suppose this is the y direction this is my x direction and this is my z direction and the electric field E is along the x direction and it is sinusoidally changing. So, the figure will be something like this the figure of the electric field. If I draw the magnetic field which is along the y direction it will be like this is the direction of the polarization the electric field will vibrate along this direction let me draw these arrows here you will find a much better picture in the book but you need to understand how these figures are constructed so along y direction the electric field is vibrating and it is vibrating with this sine function around z direction it is changing also it is changing over time and essentially we call this a propagating wave why this is a propagating wave why is this specific structure is there k z minus omega t that we will be going to discuss in detail maybe in the next class the magnetic field I draw will look like this in the same plot magnetic field if you look carefully it is in this white plane so maybe I can draw it in a different color that this is the direction of the magnetic field and it is also vibrating sinusoidally and this entire wave is propagating along z redirection is okay so now after having this structure we will go to the quick picture that if a light wave is if I consider light as a wave how the different sources will emit light waves so light waves emanating from different source so same old figure I have a torch and if I have this is my torch so it will emit the light a bunch of waves but there is another important issue here that I need to discuss these are a bunch of waves that are coming out of this torch and there is a very specific term I'm going to use here incoherent incoherent light so what is incoherent light? again we will going to discuss but let us for the time being consider this to be incoherent light that is coming out from the usual source that we have thoughts however if a laser is emitting a light then I need to draw in a very precise way about these waves like this schematically I am drawing but I need to I need to be careful about what is going on here So, there is a fundamental difference between the first picture and the second picture. The laser that is emanating the light is coherent in nature, coherent light. That means the light that is emitting from this laser, all the light beams, all the light waves, they have a specific phase difference phase relationship rather among them which was not there in the other case so we will discuss this coherence and incoherence temporal coherence then spatial coherence etcetera in our later classes in a similar way another

source I drew which is a very which is the sun which is a very general source. Source of all right the other it is also emitting the light but this light is now forming a wave here a bunch of waves is emitting all directions so this is also incoherent this is also incoherent light that is coming out from the sun, but it is in all direction it is going to all directions.

So, so far we have discussed the light that is coming from different sources differently. So, if I go back you can see that in one case we have a ray that is the way light is going as a ray path or as a straight line. In another approach we consider that the light behaves like a wave and from different sources if I draw a a very very simple picture of different sources how it emit how the light is emitting from these kinds of sources in standard books you will find these kinds of figures Another thing is still there, today we do not have that much of time to discuss, maybe in the next class we are going to discuss and that is the quantum optics.

In the very beginning, I mentioned that optics is basically, there are three approaches through which one can study optics, one is ray optics, another is wave optics and another is quantum optics. So, very briefly we are going to discuss quantum optics in the next class, and then we start our main topic and that is what happens when we consider the light to be a ray. So, all the wave nature of the light we will going to discuss and then go one by one with different topics. Before the completion of today's class, I like to give a few names of the books that the students who take this course should study. So, list of books. So, textbook, first I like to mention. So one is called Optics by Hecht, a very famous book, and then we have also a very well-known book optics by Ajay Ghatak and another book you can also try that is called Introduction to Optics by an author called Pedrotti apart from these textbooks you can also read a few reference book a couple of reference books I like to mention here as well one is a very very famous book called Principles of Optics by Max Born and Emil Wolf so Born and Wolf and another fundamental of photonics by Saleh is also a very well-known book to teach so this is the list of the books I wrote here so as a the textbook you have three books all three are very famous so my suggestion is you can go through these books you can read the book carefully and then there are many exercise problems are there you need to do all the exercise problems I also like to cover a few exercise problems from these books and do in this specific course and time to time you can also go to check what is there in these

reference books for a particular topic with that note I like to conclude my class here thank you very much for your attention see you in the next class.