WAVE OPTICS

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Lecture-02

Hello, student to the second class of our course wave optics, where we are going to introduce the brief concept of quantum optics that we mentioned in the first lecture. So far so let me go directly okay? So, in the previous lecture, I mentioned that optics can be understood in three basic approaches. One is the ray approach we call ray optics, another is the wave approach considering light to be a wave we call wave optics, which is our course in fact and another is quantum optics. We already discussed how the ray optics and wave optics picture one can schematically show when the light source emits the light. However, quantum optics is also a very upcoming field or the most modern approach where one can introduce light as a quantum particle that we already know. So in quantum optics what happened is the proposition of light is described by or described in terms of or described by a large number of tiny particles like packets of optical energy So packets of optical energy are like the light can be described, the propagation of the light can be described by a large number of a tiny particle-like packets of optical energy. And this particle is like packets of optical energy in general called photons. So this wave packet is generally called a wave packet, the energy of a wave packet. If I calculate e that is the energy of photon depending on the frequency of this light and it is simply written by e equal to h nu or h c divided by lambda where c is the velocity of light lambda is a wavelength is Planck constant whose value is around 6.626 into 10 to the power of minus 34 joule second this is Planck constant lambda is a wavelength of the light and c is a velocity.

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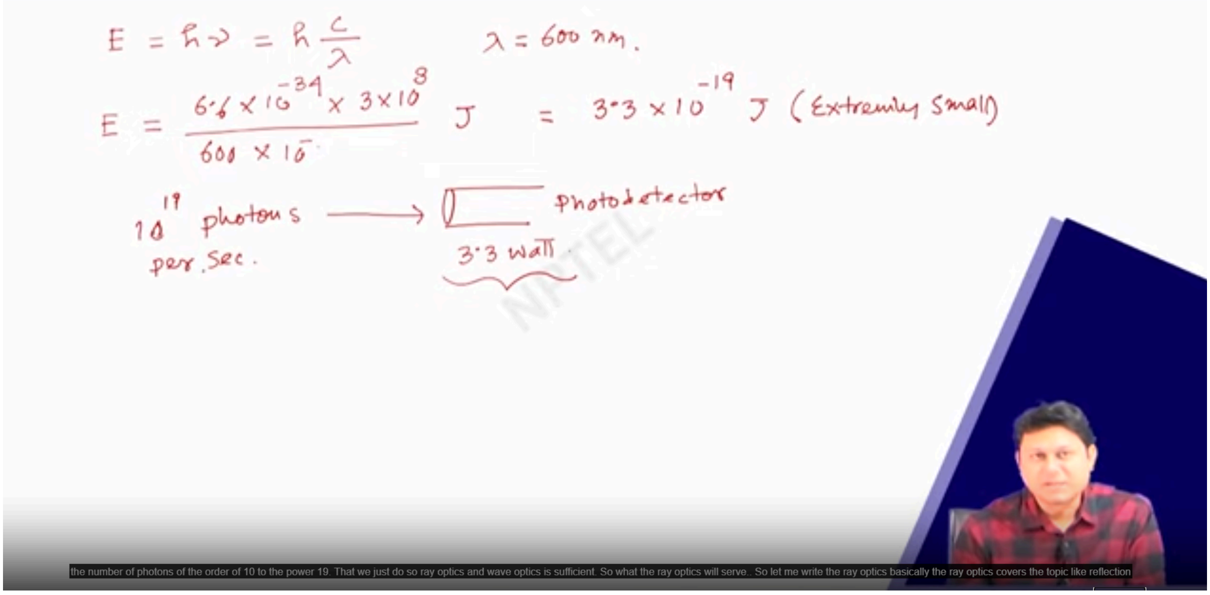

$E = h\nu = h\frac{c}{\lambda}$ $\lambda = 600\ nm.$

$E = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{600 \times 10^{-}}\ J = 3.3 \times 10^{-19}\ J$ (Extremely small)

10^{19} photons per. sec. $\longrightarrow$ Photodetector

$\underbrace{3.3\ \text{watt}}$

the number of photons of the order of 10 to the power 19. That we just do so ray optics and wave optics is sufficient. So what the ray optics will serve.. So let me write the ray optics basically the ray optics covers the topic like reflection

So, the energy of the photon, one single photon or wave packet can be described by this now in a similar way that we had done in the previous few cases, how the normal source will emit light in terms of these web packets, then the schematic picture will be like this. So if I have it say torch again a very well known light source so instead of having in the ray optics we have ray in the wave optics. We find that it emits light in the form of waves but here is what happens: it will emit light in terms of photons. So the picture will be something like this, like a bunch of photons is emitting from so this bunch of photons are emitting in a similar way. If I have a laser source it will also emit a bunch of photons like this is a very simple schematic figure to understand, the different approach of the light, and similarly for the Sun it will emit the light in all directions okay so so in quantum active in quantum optics this light-matter interaction is very important so what is the meaning of that so suppose we have a medium and when the light is falling here over this medium it will interact the atom inside the medium that is the basic thing that we have and then from the medium light will going to scatter or there should be absorption or something is emitting But the important thing lies here and that is light matter interaction. So there are different models that we have to understand how the light will interact with the medium and if I write here the model says this is the model it can be classical it can be semi-classical or it can be quantum.

So suppose I make a chart like this is the model through which we describe the light and the interaction of the light with the material and this is the atom we have the nature of the atom how we define the atom and here how the nature of the light is I write then in model one which is the basic classical model that we are going to discuss in this course then the atoms are merely considered to be like an oscillator. These atoms behave like a classical oscillator and light is also considered as a classical electromagnetic wave. So an atom is also considered as a classical object and light is also considered as a classical object. So the model is classical, there is another model also semi-classical model, in the semi-classical model atoms are no longer considered as this oscillator rather. If I write in a schematic way, if I draw, it is quantized.

The atom can go from one level to another level in a quantized manner. Quantized states are there. Atoms are considered quantized. However, light is still considered here as a classical electromagnetic wave. In the third approach which is basically a quantum mechanical approach, the quantum approach is a quantum mechanical model or quantum optics. Here, both atoms and the light are quantized**.** So atoms are quantized and also light is no longer considered as electromagnetic waves rather they are considered as quantized particles. This is quantized so very roughly I try to describe different models and here we are describing quantum optics. Why quantum optics is important that we're going to understand soon. So, here are three different models we describe or just make a chart and one is a classical model. When the light is interacting with the material which is made of atoms we also consider it as a classical oscillator. So as the light that is incident on this kind of material, they are also classical and considered as a classical electromagnetic wave but in the quantum approach, both atoms and the light are considered to be quantized in nature. Now we know that for quantum optics the light is considered as a photon and if I calculate the energy of a single photon with a certain wavelength for a given wavelength then we will get some number and that number decides a few things. For example, this is the expression of the energy of a single photon. Now if we have lambda say 600 nanometers then the energy of the photon if I calculate it should be 6.6 roughly into 10 to the power of minus 34 and then 3 into 10 to the power of 8 meters per second is the value of the c divided by 600 into 10 to the power of minus 9. So that quantity will be in joules and if somebody calculates that this value will be roughly around 3.3 into 10 to the power of say minus 19 joules. So the energy of a single photon is of the order of 10 to the power minus 90 which is extremely extremely small. This is an extremely small quantity, right? Now that means if 10 to the power 19 photons this is the number of photons that hits a photodetector per second. Then it will give 3.3 watts the number of photons so that is normally the value in the usual in normal life we deal with 10 to the power 3.3 watts or some watt level of energy, light energy. So that means in order to have this light energy, which we use in our daily life, the number of photons that is associated with that is of the order of 10 to the power 19, which is very, very large. However, if we want to study the nature of the light, photon level with one or two photons then the amount of energy will reduce radically. There is a very small amount of energy we need to deal with but in normal life, we don't have that much precision. We don’t have that kind of instrument in a normal life. The regular life detects the light in that order so that's why precision is something for which it basically decides whether we need to go to a quantum level quantum optics level or a ray optics and wave optics is sufficient to understand different light phenomena. So that's why wave optics and ray optics are normally used to understand the nature of light in daily life. Rather going to this understanding the very precise nature of the light and the quantum nature of the light . Where we need to deal with the photon one or two photons there are instruments available in the market. Where you can have one there are photodetectors. We can detect even one or two photons but that is not required in daily life. Because, in daily life, we deal with the number of photons of the order of 10 to the power of 19. We just do so that ray optics and wave optics are sufficient. So what do the ray optics serve? So let me write about the ray optics. Basically, ray optics covers topics like reflection and refraction then dispersion. This kind of phenomenon is very nicely described by a simple ray optics approach, on the other hand, wave optics can cover phenomena like interference and diffraction of light and polarisation. So in our topic, we're going to discuss all these three phenomena that are in our present course. These are the three phenomena that we're going to discuss under web optics. So with this small discussion from the previous class to this class, we try to understand that different approaches are there to understand the nature of the light. Ray optics is used to describe certain phenomena, wave optics is used to describe certain phenomena of light, and finally, quantum optics is the most modern approach to understanding the phenomena of light. Different phenomena of light are used for understanding sudden phenomena based on the quantum level where the number of photons is less well with this note.

I like to go to our main topic which is wave optics and we essentially start our topic today with something called wave propagation. So, so far we have discussed wave optics, and several times we mentioned waves and all these things. So, now we are going to quantify what wave propagation is. We quantify the wave equation and its solution etc in detail. So wave propagation is the first thing we are going to understand before going to typical wave optics. First, we need to know what a wave is and how it propagates wave propagation. So in wave propagation what we have let us first draw a coordinate system. Suppose, we have a coordinate system O' and in this coordinate system I have a wave. Maybe I can put the wave in a different colour, a disturbance, or a wave like this. This is the point of some point on the wave okay? Now this function I can write as this disturbance is a functional form like y fx and this is my x prime coordinate and this is my y prime coordinate and we call this a stationary wave because this wave is not moving stationary wave well. If the waves start moving, this is my stationary frame, actually a fixed frame. Now suppose the wave is moving and it goes to some other point here in this location then the coordinate associated with this fixed wave. If I draw that, it is also moving with a certain velocity and that is my old O' frame. And here, this point, whatever is marked here, I mark here once again, suppose that was my X' point previously. Now this point with the O reference frame which is here fixed is X. But from here to here, it was X prime. And this value is with respect to O prime. So from here to here at this point, it is x prime. And if the velocity of the wave is v, then from here to here, this length should be vt if I consider the wave at some time t . Ok So, this figure is when the wave is travelling. So, this is for stationary waves and this is for travelling waves. But the point is I can have the coordinate x like x prime plus vt.

So, here x from here to here this length is this length plus this length or in other way x prime coordinate is simply x minus vt so y which is the same here because the structure of these waves is not changing. So here also I can write this disturbance as y in the oak frame which is equal to y prime that is f of x prime because it is not changing its shape and x prime I now have x minus vt so this is x minus vt so if this wave moves in opposite direction I can also have then this sign can be plus. So we have in general for a moving wave y is equal to f x plus minus vt okay. Now with this note, we can also write something that if that is the case then all the waves or all the functional forms having this specific argument can behave like a wave. So if I write okay before that let me write something so x equal to x prime at T equal to 0 that is the original shape we have. The original shape that we have of the wave that was y prime is equal to f of x prime and does not vary as I mentioned, but simply travels along X direction. So that means initially I have a wave here and after some time this wave moves here. If this is my one coordinate system o so it is now here this moving coordinate system is not moving at all but there is a relationship between these two coordinate systems and this relationship is x prime is equal to x minus vt in this case, where; v is the velocity of the wave or the velocity of the reference frame that is moving. Now if I write y equal to a say sine some constant k x minus vt that is one functional form we have. Now I'm putting some functional form I can also have a different kind of functional forms right simply an x plus vt square of that or we can have a function like e to the power of k x minus vt and so on the point is in all the cases the argument of this x argument of this function is x minus vt or x plus vt or x minus vt or in general x plus minus vt. Whenever you have the two coordinate systems associated with each other like x plus minus vt then that particular function always represents a propagating wave so all this function here all these functions represent a travelling wave.

So in general if we have a function like a phi equal to if some constant c1 if x minus vt plus c2 g x plus vt so these essentially a general form of a function that expresses a wave that is moving along x direction positive x direction with velocity v if the sign is plus like this then it means that the wave is moving in an opposite direction. In this case, it is moving from this direction to this direction in a right from left to right, if the wave is moving from right to left then the sign will be plus.So today we find a very important thing if a function has its argument in the form of x plus minus vt . Where x is a coordinate along which the disturbance is moving and v is the velocity and if I manage to write the function in the form like x plus or x minus vt then that particular function always represents a travelling wave. In the next class we will show that if we have a functional form like this it should follow a sudden differential equation and that differential equation is called the wave equation. So we will formulate the wave equation in the next class and show that this particular form is a general solution for example phi.

Here is a general solution of the wave equation and with what we are going to understand in the previous class, we write the electromagnetic wave in a very specific mathematical form. Why do we write this mathematical form in that specific form? We will then understand why we have written that particular form after having an idea about the wave equation.

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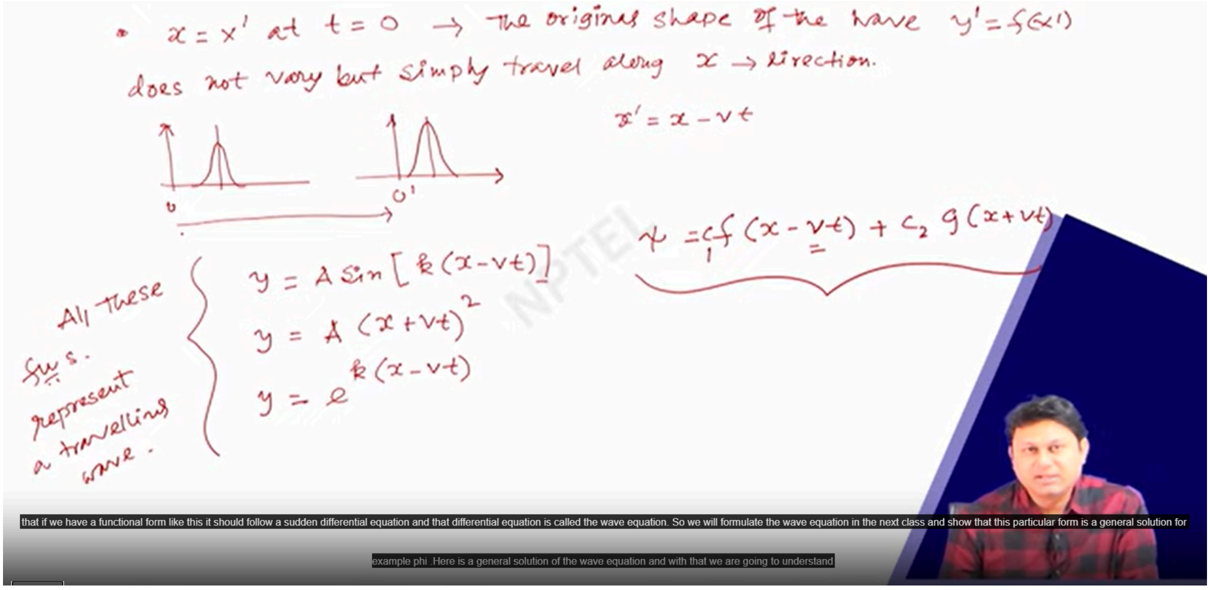

- $x = x'$ at $t = 0$ → The original shape of the wave $y' = f(x')$ does not vary but simply travel along x → direction.

$x' = x - vt$

$$\psi = c_1 f(x - \underline{v}t) + c_2\, g(x + vt)$$

All these fns. represent a travelling wave.

$$y = A \sin[k(x - vt)]$$
$$y = A (x + vt)^2$$
$$y = e^{k(x - vt)}$$

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