Biophotonics
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Lecture No. 05
Nature of Light – Part – 2 (As Particle)

Welcome back, let us continue our discussion on the nature of light. So, in this particular class we are going to discuss the nature of light from a particle point of view, where light will behave as a particle.

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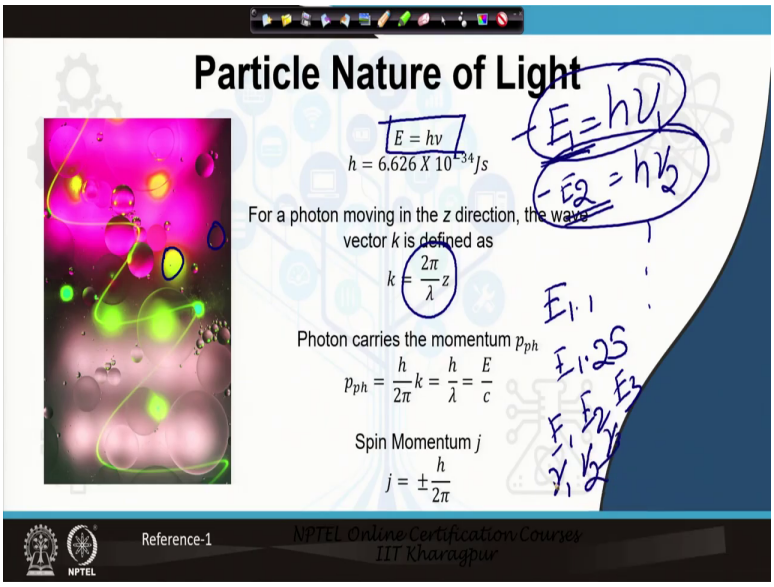

Now, obviously the question comes that why there was a requirement to discuss light as a particle, the quanta of light or photons, why there was a requirement life was good with waves, we have described several properties of light interference, diffractions, so why there is a requirement to go and return so like a full circle when Newton described light as corpuscular theory, why we need to discuss or why we need to describe light from a particle point of view?

Well, the answer was I remember I told you that there were few gaps remaining in the line of physics which physicists were still unable to understand these pockets that they thought that once we full once we feel it physics will end, one such topic was the gap which the wave nature of light could not describe was photoelectric effect. Photoelectric effect in which you bombard a surface of a material with light and when the energy of the light reaches a particular threshold

electrons could be ejected from the surface and you can see electric current flowing or effect of that nature.

The significant point here is that only when light of a particular frequency particular energy a particular specific threshold is crossed, this phenomenon is observed. Prior to that if you have shown light onto this material surface of very high intensity for a very very long period of time but still the energy of the light is less, if the threshold, the frequency of the light is less no matter how intense your light beam is, no matter how long you have shown it, there will be no ejection of electron.

Now, this fall flat on the topic of wave nature, because if you are shining light for a long period of time a very high intensity of light surely the wave should build up constructive interference it will go on happening and happening building and building at one point of time the threshold will be reached and the electrons will be ejected. But no matter how long you have shown that light on to the surface, if the energy if the frequency of the light is below a particular threshold, no effect is seen.

Einstein described this effect by taking the Q from Max Planck who has described that light comes in specific particle specific quanta and these quantas have a specific frequency and there by utilizing all of this he described that it was the photon nature, the particle nature of light that was bombarding, that was passing its energy as well as its momentum onto the electrons that are present on the lower surface resulting in the ejection of the electron from the surface, the threshold needs to be covered.

Several other effects have also been encountered which could not be described completely from a wave nature of light say for example Compton effect, when light was interacting with a charge particle say for example electron the overall after the interaction after the collision had happened between light and the charged particle electron the frequency of light has reduced. Reverse Compton effect is also shown where the frequency of light has increased, the energy of like has increased.

Several times a charged particle is encountering or it is passing through a light field is passing through an electromagnetic wave field and there is no change whatsoever neither the electron is getting energized nor there is much of a difference in the wave per say. All of these things could

not be described by simply the wave nature of light, therefore we need to describe or we required a different definition a different explanation that explanation was given by the particle nature of light in which we describe that light is also, light is also a particle the particle of light is called photon and that photon interact with matter and impart energy as well as momentum.

This momentum is quite important the momentum overall gives rise to direction and although several topics of the photon several nature of the photon is very very similar to that of the wave say for example the wave vector, however this is the fundamental aspect in which we describe that the energy of each photon is discrete, they are lumped together and they have specific value, so E_1 happens to be $h\nu_1$, E_2 happens to be $h\nu_2$ and so on and so forth. Meaning that the different photons different particles will have specific frequencies and thereby specific energy, there is a gap between E_1 and E_2, there is a discrete difference between E_1 and E_2, it is not continuous there is no such thing as $E_{1.1}$ or $E_{1.25}$ as such it has to be E_1, E_2, E_3, because it is ν_1, ν_2, ν_3 as such.

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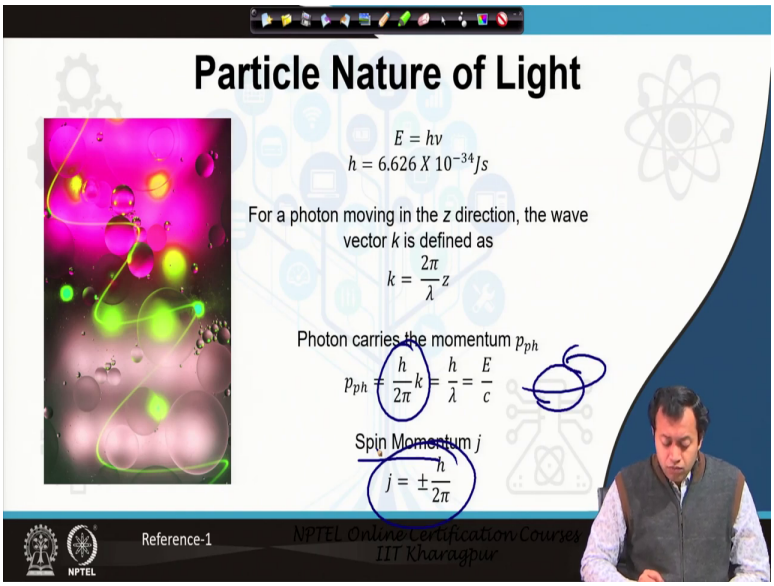

Anyways several other topics came up for example photon carries a momentum which is given by this particular formula and there is a spin meaning the photon has a rotation on its axis, whenever photons interact with electrons this spin momentum is quite significant even if the spin is quite different the electron might not be able to absorb the particular photon and gets energized.

We have been discussing about photon from almost 100 years by now, It could very well be said that the amount we knew before when photon was discovered was much larger than the information that we have about photons now. So, I will give you a description of what people thought about photon in the early stage.

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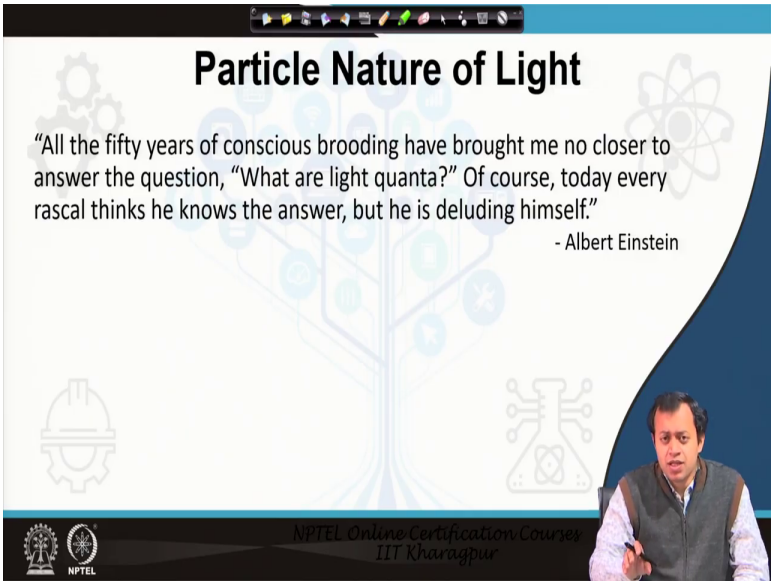

Please go ahead and read this ultra-famous very famous quotation, "all the 50 years of conscious brooding have brought me no closer have brought me no closer to answer the question, "what are light quanta"? Basically what exactly are photons? Of course today every rascal thinks he knows the answer, but at the end of the day, he's deluding himself." You know, who said that, it was said by Albert Einstein, the gentleman who got Nobel Prize, one of the greatest scientist who got Nobel Prize for photoelectric effect and describing how these things happening. But this was in the year when 1950's or such as such.

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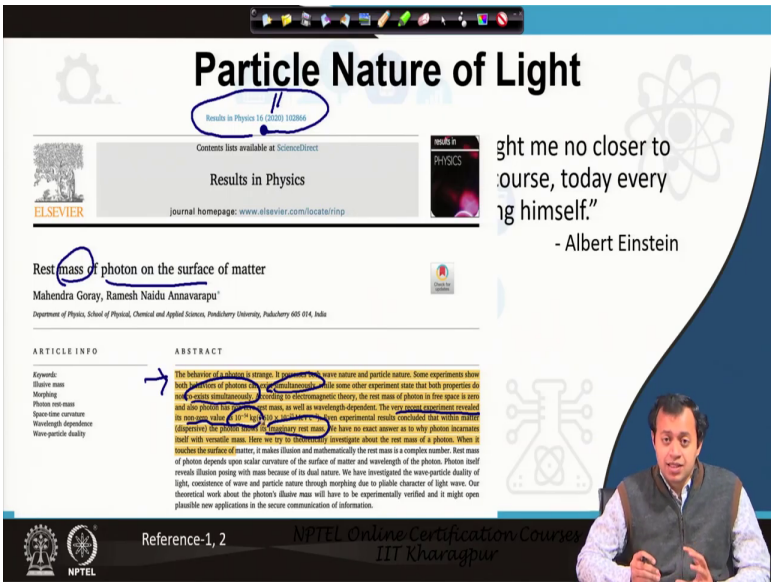

Recently this is the paper that you can refer to look at the year here 2020, where in this particular paper Results in Physics they are still trying to ascertain if photon have a mass or not, I have purposefully avoided going into the direction of mass or photon or the spin of photon because it will deviate us from the topic of bio-photonics to quantum mechanics, but still the year 2020 we are discussing about the rest mass of photon and if you can read the highlighted part, it starts with the behaviour of photon is strange, it possesses both wave and particle nature, some experiment shows both behaviours existing simultaneously, while some experiments state that both properties cannot exist simultaneously.

So, what is it? In the year 2020 we are still unsure about it. Previously we have discussed or we have understood or we have thought that light waves have no effect on gravity and photons in general are massless charge less particle that moves around, well very recent experiments reveal that it has a nonzero value, light or photons particles have a nonzero value. Then there is the topic of rest mass, imaginary rest mass, several new things are coming up and if you want to know I asked you to explore the topic of quantum physics rather than the topic of biophotonics to understand the nature of electromagnetism or the nature of light in general.

For the time being read about what Albert Einstein said more about the nature of light in quantum. Nevertheless, despite the given fact that we have not fully comprehended what light is, whether it is wave or whether it is particle, it is fashionable to say it is both but Richard Feynman

tries to describe it as it is neither, light is neither wave nor particle, but there is a small problem with this definition, when anybody says that it is neither this nor that then the counter question comes then what it is.

And to be frank I do not have the answer, I do not know what light is whether it is wave or whether it is matter, whether it is both light and wave and matter simultaneously or it is only one at a time, I do not know and before you switch off this course thinking that your professor is rubbish, remember what Albert Einstein just said, he had no idea till the end of his life as well. And if Einstein can say he does not know I can very well say that I do not know either.

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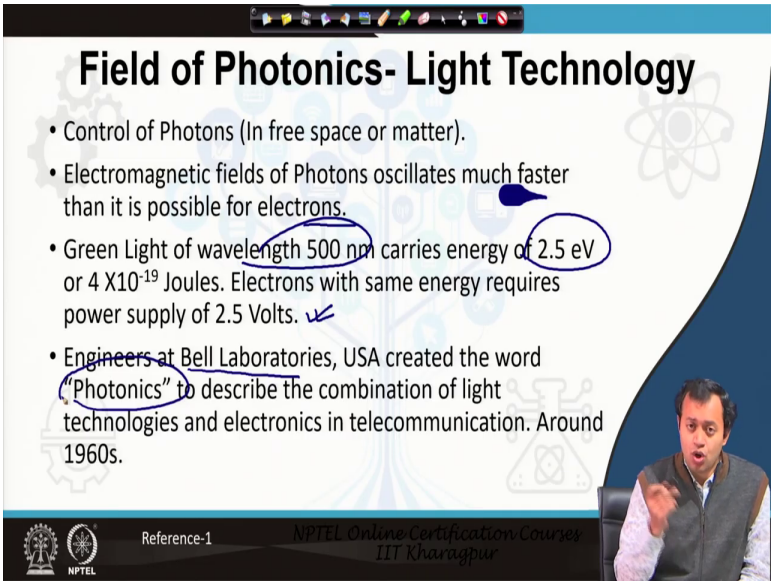

So, despite the fact that we do not know entirely about the nature of light or the nature of photon, it has not prevented us from developing the topic of photonics and that is the most significant part we do not need to understand something comprehensively to use it, consider yourself the example of mobile phone or computers, several people from different educational background difference social background these days utilizes mobile phones or computers, do very very few people actually know the inner working of a mobile phone, do you think every single person who uses a mobile phone understand the entirety of the process how it is connecting how it is wirelessly connected what is happening inside or for example what is exactly happening inside the computer CPU the algorithms being done.

But it has not prevented us from utilizing it. Several drivers, drives a car but how many people actually know the mechanical properties the combustion engine properties that goes inside the car. So, technology does not require for a particular field to comprehensively developed, technology and science can go side by side and using whatsoever meager information we already have about this particular area this particular field we can utilize technologies to it. And it has been many times observed many times seen that the technology is helping you understand what this particular field what this particular subject is.

Photonics is one such technology granted, granted we do not fully comprehend what photons are, it has not prevented us from utilizing photons for several different applications to. And why we should stop? We cannot wait that we need to fully understand what photons is and then only technology come up, the technology can starts simultaneously parallelly side-by-side with whatever meagre information we have. And that gave rise to the field of photonics. Photonic simply is control of photons in free space of matter, electronics is the control of electrons, control of photons in free space or in matter is basically what photonics is.

The idea is we do not want to discuss the mass of photon in this particular class this is not a course on electromagnetism neither is a course on quantum mechanics, but since the mass of photon is quite less; previously it was considered 0, nowadays they are considered it as a less but not specifically 0 value. Since its mass is less, it can oscillate much much faster than electrons and thereby, you can pack more amount of information to it, so small photon say a green light of 500 nano-meter can carry this much amount of energy whereas electrons will require a 2.5 volt battery to produce the same energy. So, photons are faster, they have more energy, they have larger frequency all of these things.

So, engineers at Bell Laboratories USA, they use the term photonics, we already knew what photons were Bell laboratory engineer certainly did and they thought that it will be better if we coined a new term photonics in which we utilized photons or light technology for several different applications.

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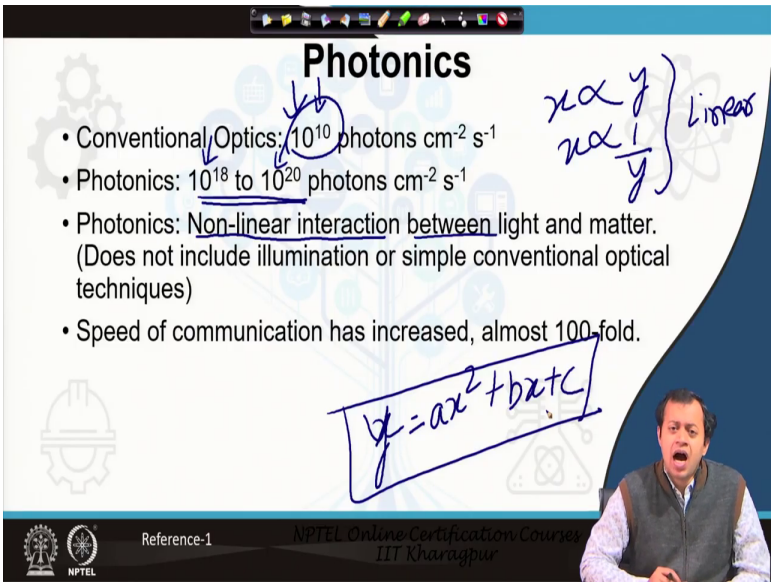

What is the difference of photonics with respect to conventional optics? This question comes up all the time that we already knew about light by the end of eighteenth century or early nineteenth century even with the particle nature, we have utilized optics for a long period of time we have magnifying glasses, we have microscope, we have telescope, Galileo have developed telescope, so how are photonics technologies or the field of photonics in general different from the topic of optics?

Well, to be frank, though the boundary has been breached, though the boundary has is no longer that much rigid or that much valid from a historical point of view, conventional optics utilizes 10 to the power 10 photons per centimeter square per second, whereas photonics is almost double that of the number. So, you could say that photonics utilizes more amount of photons, this amount is much large, there are more amount of photons per unit area per second.

However, that boundary is regularly being breached, this is just a historical perspective, we make photonic integrated circuit probably you will learn it at a later stage where the photon count keeps on modifying keeps on changing and no one will say that up till this part this is photonics then it has become optics and then it is becoming photonics again, so from a historical point of view the difference between photons and conventional optics is the amount of photons, but overall it is not a very strict rigid boundary.

Secondly, photonics basically deals with nonlinear interaction between light and matter, nonlinear means where there is not a linear or there is not a straightforward, if x is directly proportional to y or x is inversely proportional to y these are basically linear terms, but if x is equal to or say y is equal to ax^2+bx+c some kind of a complex relationship we can very well say that this is a nonlinear phenomenon.

So, nonlinear phenomenon describes say how light is interacting with electrons, how the electrons are getting are colliding with photons, we described spectroscopy, we described fluorescence per say several non-straightforward matter, not straightforward matter are the purview of the realm of photonics where optics mostly deals with reflection refraction just straight forward nature.

And obviously by using photonics optical communication for example fibre-optics based systems you have a speed of communication increased almost a 100-fold, you all must be watching Netflix at home or you have streamed live streamed videos, high quality etcetera, how do you think that have been possible? You have an optical fibre-cable that can stream light which contains information, remember the wave packet that I described in group velocity, so the speed of communication has strongly increased as compared to the wired copper wire based communication that we used to have at earlier stages which used to describe information.

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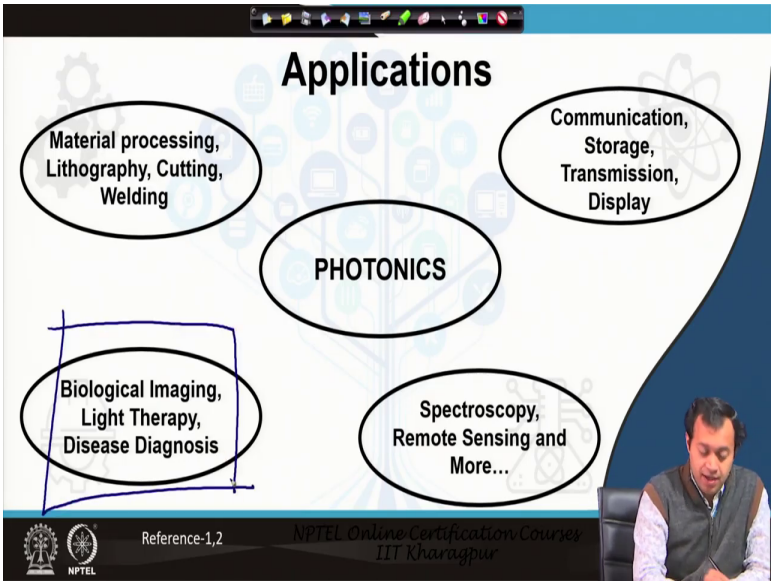

So, what are the different applications of photonics? Since we are discussing about biophotonics, but natural that we described little bit about photonics as well. So, there are several aspects of photonics you have communication of course, you can store information in the form of light, you have transmission, you have display, you can utilize lasers which are integral part of photonics for lithography material processing, cutting and welding, you can utilize photonics, you can utilize light intense photons for biological imaging, light therapy, disease diagnostics and obviously, for several different things such as remote sensing, spectroscopy et cetera.

Now, please tell me by this time you have understood which part of photonics we will be mostly discussing, this course for all intent and purpose we will be focusing itself on this matter where photons will be utilized to describe biological material. So, that is more or less the end of our course.

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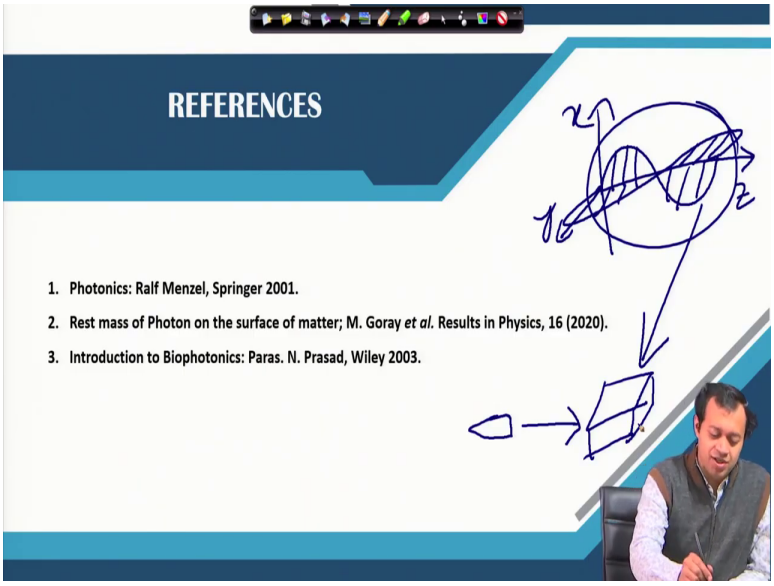

These are the references. But before I let you go, I have two basic questions for you, these are not part of the assignment, this is for you to exercise your mind, read about it a little bit and maybe you will get interested. So, first question usually photons are considered as massless and charges, forget about the mass for the time being considered photons are charged less particle, light is a neutral particle, light does not have any charge. But if we described a light which is moving in this particular direction with an electric field in this direction and the magnetic field in this direction, light is moving in this direction, this is x this is z and this is y, it has an electric

field and a magnetic field. So, how come it is charge less? It has an electric field, electric fields have their values and it has it magnetic field as well.

So, how come photons are charged less? Number 1 question for you. Number 2 question, if there is a magnetic field, can we not have a magnet in our hand and simply attract this wave towards this magnet? So, consider this as a photon, photon has an electric field and a magnetic field, I have a magnet, I have a magnet like this, can I not attract like you attract an iron particle with a very strong magnet towards it, can you not attract a magnetic field from light using a magnet?

You have been seeing this image since middle school, there is an electric field hand, magnetic field hand, so if there is a magnetic field hand, we use a magnet to attract it, the magnet in magnetic field is oscillating we use an oscillating magnetic as well, you know electromagnets they can oscillate, they can give south pole at one direction, north pole in one direction, we rotate the magnet. So, if we constantly rotate the magnet at a speed matching that is the speed of the light, speed of the photon, can we not, can we not simply attract light towards this magnet?

Imagine how beautiful our light would be we will have a magnet photon particle will be sticking to it and after some time it will start emanating light, but we do not see that happening. Can you tell me why? Remember this is not part of an assignment, this is also not particularly part of biophotonics, in biophotonics, we are going to discuss how to detect diseases, so Maxwell's equations or the mass of photon or for example these two questions that I asked have very little consequence, very little relevance, so I am not going to discuss that in detail.

But if you are interested try to think about it, try to think about it that perhaps a little bit more depth on the already known topic something which we have already discussed probably is required because some very important things can be lying in plain sight which we have thus far only ignored. So, this basically ends my topic on the first module, this was merely the introduction, I know physics students will not be very happy because I have not gone to the entire depth of light and quantum mechanics, but I want to go as soon as possible into the heart of the matter and that is how to image or how to see biological matter with light.

For the time being the information that we have on light will suffice, this was just to refresh you, so the next time when I use topics like refraction or diffraction limit this light in under microscope is diffraction-limited you will be able to recall what diffraction basically is and what

constructive interference is, things like that. Anyways, please drop below on the comment box what you think what I should change what I should keep and any feedback as long as it is constructive please welcome. Thank you, thank you very much.