Optical Spectroscopy and Microscopy
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Lecture – 4
Fundamentals of Optical Measurement and Instrumentation

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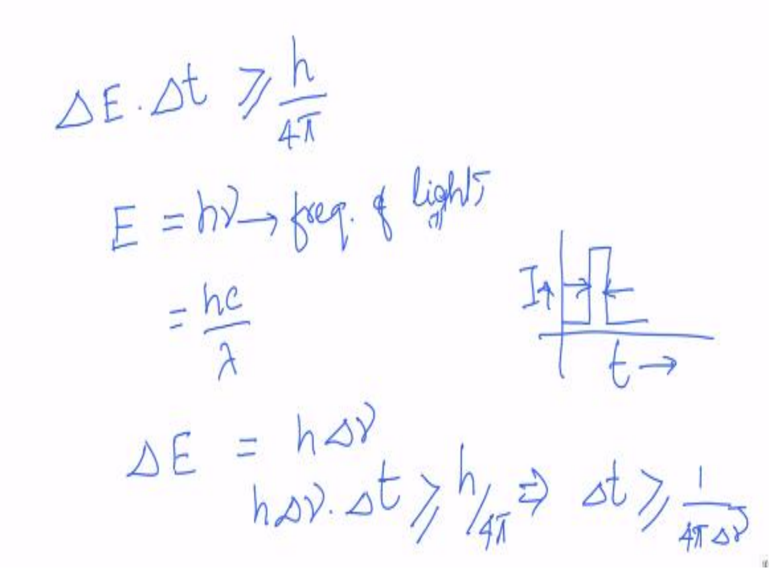

So until now what we have seen is that 2 different aspects of uncertainty principle. One uncertainty principle that utilizes the momentum and the position and the other uncertainty principle that connects the energy and the time and what we said is that using the position on the momentum uncertainty relationship, we were able to obtain the localization accuracy of the photon, alright. We saw that corresponds to or even it is slightly lesser than the diffraction limited focus that has been proposed, the spot size of the diffraction light that has been proposed.

With the energy and the time relationship, we are able to come up with the minimum bandwidth that is required, alright, the amount of color content that the light should have so that we can localize the light in time, right. If you want to what we saw here as you are seeing in the slide is that if you want to localize the light to a sharper and sharper in time, then you need to have a higher color content.

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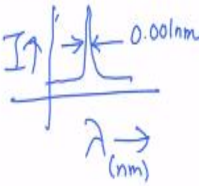
$\Delta\nu \rightarrow$ Bandwidth of the light source



632 nm

$$\Delta\nu = \frac{c}{\lambda_2} - \frac{c}{\lambda_1}$$

$$\approx \frac{\Delta\lambda}{\lambda_{ctrl.}} \cdot c$$

(0.001 nm)

(= 632 nm for HeNe in our e.g)

$$\approx 1\,GHz, \quad \Delta t \Rightarrow 1 \times 10^{-9}\,s\ (ns)$$

Another facet of quantum mechanics that Dirac realized and he proposed is the idea of superposition, alright. So now this is new and I am not sure if there is a classical equivalent that we know of. So let us look at it in a similar manner like what we did in an uncertainty principle, let us look at it using the analogous manner. Now what we are going to do is that I am going to state few ideas or assumptions that are important for us to go and proceed forward.

Then take an example of where it might be useful okay and then illustrate how using quantum mechanics were able to nicely get this fundamental result. The idea is that while I am motivating you for developing this quantum mechanical formalism, I am also emphasizing the fact that we will be using this in a very basic manner to understand how the light interacts with the matter, okay. So let us look at the superposition principle that I told you about right.

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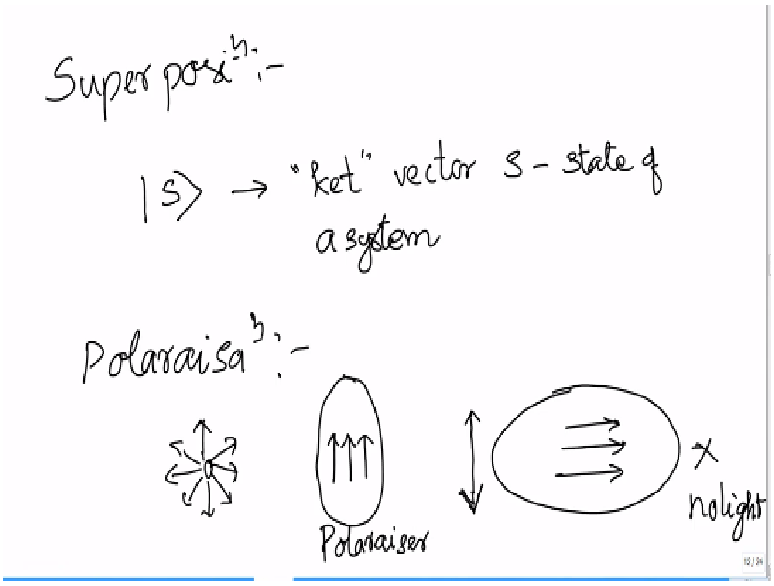

So, the principle of superposition. To understand this, Dirac drag proposes that if you are studying a system now, then every system has its unique characteristics, unique parameter definitions, and unique descriptions. Dirac says that all of this could be encapsulated into what he calls it as a state vector, okay. So what is the state vector? A state vector is an entity that you can think of which contains information about everything that you all like to ask about a system in that context, okay.

So these he represents by a special notation called as bracket notation and we are looking at one half of the bracket where we call this as ket vectors. So, this would mean ket vector S, representing state of a system. Now the benefit of doing this as you will see in a short while is that the moment you take this, you transpose this problem of physical measurement into a vector space description.

Some of the peculiar properties that we see are that may appear as peculiar is no longer peculiar, but it is very natural to the description of the system and it comes out naturally from the description of the system itself. What could be this kind of properties? Now, I am going to give you one example okay. So, I told you that we are going to make use of these state vectors to explain the property, but then I am going to now describe to you the experiment that might need such a description and why this is a good natural fit.

Please note the example that I give you it is not to say that you can only explain through the description that I am giving, I am using this example as a way of introducing the system okay. You can actually very well describe this whole process over time in the experiment I am going to describe, you can very well understand this by classical mechanics, but then, I will tell you where the limits are and why we need this. So the example that we are going to see is that of light itself again and light is known to have a property of polarization, okay.

What is polarization? We know of certain materials we call optical materials and these materials have the unique property that when you send in an unpolarized light, unpolarized light is just light that is generated from common light source like bulb or sunlight so on and so forth, right. So we take that light source and then what we see is that if we pass them, let the light pass through these polarized filters, then this special optical substances we call them polarizers or polarized filters which I represent as the circle with this arrows, these are called as polarizers.

People who are familiar with the photography would have used this quite extensively to enhance the contrast and bring out some features or to suppress some features. So what it appears to do is that, it appears to when the light passes through these polarizers, the resultant light seems to be polarized along a particular axis in relationship to the crystal, polarizer. So what do we mean by polarized? That is, I can actually take the same polarizers, alright, or another polarizer of its same kind and then rotate it.

Now rotate this axis such that now it is at 90 degrees to its original axis okay. So let us make this as an ellipse so that we can differentiate this, okay, and then they go into ellipse. Now since it is rotated, now you would see some ellipse to be this way. What do I mean by polarized light is that once the light passes through this and then if you put in a polarizer that is rotated to 90 degree, you would not get any light, no light at all, very minimal light that comes through.

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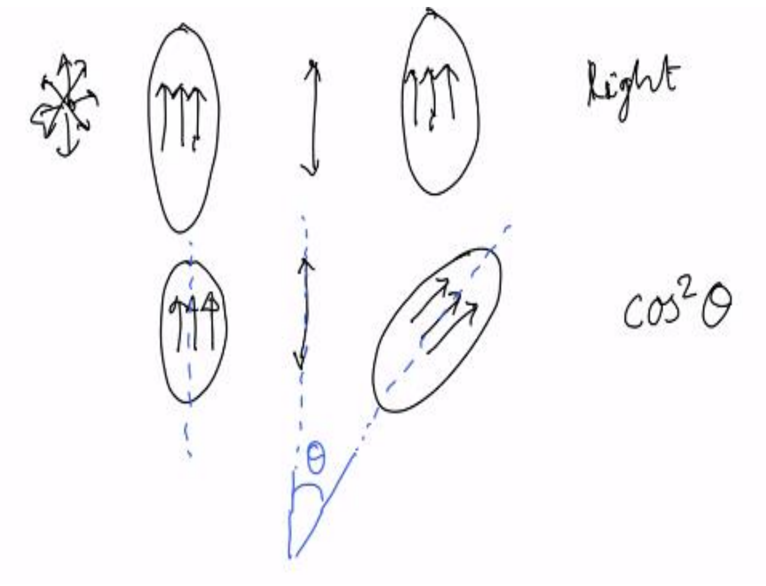

However, you can actually put in, do the same experiment, I will draw the same schematic, alright. Now the polarizer here okay and then if you put in another polarizer that is the same orientation right. It is nothing to do with having 2 polarizers. If you put the same polarization with the same orientation of the first one, then what you see is that the light coming out, there is no problem at al. In fact, you can actually generalize this to the point where let us have the first polarizer, alright.

Then the second polarizer you do not have to even put it at a 90 degree orientation with respect to the first one, but you can put it at any arbitrary angle, alright. Now, the light intensity that you see has a very unique dependence on its orientation. That is, the intensity will go as cos square of theta where theta is the angle between the orientations of the first polarizer and the second polarizer, I mean assumption is there is no other polarization in between. So the first polarizer leaves you with the light whose polarization is along this axis.

So technically what you are actually trying to represent is this angle, this is your theta. Since this axis is determined by the first polarizer, I kind of generalized to say that it is a angle between the first polarizer and the second polarizer. So it has cos square theta dependence. This is pretty well known and it is like elegantly treated in classical electrodynamics and as a necessity, there is no, I mean we do not need to go into quantum mechanics to understand just the effects as I have described. However, something peculiar happens or something surprising happens when you do 2 things.

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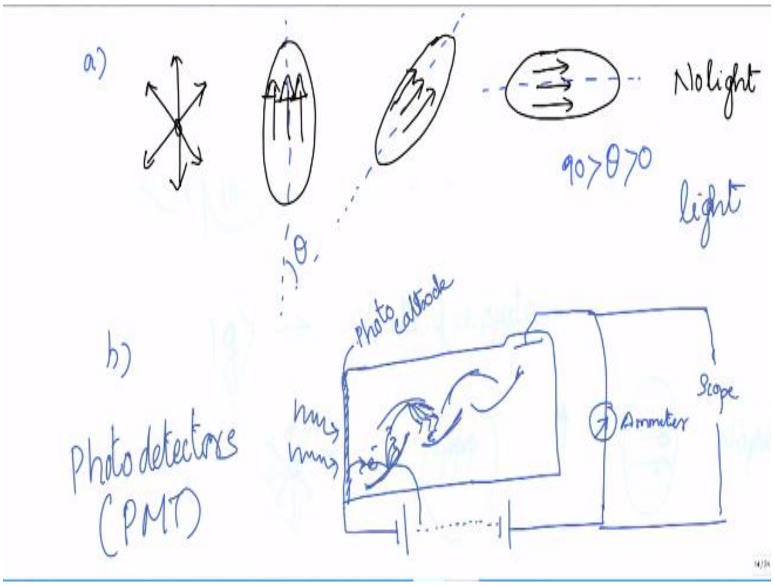

Number 1, we are going to introduce, we are going to take a system that we described previously, I am going to go to the next page, which is I am going to take the light and polarized light and then send it through by polarizer, alright. Then keep another polarizer that is at a 90 degree at an orthogonal direction to the first polarizer. We said there will be no light at all. However, if I introduce another polarizer that is at an angle theta and which is not equal to 90 or not equal to 0, it is greater than 0 and less than 90.

Then what you see is that, okay the theta here is again I am talking about the angle between these different, this is my theta. So as long as this theta is greater than 0, then we have but it is still lesser than 90 okay. If you have the theta in between these angles, what you see is that you see the light emerging from the second polarizer. How is that by adding an extra filter, extra optical element you are changing the situation from a no light to a light situation?

So it is easy to understand by adding an extra filter if it were to reduce or if you were to block, I mean the adding an extra filter at a 90 degree orientation if you are losing the light, that is understandable, but you are rescuing a situation where it is actually completely blocked, there is no light coming in, but now virtually by adding one extra filter that to at an angle that is defined within this interval, you can actually generate, you can start to see some light out from the third filter that you did not see before.

So, that is situation a and situation b is that I kind of said there will be light and no light and all that stuff, but how do we do it in lab, how do we experimentally measure it. We use photodetectors, particularly we will be talking about photomultiplier tubes, alright. So, what are they? So, they are essential we will definitely talk a lot about the photodetectors, what is the signal, how do we understand the signal and so on and so forth, but here I am introducing the photodetector or a photomultiplier tube as a photodetector just to illustrate a point of how light in general behaves at low intensities, okay.

This is of great use because we would use that behavior later in the course. So these are nothing but devices made in a special way. So they have a referent element that is called as a window, which is coated with a substance called photo cathode, essentially they have a property that when light impinges on this device, they send out electrons okay. Now, these electrons then can be actually amplified, these electrons per se cannot be detected that easily, so what you do is these electrons are amplified.

The way amplification works is that since electrons are negatively charged, you set up a consecutively increasing a gradient, I mean potential gradient alright, something like that such that at the end you have electrical output given by your anode okay, so looks something like that. Now, this is connected do a negative end of the battery. Now, this grid is connected somewhere in between and so on. So this guy, the first grid is called as a diode is more positive than the photocathode and the second is even more positive, third is further more, and so on.

So in such a scenario and its geometry is such that the electrons coming out from the photocathode are more easily falling on the first dianode which by itself generates, because of its kinetic energy, it generates a bunch of electrons called as secondary electrons. Each one of them then can go and then hit the second dianode by which in turn produces a bunch of secondary electrons. As you can actually see, each one of these electrons can produce that cascade of electrons, ultimately leading into detection by an anode.

Then we can actually measure the current flowing through this circuit through an ammeter or connecting it to an oscilloscope, and when you do that it is interesting to know what happens, what do you see what as an output?

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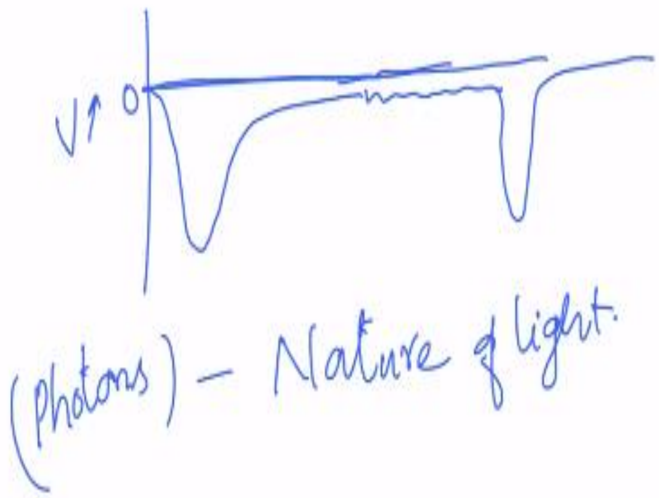

What you see as an output is that at a sufficiently low enough intensities, what you see is that what you see is that the output of the PMT looks something like this 0 and actually these electrons are put across small resistance of the oscilloscope, so we are actually measuring the voltage output on an oscilloscope screen since these electrons coming out, it is a negative current, so you measure actually is a negative voltage coming out like this. So now that you either see this or do not see anything okay.

It is then later sometime you see it like this, it is like a blip, nothing at all, blip, blip and so on and so forth. When you actually reduce the intensity, what you see is that the peak of this blips do not change, but the frequency at which these blips happen start to change okay. What I am illustrating here is that the nature of the light seems to be particulate, meaning there seems to be presence and absence of the particle defining the intensity rather than anything else, right.

It is a very quantized to say the light is photonic in nature okay, I mean particulate in nature and we call them as the nature of light is given by photons okay. So in order to explain what we have seen in the polarization and still be consistent with the fact they are photons, we need a description that is beyond a classical description of the wave theory okay. Now how that is developed and what effect, we will see in the next class.