Optical Spectroscopy and Microscopy
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Lecture – 7
Fundamentals of Optical Measurements and Instrumentation

Hello and welcome to the lecture series on optical spectroscopy and microscopy. In the last lecture, we were talking about how the polarization of a photon can be explained and we were doing some experiments on using the polarization of the photons and then the results that we have gotten. We would like to describe that using photonic picture as I was trying to motivate you that we can actually use Dirac's formalism actually to describe these principles.

I mean describe these experimental observations such that on one hand, we will be able to explain the photonic nature of the particles with the photoelectric effect and all that, we do not have to switch our interpretation or switch our description, but at the same time, be able to observe these phenomena that otherwise needs description using a wave picture.

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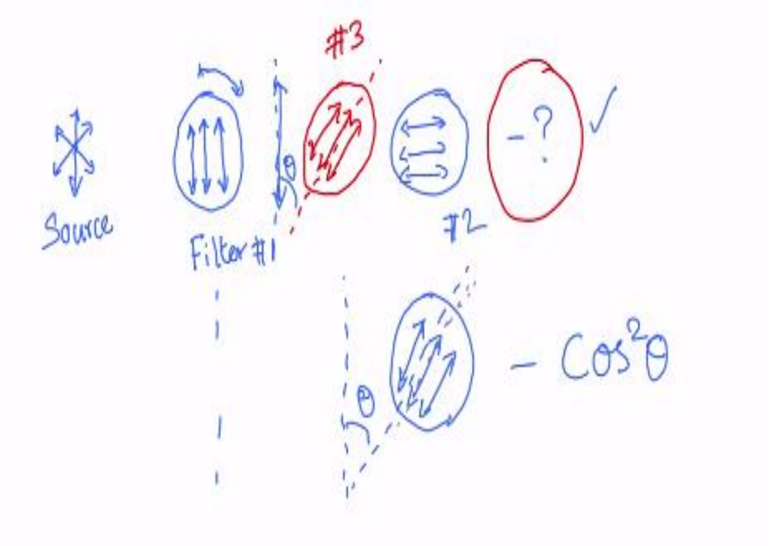

Briefly, the experiment is that we have gotten a source of light, we were using polarizer as a filter and then I told you that when you measure the light that is coming out from there, you always seem to get photons that are aligned that are having polarization that are parallel to that of the filter axis or we say that they are aligned to the filter axis. However, how do we know this is the case because we can actually take another filter and then put it on a 90 degree orientation with respect to the first filter, right.

The crystal axis of the first filter and the second filter are 90 degree apart, then what you see is that you do not see any light at all right, shown by this no light. However, you introduce now a cross filter, a filter that is about that is at an angle theta with respect to the first filter and that angle theta is somewhere between 0 and 90, in fact preferentially about 45. Then what you see is that you start to see the light coming out from the whole assembly. So we were trying to explain this.

So, one way to explain this is using a formalism that Dirac has developed. So, I am going to use that and illustrate how useful it is and then from there, we will go into understanding the interaction between the light and the matter, alright. So now let us go to a new page.

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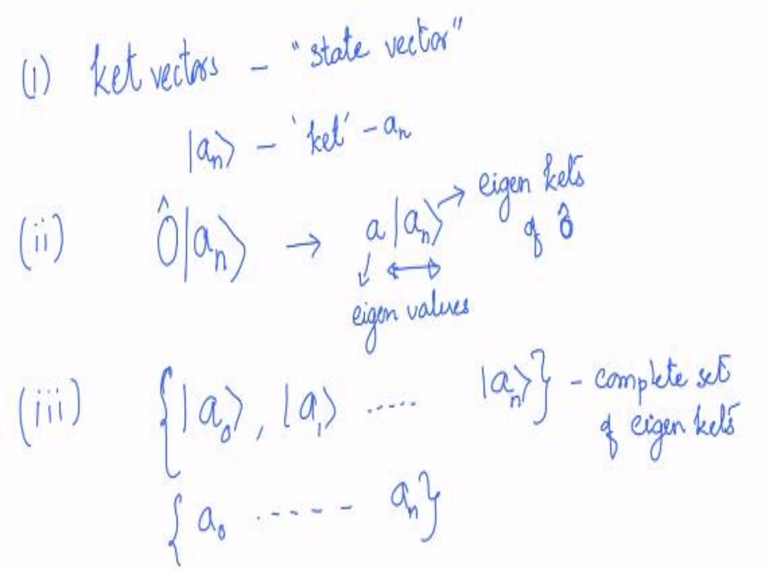

So, the formalism goes something like this. So first thing he says is that the observations that we make, the measurements that are resulting from an experiment are called observations that we make or result of an interaction of interaction that happens between the system that we use to probe and the system that is being probed. So in this case, we are using a polarizing filter and that is going to interact with the light photons emanating from the sources and then we are going to make the readout of whether what is the polarization is going to be.

The first thing that Dirac days is that all the systems can be described by using a system of vectors, and in this particular case, he is going to define a special case of vectors, they are called as ket vectors and among this ket vectors, a particular vector of interest is called as state vector. So, all we need to know at this point is that this is a vector or a mathematical tool that we have and a mathematical way of describing the system that we have, physical system that is existing with us such that any information that we would like to probe from the system can be obtained using this state vectors, right.

That is what we need to know at this point in time that is sufficient to know. So they are denoted by symbols something that looks like this. So in here, I am going to write it as this, we will call it as ket an, right. So, this would represent a state, if it happened to be a state vector, we would say that it represents state an, alright. Now, the next important aspect of this is that every measurement that you would like to perform on the system, you would be able to find an operator.

Basically an entity that is supposed to have a mathematically let us say written as O cap, that is thought to be operating on vector an and the result of that could be quite a few possibilities, but let us say in one of the special cases we write that as some scalar a times an itself, then we call these vectors as eigen kets of operator O, okay. Now this is equivalent to, we taking a physical system and then we are interrogating with a measurement process that is captured by this operator O cap and because of this what we have done is that the system has undergone a change.

If we have not disturbed the state of the system though, so we get back the system and that is what you can think of this as an eigen ket. Basically, these are the kets where the act of measurements have not affected except for giving a small scalar multiplication in some sense. Then if you are talking about vector algebra here, then what we are talking about is vectors whose direction we are paying attention to, not necessarily the magnitude at this point, right.

So, in such a case, then what we have done is that we have gotten back the same vector multiplied by some scalar constant and these constants we call it as eigenvalues, okay that is good, and then the third important point is that any state of a system you could express as a linear combination of a set of actors, okay, and they have certain property. So we are going to look at that in a little bit more in detail because that is the bottom line of the superposition principle.

These eigen kets, right, if you write down all the possible values of the eigen kets, that is to say I am making an operation O cap, and if I were to write down all the possible values that the O cap can provide me, then what you have is that you have a state corresponding to each of this possible values and we would call them as eigenvalues and corresponding states as eigenstates. So, in general let us say since a represents the eigen kets, we could think of a set of eigen kets starting from a0, a1, so on and so forth in general an.

All represent a complete set of eigen kets corresponding to eigenvalues a0 till a9, okay. Now what do you mean by complete? We have written down all the possible answers that we would expect from the operator or O cap right so that if you have written all the possible values, then you can think of that as a complete set and it does not have to be a finite set and we are going to soon see that it does not have to be a finite one.

It can be an infinite one and they have some wonderful properties that comes in handy, but the important fact of the matter is that when you have a complete set, then the assumption is some other you can always write down, so some other vector right.

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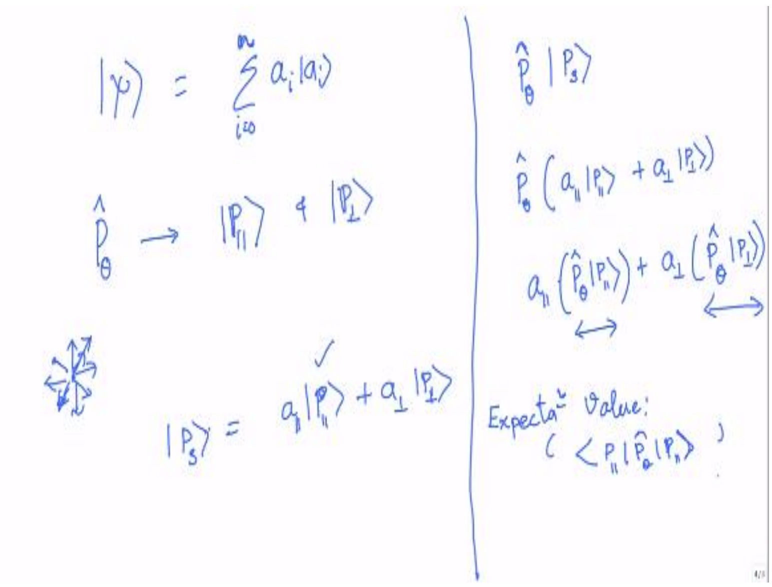

So, let us write down a vector in general en, sorry we will take it as some psi as a linear combination of all these vectors, ai where i goes from zero to n. The implication is that these could possibly also represent a state of a system at any time and in fact, he says that normally a system which one should consider as to be existing in this kind of a superposition state, and when they exist in the superposition state, the act of the measurement, right, act of we operating with operator O cap, what it does?

It collapses the superposition state into one of its very possible values. Now, what does it all mean? Let us see that in relation to what our polarization experiment meant. So, what is the operator here? My operator would be we will call that as P and I am going to write down as theta, okay let us write it as P theta. So basically, this theta represents the orientation of the crystal axis and we are going to keep that in mind right, orientation of the crystal axis with respect to the laboratory frame okay.

So now, what we are going to do is that we are going to write down all its, so this operators has cap, so all its possible values, right? So when you have a light source and we are going to orient this light source and then make the measurement of the polarization, right, so the values that are possible here are I am going to write down as P parallel and P perpendicular, right. So what do we mean by P parallel and P perpendicular here, well the states, we will come to that in a minute, so let us hold on that part.

So then, let us start writing out this expression. So to start with in our source of light has the planar polarization in all possible orientations and so that can be nicely represented as superposition state Ps consisting of P some coefficient. Let us call that as maybe a parallel plus a perpendicular, okay. Now this has a mixture of all the states. So in between states, in between polarization, just the way you would have represented in the electromagnetic wave that the vector where it is the linear combination between the parallel and perpendicular you would be able to represent any of the in between states too, well, that is good.

So then what happens when we are actually making a measurement? When you are making a measurement, so what we are going to do is that we are going to take this state. Now, these parallel and perpendicular states are defined with respect to the polarizer which is in turn oriented at an angle theta with respect to the laboratory frame, right. So if your polarization vector is also having an angle theta with respect to the laboratory frame, then you would say they are represented by this state okay.

In the laboratory frame they have an angle of theta and these state would represent all those photons whose polarization is theta plus ninety 90 with respect to the laboratory frame, okay. So now what we can actually do is that we can go ahead and write down what we mean by making a measurement or introducing a polarizer. So now, I am putting in P of theta. So now, we can write that as P of theta acting on P of s of okay. Now, the result of this would be some P of theta operating on a perpendicular and P perpendicular, good.

So, all we need to know then is that what has happens when this operator operates on these states, P parallel and P perpendicular, right? So that is given by a parallel P theta plus since it is a scalar, you are allowed to do this, you can actually do this. We can break down into this two terms and the point here is that we need to be able to evaluate and then relate these terms to the measurements that we make in the lab, alright. So how are we going to do this? The way we are going to do this is to develop the formalism that I have described until now, a little bit more.

So, one of the key features here is what we are able to do right now is that we are able to write down an expression for the experiment that can be done in the lab. So now, the key features of this is that the experiment yields a result that is represented by something called as an expectation value or you can think of what the quantum mechanics states is that it is not necessary that you would always get a deterministic.

I mean what is sure about your experiment is that you can associate a probability for obtaining a given result, and that probability is given, the probability in turn means that on an average what is your chance of getting particular value and that is given by this term which I am going to be writing here which is in this scenario equivalent to P theta cap P perpendicular, okay. What this means, we will see in the next class, but the idea here is that the three key things, one is you can represent the states of the system in terms of a vector algebra.

Then the members of this vector algebra are known as ket vectors and then there are special vectors called as state vectors among these ket vectors and they are supposed to represent the system in a way where whatever the detail that you would like to inquire, you would be able to obtain from them and then the every single measurement that we would like to make corresponds to an operator and I gave you an example of an operator for a polarizer, you can think of that as some operator P, but they have their very nice properties.

But then one of the important properties is that these operators have a set of vectors, a given operator you have a set of vectors called as eigen kets or eigenvectors, whichever property when they operate on, they do not change the orientation of these vectors, they just leave them in whichever the orientation they are in except for multiplying by a scalar. Now, that would correspond to a physical measurement where our interaction to make a measurement have not changed the state of the system, okay.

That is very much possible and those states are of very special interest to us because any other state, any other vector that the system is existing in can be described as a superposition of all of ket vectors. Now, how we use these principles exactly in our polarization experiment, we will get to that in the next class. Okay, thank you.