Quantum Electronics
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Module No. # 5
Lecture No. # 25
Review of Quantum Mechanics (Contd.)

So, we will continue with a bit of review of quantum mechanics. This is to recall, what you may have discussed earlier and to present something and to sort of raise some questions and try to answer them, because some of this will be relevant to what we will be doing with the electromagnetic waves. Do you have any questions in what we have discussed in the last class? Let me… So, what we did in the last class was we we said that in quantum mechanics, we will represent the state of a system by a ket vector. For every ket vector there is a bra vector, all observables are represented by Hermitian operators that means an operator, which A cap is equal to a dagger and we define an expectation value.

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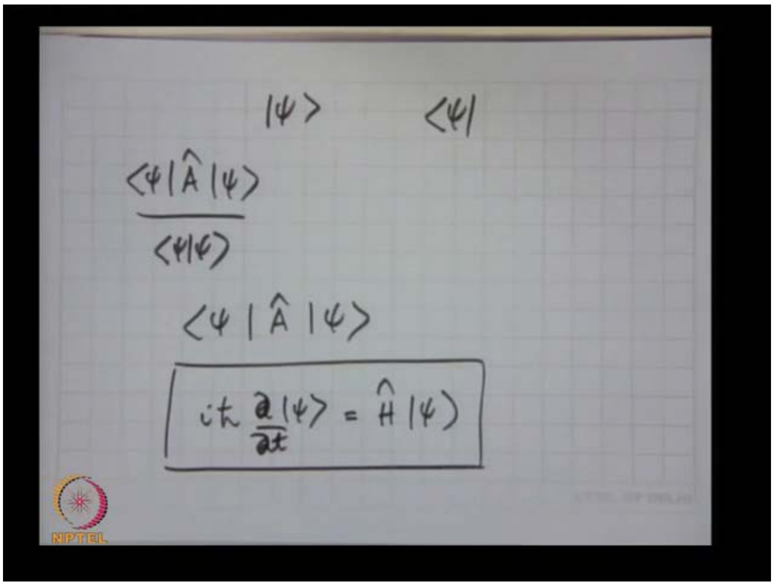

So, if you have, if you if you define a state by a function ket psi then it, with it, we associate another bra psi. And if you have an operator A, you define an expectation value of the operator in this state as this. So, this essentially implies that, if you prepare an ensemble of states, an ensemble of systems all in the state psi then if I measure the observable corresponded detected to the vector to the operator A, on each one of this systems, I will gets some results. And this implies essentially the average over the results of my measurement, on individual elements of the ensemble.

So, if for example, A corresponds to momentum operator and psi corresponds to some system, a particle, for example, this implies that I prepare a large number of particles in an identical state. I measure the momentum of the particle in each one of the states and then I take an average and that we what I will define here. One second, all in spite of the fact that all the states are exactly in a same prepared in the same state. All systems are exactly in the same state. I may not get the same result of measurement of that observable on each one of this element of this of the ensemble. Yes Mohith

Sir, what is bra psi exactly represent

It is something like that a complex conjugate, but it is a it is a for every ket psi, I will have this bra psi in actually this is another space - another vector space. So, if you read Diracs book, you will see a much more clear definition and sort of introduction to this. So, this is for every ket psi, I can define a bra psi, such that, for example, I can define a norm of the vector that means the length of the vector, for example, in the Gilbert space and I can use this vectors to define ensemble averages or expectation values. So, for every ket psi, I will have a bra psi; and they are actually in two different spaces with these vectors, I can define something similar to scalar products, vector products and all kinds of products

So, these in matrices, for example, this may be a column vector and this may be a row vector. Although they are then related completely, but in principle in the abstract vector space they may they may correspond to two different spaces. Now, what is most important finally is, this? This is what I will observe; this is what I will measure. Now, it is not sufficient for me to say that I have a state ket psi, how does it evolve with time. And that is the Schrodinger equation comes in, and Schrodinger equation is essentially i h cross d by d t of psi is equal to, this is duo by duo x, H operator is the Hamiltonian operator, which in most cases corresponds to energy of the system.

And this this equation tells me the time evolution of the state of the system. So, the time evolution state of the system is determined by a first order differential equation in time, which means that, if you define psi at t is equal to 0, you can find out psi at any other time; it is a first order equation. If it was second order equation, I would also have to need the first derivative with respect to time; I do not need that here. So, if I if I know psi at t at a given time I can calculate psi at any other related time by integrating this equation. So, in this this is this is an equation in this equation I assume that psi is evolving with time the state of the system evolves with time.

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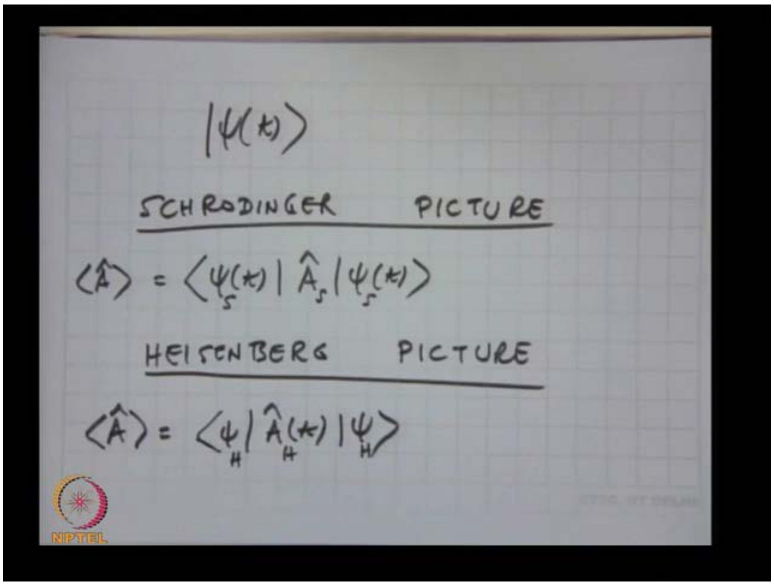

So, psi is a supposed to be a function of time. The psi is a function of time and in this picture, this is called the Schrodinger picture, in this picture the wave the the ket vectors evolve with time, but the operators are independent of time - the Hamiltonian operator independent of time; the position operator is independent of time; the momentum operator is independent of time etcetera etcetera. All the operators are actually time independent operators. So, this called the Schrodinger picture.

How I calculate the expectation value as a function of time? So, for example, for an operator A, I will have to calculate, how the expectation value of this is expectation value of A and this may change with time, because psi is evolving with time, A is independent of time, this expectation value is evolved with time. So, it tell me, for example, if A corresponds to position operator this will tell me, what is expectation value of the position of the particle as a function of time; expectation value means average value. Where do you where would you where is the, what is the probability of finding at a different point essentially.

How does the how does the average value of position, which I will get by multiple measurements vary with time. So, in this picture called the Schrodinger picture, the kets evolve with time the operators are independent of time. There is another picture called the Heisenberg picture (no audio from 07:18 to 07:26) in fact that came before Schrodinger picture. In which the operators evolve it time this state vector is independent of time. So, I will have some psi A as a function of time psi. I have shifted the time variation from the state vector to the operator. So, in the Heisenberg picture the state of the system is fit the operators evolve with time. So, expectation value still evolve with time.

Now obviously, the expectation value cannot depend on what which I use to describe a system. So, these two expectation values have to be the same. So, there is a relationship between the way psi varies with time through the Schrodinger equation and the way the operator will vary with time. So, for example, I may like to write like this. So, this is in Schrodinger picture s subscript s and this is Heisenberg picture; I put subscripts H for Heisenberg picture; subscripts s for Schrodinger picture. So, I would have a situation, where the wave mechanic that you must have studied uses the Schrodinger picture, where the wave functions evolve with time and the operators are independent of time.

Look at the energy operator, the momentum operator, the position operator, they are all independent of time. They are operators fixed with time. I can actually go from the Schrodinger picture to the Heisenberg picture by what are called as unitary transformations, but I can make the wave, the ket independent of time and move the time depends to the operator.

So, I have an equation in the Schrodinger picture, how the wave or how the (( )) ket evolve with time or the kets evolve with time in the Heisenberg picture I would have an equation of how the operators evolve with time that is called the Heisenberg equation of motion. And Heisenberg picture is closer to classical mechanics, because in classical mechanics you will say how momentum varies with time; how position varies with time; how energy varies with time. This will tell you how the operator corresponding to momentum varies with time; how the operator correspondent to something else, where its position varies with time. So, the equations of Heisenberg equations of motion will be very similar to the classical equations.

And as we go through the quantization of electromagnetic field, we will be using both the pictures. And there you will start to understand the relationship between these two pictures; and I will later on, I will derive an equation from the Schrodinger equation. I will derive an equation for the how the operators vary with time, because the electromagnetic field remembers in electromagnetic fields. The fields are the operators the electric and magnetic fields are observables. In electromagnetic wave, I can measure the electric field, it is an observable; I can measure the magnetic field that is an observable; I can measure the pointing vector etcetera etcetera. So, when I quantize the electromagnetic field, I will represent these observables by operators.

There will be electric field operator, magnetic field operator, pointing vector operator etcetera, these will become operators and in in the Heisenberg picture. I will have this electric field operators evolving with time, exactly like in a classical picture, electric field vary with time; magnetic field varies with time. So, I will have to I can actually move in to a situation, where I can use Heisenberg equations to find out. How the electric field varies with time or I can move the time dependence to the state vectors. And keep the operators electric field operator, magnetic field operators independent of time, while the state vector evolves with time.

These are two main pictures exactly opposite to each other. There is also another picture called the interaction picture. In which both the wave function and the operators become time dependent. And that is a very useful in looking at situations where systems interact with each other. So, the total Hamiltonian is written as a sum of two components. And then you split the time dependence between the wave function the the the I the ket and the operator. And you simplify the mathematics finally your trying to simplify the analysis to help you find the solution to the problem. So, these two pictures we will come back again and again as we go through the analysis.

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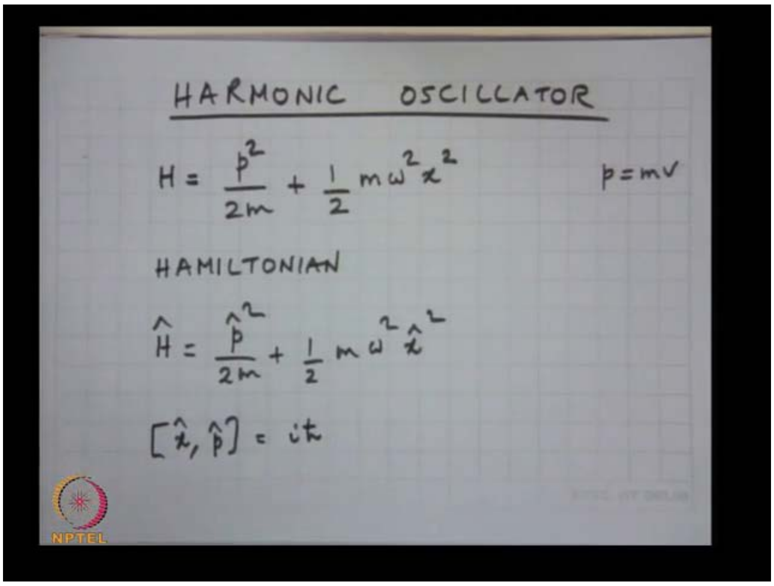

Now, today what I want to do is quickly recall the problem of the harmonic oscillator. (no audio from 12:19 to 12:28) that means, it is a system in which the potential energy goes as half k x square proportional to square of the displacement from a point. Why harmonic oscillator, because I will show you later on that electromagnetic waves can be considered to be a superposition of different harmonic oscillators. So, the problem of electromagnetic field will get reduced to a problem. In which the total energy of the electromagnetic field will look like it is a sum of the energy of a large number of independent harmonic oscillators.

Say how I how I how I quantize a problem, what do you mean by quantize I have I have a classical problem. What is the corresponding quantum equivalent of that problem. So, there must be some kind of a procedure there must be some way in which I can quantize. So, what I will do is I here I can I know how to analyze a harmonic oscillator problem. And when I show you that any system given to you the energy of that system looks like a harmonic oscillator problem. And the equations the equations satisfied by the problem given problem looks like a harmonic oscillator problem. Then I can actually use the same quantization that I am using in harmonic oscillator to go in to quantization of that system. So, I give you an example an lc circuit for example, an lc circuit is a harmonic oscillator there is nothing oscillate, but it looks like harmonic oscillator.

You know resonance frequency and you can write the total energy of the system. And the total energy of the system of an lc circuit. I will make it look like a harmonic oscillator problem. And once I have the solution for harmonic oscillator. I can quantize the lc circuit, which means the energy of the lc circuit cannot become 0 will be zero point energy will be fluctuations. We will calculate and I will show you that this quantization is so, fine that it is almost impossible for you have to see. Unless you make an lc circuit which is almost a quantum lc circuit.

I am sure with with nanotechnology with etcetera. It is possible to make devices, which look like quantum lc circuits. So, I am sure you done harmonic oscillator problem in detail, but what I will do today is quickly review. And recall some of the basic concepts in harmonic oscillator. So, what is the total energy of harmonic oscillator can you tell me, which (( )) write as H. Now, this is a classical what is the total energy for harmonic oscillator kinetic energy plus potential energy. So, what is the kinetic energy sorry p square by 2 m plus half k x square in terms of frequency can you tell me.

(( ))

m omega square x square that is a kinetic energy and that is a potential energy. p is m v m d x by d t. I am writing in it in a form, which contains the position and momentum and this is called H is called the Hamiltonian (no audio from16:00 to 16:09). This comes from whose name Hamilton. He worked for ten years in developing what is called as Hamiltonian theory of optics. The entire optics field developed with a harmonic with a Hamiltonian, Lagrangian everything and then he shifted into mechanics. So, he has a lot of research in the area of optics it is called Hamiltonian optics.

It is a very strong field in which you actually compared to Newton's equations. This formulation is much more general the Hamiltonian formulation very general. And he also worked on what is called as quaternions. And which he actually considered as his greatest contribution not all this. You may go you may go and look at what is what are quaternions and ah he has done a tremendous amount of work in that area. Now, so please note that this is written in terms of position and momentum. And not in terms of velocity and position, because in the Hamiltonian formulation. You have to write the total energy in terms of a coordinate and a coordinate conjugate with that x and p are conjugate variables.

So, if you go back to classical mechanics, and look at the Lagrangian formulation and the Hamiltonian formulation. You will see that you define a Lagrangian from the have you done Lagrangian mechanics in classical mechanics. So, you write you write a Lagrangian and then you defines the action principle on least action then define the Hamiltonian and then get Hamiltonian equations of motion. So, it is not velocity, but in terms of p. So, what I do is for going to the quantum formulation. I write all this as operators. So, H is p square by 2 m plus half m omega square x square this caps represent no operators.

H is a Hamiltonian operator, p is the momentum operator, x is the position operator in the Schrodinger representation. You would replace p cap p operator by what minus i h cross del by del x for a one dimensional situation. And then substitute into the Schrodinger equation and solve the equation, but I I think you have done a Dirac bracket formulation of harmonic oscillator. So, I will just reproduce that without going to the Schrodinger picture formulation. Now, what is the meaning of quantization from here. Just by representing by operator I have not quantized I must do something what else do I.

Yes commutation relation between what and what. So, I must introduce this fact that x p is equal to i h cross this is the commutation relation. And this commutator bracket comes from the equivalent (( )) bracket in classical mechanics. So, you replace the (( )) bracket by the equivalent commutator bracket and that is the quantization. If h bar is 0 then x and p commute and these are two variables, which then become to be able to measure simultaneously. So, as I said earlier if the commutator are two operators if they commutator as 0; that means, both the observables corresponding to those two operators can be measured simultaneously precisely.

Please note that can I can always measure one of the variables very precisely at the cost of an infinite in precision in the other variable. So, this is the so, this is the quantization condition, which I impose on this and I then to solve the problem. So, what is the so, what I want to do is I want to calculate next problem is I want to calculate the eigen values of the energy operator. That is what are the allowed energy values of this system, which is represented by Hamiltonian like this. And in which x and p satisfy this commutation relation. So, I will just give you a couple of steps intermediate steps and then let you recall the discussions.

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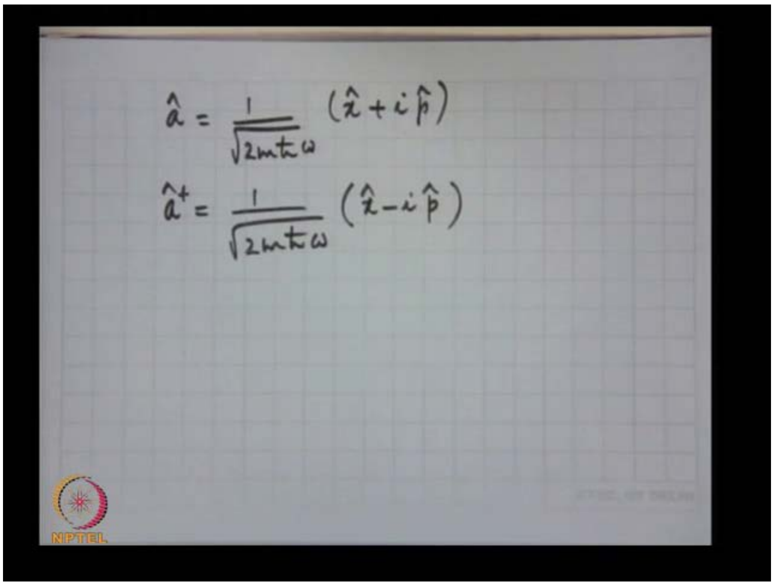

So, to do this what we do is we introduce two operators 1 by square root of 2 m h cross omega x plus i p and the corresponding dagger operator is 1 by 2 m h bar omega into what why not x dagger

Why not x dagger minus i p dagger. yes because it is an observable x and p are observables. So, they are Hermitian operators. So, x dagger is equal to x e dagger is equal to p is a an observable is the is the quantity corresponding to this a an observable.

(( ))

My definition I I quantize a a problem by defining. I first represent the observable operators - Hermition operators. In fact, all quantities get represented by operators time is still an operator. Then I this condition is my quantization condition. The way I I say that my now my problem become quantum mechanical is to say that this operators, which are conjugate operators satisfy this commutation relation. This harmonic oscillator so, this problem I write because the corresponding Lagrangian equation and Hamilton equation when I go back I will define a poisson bracket between x and p and that is come to.

Whenever we include the Heisenberg uncertainty with 1 (( ))

Yeah this is this tells me this this will give me the fact that delta x delta p is h cross by 2 this and your Heisenberg uncertainty principle are the same. The fact that x and p do not commute can be used to calculate, what is delta x and delta p. That will come out to be that will depend on this number, which is sitting on right hand side and delta x delta p will be h cross by 2 from here. So, but by telling delta x delta p h cross by 2 how do I quantize. I am not able to find the eigen values I have to find the eigen value I have to find out how the system evolve with time etcetera etcetera

So, in this problem my quantization essentially implies that x p communicator is now i h cross, because the corresponding x p poisson bracket was how much do you remember the poisson bracket (( )) poisson bracket how do you define the Poisson bracket. (no audio from 23:16 to 23.20) Poisson bracket between two quantities you have done a classical mechanics right.

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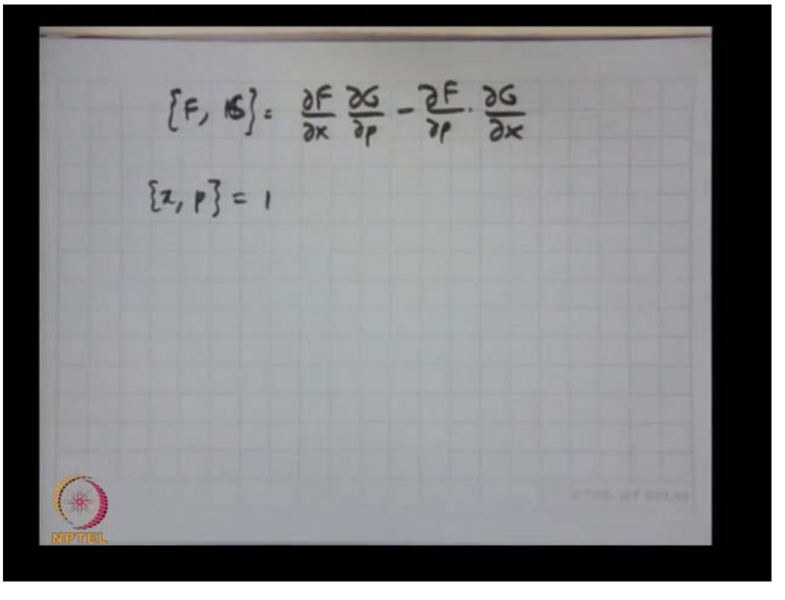

f h F G for example, two functions del F by del x del G by del p minus del F by del p del g by del x that is a poisson bracket. So, what is poisson bracket between x and p. (no audio from 23:45 to23:52). This is the two any two variables F as a function of x p G as a function of x p. So, that is the poisson bracket and that comes, when you actually derive the equations in the Hamiltonian formulation. yes what is the value of x p poisson bracket 1 this is one this is 0 and quantization essentially replaces the poisson bracket by corresponding commutator bracket. If this was 0 the commutator bracket is also 0. So, this is the way Dirac introduced quantization into the picture. I replace observables by operators and I replace the poisson bracket by the commutator bracket which of course, an (( ))

So, you have to go back and read Dirac to get a little more clearer picture in terms of, what is the meaning of quantization and what this is for harmonic oscillator we are discussing. So, if you have given some other problem (( )) quantize the problem. If the problem reduces to an equivalent harmonic oscillator. I have no problem, because I know how to quantize harmonic oscillator it is not necessary.

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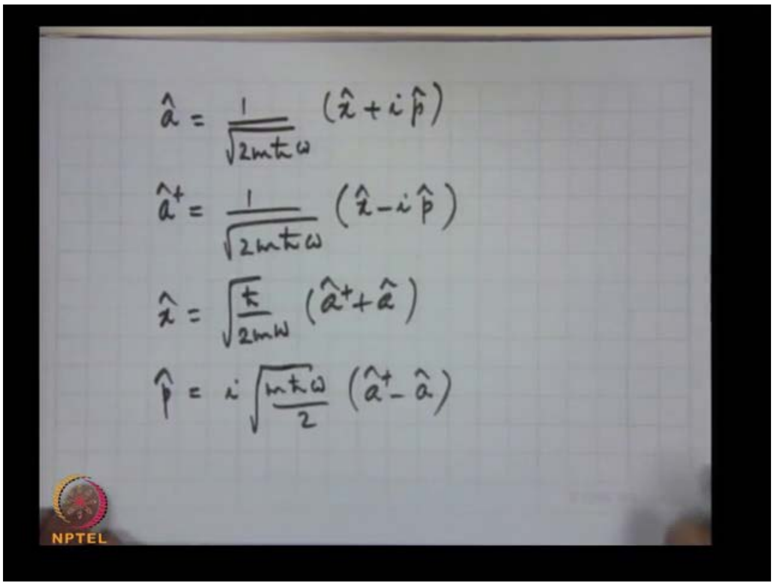

So, is is the is the is is a Hermitian operator why do you say no

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A dagger is not equal to a. So, a is not a Hermitian operator. So, a is not an observable. Anything that corresponds to a and a dagger are not observables because a is not a Hermitian operator. So, actually you can invert these two equations and write x cap is equal to under root h cross by 2 m omega a dagger plus a and p is equal to i times under root m h cross omega by 2 into a dagger minus a. You can invert these two equations to get x cap x and p in terms of a and a dagger. Now, so let me do one or two steps and then I will leave the remaining steps to you.

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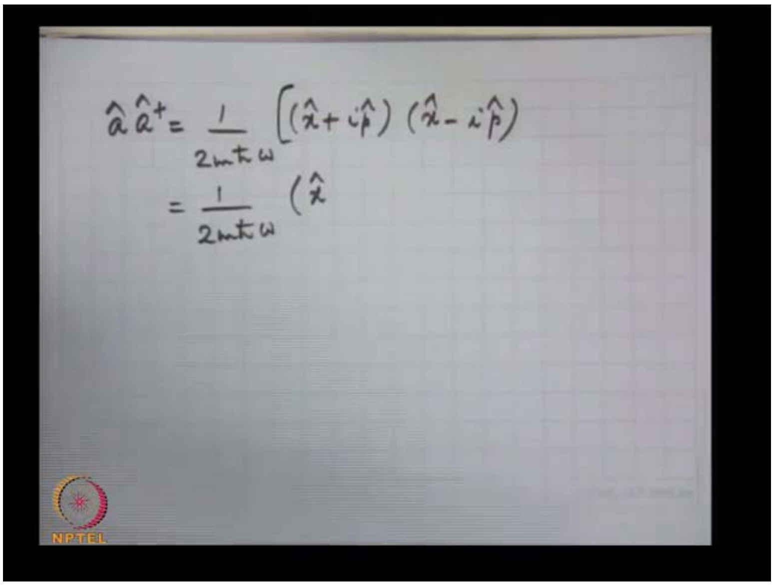

So, let me calculate a dagger. So, a into a dagger I multiply these two, but because these are operators. I need to be careful in keeping them in the right order. So, if I made product may take a product of these two. I will get 1 by 2 m h cross omega into x plus i p into x minus i p. So, this is equal to 1 by 2 m h cross omega sorry. Let me calculate what is the what is the Hamiltonian this is this is this quantity p square by 2 m plus half m omega square x square. So, I substitute x and p into this from these equations use the fact that let me let me start again ah

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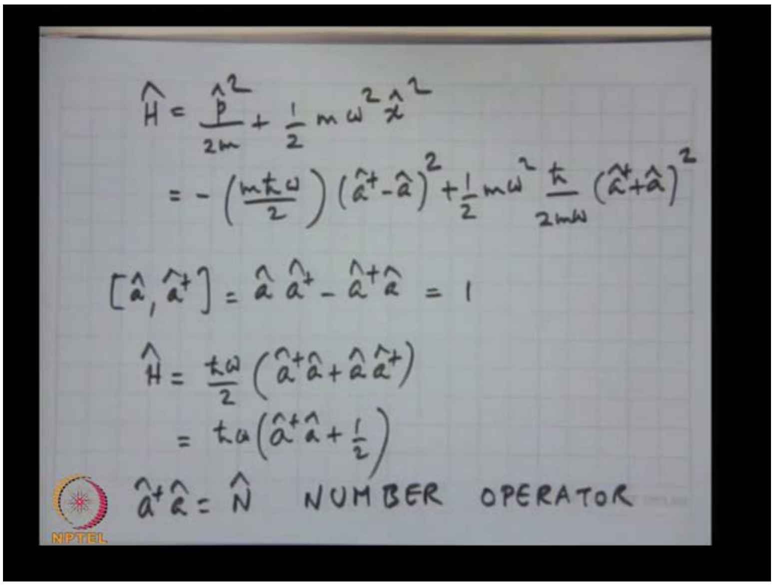

So, H is equal to p square by 2 m plus half m omega square x square. So, this is equal to so, I substitute for x and p. So, minus m h cross omega by 2 into a dagger minus a whole square plus half m omega square into h cross by 2 m omega into a dagger plus a whole square.

Sir will you just go back once

This one

Yes is not x operator (( )) we just add these two equations should not it be

If I add which two equations sorry sorry oh sorry yeah yeah you are right yeah sorry I am sorry thank you.m omega x plus i p. (no audio from 28:21 to 28:29). So, what I do is. So, to calculate this when I expand this I need to keep the fact that a and a dagger may not commute. So, to calculate whether a and a dagger commute I need to calculate this. So, a a dagger minus a dagger a. Now, you can substitute the expressions for a and a dagger given here into this equation. Use the commutation relation between x and p and show this is equal to do you remembered 1. So, a a dagger minus a dagger a is equal to 1.

So, you have to substitute expressions for a and a dagger from here into this equation remember that x and p do not commute. So, x into p is not equal to p into x use this commutation relation between x and p. And simplify to get a a dagger commutator is equal to 1. So, this is just a recall of your analysis that you have done. And then I use this in simplifying this equation, because now I have a dagger a a a dagger etcetera coming here. And I leave it to you to show that H operator is h cross omega by 2 a dagger a plus a a dagger or if I use this commutation relation this is h cross omega into a dagger a plus half. (no audio from 30:20 to30:33)

I use the commutation between x and p and the definition of a and a dagger to show the commutator a a dagger is equal to 1. Once I know this I can use these commutation relation in this equation. And I simplify and and I can calculate that the Hamiltonian operator is actually h cross omega a dagger a plus half. Now, this quantity a dagger a is given a special name this is the number operator, because as you will see this is related to the state of excitation of the harmonic oscillator. How many quanta of of x station are present in the harmonic oscillator. (no audio from 31:19 to 31:27)

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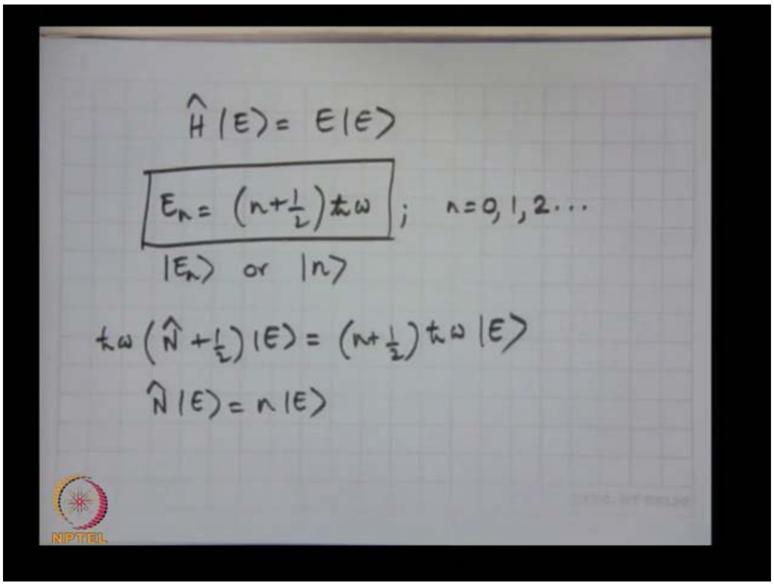

Now, there is a bit of procedure that is involved in. So, what you (( )) to solve this equation remember I defined an eigen value equation. This is an eigen value equation to calculate the eigen values of the Hamiltonian operator, which I am call which I am calling E and the eigen ket ket E such an equation is called an eigen value equation. E corresponds to the eigen values and this corresponds to the eigen vectors or eigen kets. So, I do not want to go through the algebra now. So, I will ask you to go back and refer to your quantum mechanics. Notes that you must have done before and so, that the energy eigen values are given by e n is equal to n plus half.

And we represent the corresponding eigen states as e n or simply n ket, where n ket corresponds to energy e n is equal to n plus half h cross omega. Now, if you substitute for H for example, if I write this equation tells me that h cross omega into N plus half E is equal to N plus half h cross omega into E. So, this implies that N E is equal to n E. So, this N operator is called the number operator it tells me the value of n when I operate with N operator on the on the ket.

I will get if is an eigen if is an eigen state I will get the number the number of quanta in that state. So, n so, here this equation tells me essentially that the energy of the harmonic oscillator is quantized. It also tells me that I can never have a situation, where energy is equal to 0 because the lowest state is half h cross omega. The lowest energy that you can have is half h cross omega and that is called the zero point energy. Why is that a zero point energy, because (( )) you cannot have a situation if the particle comes to complete rest.

You know x is equal to 0 and p is equal to zero, which means you know precisely the value of x and p and that is not consistent with the (( )) principle. So, the particle can never come to rest. (no audio from 34:28 to 34:34). So, n values are integers. So, you can have half h cross omega 3 by 2 h cross omega phi by 2 h cross omega etcetera. So, every time you have you can only increase or decrease the energy by h cross omega.

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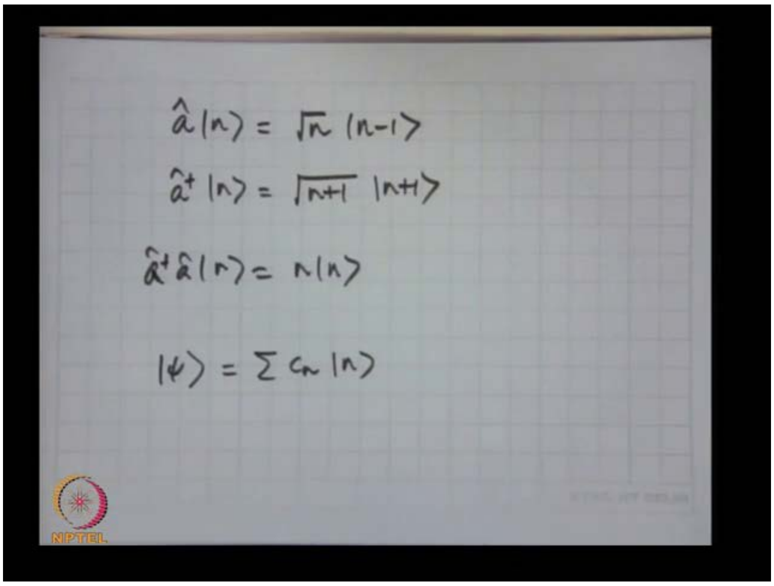

Now this a how much is this do you remember.

Root n

Root n

n minus 1

n minus 1 and a dagger n is equal to

(( ))

(no audio from 35:11 to 35:21) When you actually derive this equation you can work out all this analysis. So, I would (( )) those of you who have not actually solved the problem in this notation to go back and pick up a book on quantum mechanics, which uses the bracket notation to analyze this problem. Because these are some fundamental equations that you will keep using and needing as we go through the through the course. So, the operator a although it is not a Hermitian operator seems to bring the state from a state with n with e n to e n minus 1; that means, it is called an (( )) operator or destruction operator because if you start with a state having an energy n plus half h cross omega.

When you operate on the state with a the state jumps into another state with n minus half h I mean n gets replaced by n minus 1. So; that means, you have removed one energy h cross omega from the system. So, this has energy n plus half h cross omega this has energy n minus 1 into half n minus 1 plus half h cross omega. So, this called the destruction operator or the (( )) operator a and this is called the creation operator. Because it takes a state of n ket to n plus 1 ket the energy of the at the end of the operation has h cross omega more than what you started with. And as we have seen a dagger a this is consistent with the fact this is n times n. (no audio from 37:00 to 37:07)

So, these are the eigen states eigen kets corresponding to the energy operator. These are the different energy levels that the system can occupy. I could have calculated the eigen value equation corresponding to some other operator also. Now, because this because this eigen value equation this n ket form a complete set of functions complete set of kets, which means if you are given a harmonic oscillator. You can always represent it as a super position of the n ket states.

So, any state of the harmonic oscillator this harmonic oscillator can be written as sigma c n n the n kets form a complete set of functions complete set of kets. So, any state of the harmonic oscillator can be written as a superposition of n kets. Yeah it is in a super position of different energy states. And c n you can calculate by by multiplying bra n and calculating the values of c n.

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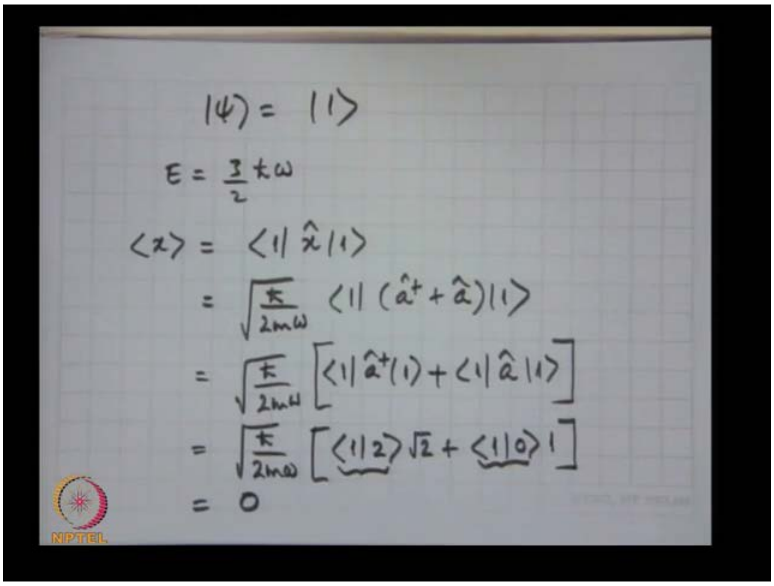

So, now let me take an example suppose I take a harmonic oscillator in the state. So, this means this has an energy E is equal to 3 by 2 h cross omega. (no audio from 38:37 to 38:41). Now, I want you to calculate expectation value of x; that means, I have a large number of harmonic oscillators all created in the one ket state. I measure the position in each one of them and take an average. So, if you look at this expression for. So, this will be essentially 1 x cap 1 and x cap is nothing, but h cross by 2 m omega into a dagger plus a 1, which is equal to square root of h cross by 2 m omega 1 a dagger 1 plus 1 a 1 ,which is equal to square root of h cross by 2 m omega 1 a dagger on 1 is root 2 times 2 plus a on 1 is 1 into 0 1 into ket 0 what are the values of these these are 0 because different eigen kets are orthogonal. So, this is equal to 0.

So, does not mean the oscillator is at the origin. (( )). It means that you will in your measurements you will get as many positive values of x as negative values of x. You have no way of finding out, what is the position of the oscillator as it oscillates. What is actually happening is you have chosen a ket, which is an energy eigen ket, which means you have chosen a state in which the energy is perfectly defined. Because the energy what is the energy of this state 3 by 2 h cross omega. There is no uncertainty complete certainty in energy.

And when you are in this state you have no knowledge of the phase of the oscillator, whether it is right the left where the center we have no idea completely. This complete uncertainty in a corresponding conjugate variable, which happens to be the phase here. So, this is the state where you know. So, please remember this does not correspond to my harmonic oscillator, when I look at a situation where the for example, if I have a mass spring system and this mass is oscillating as a as a harmonic oscillator. This cannot represent it because I know that when I observe the center of mass is moving like this.

So, center of mass the expectation value of x should have varied as some amplitude into cos omega t or sin omega t this is not happening. So, this does not represent a classical harmonic oscillator, which i c has oscillating, what happens if I take a ket like this.

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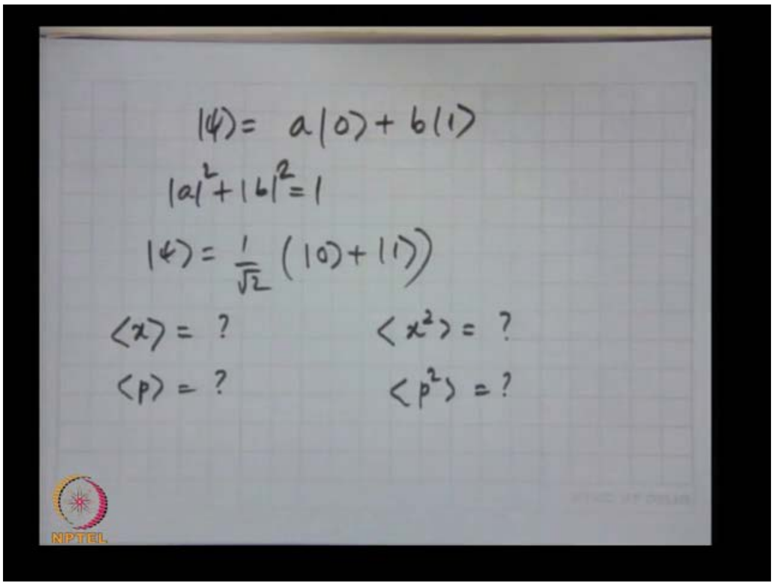

Now, let me take say 0 plus what is the condition on a and b mod a square plus a and b can be complex. So, let me take a state, which is 1 by root 2 can you calculate the expectation value of x. (no audio from 42:26 to 42:32). I leave it this I think this I leave it this problem please calculate the expectation value of x of this of this harmonic oscillator in this state. And you will find that it is not 0, because x cap x operator contains a and a dagger this if this state contains a superposition of two neighboring n value states. Then you will get a finite expectation value of x. If I take 0 and 2 expectation value of x will become 0 again, because there is an operator a because you have operator sitting here.

And if this has to be finite a dagger or a should have changed this number by 1 either increased or decreased by 1 and with a corresponding bra on the other side. So, this will have a finite expectation value. So, I leave this problem to you to calculate both this and this. And I want you to calculate the following please calculate x square average, and p square average. So, the classical harmonic oscillator that you describe as a x is equal to x naught cos omega t is not represented by one the energy eigen kets. It is a superposition state and it is a state called the coherent state. And we will discuss this in, when we come to the electromagnetic fields. Because the light coming out of from a laser is in a coherent state and so, when we discuss that we will things will become clarified yeah any questions

Sir (( )) single state presented present classical oscillator.

Yeah because expectation value of this x is 0, but if I were to give you a classical harmonic oscillator where I see a particle moving back and forth there is a correspondence principle remember. So, if I in a limit a quantum quantum mechanical ah conclusion should should satisfy the classical principle. So, finally, if I see the particle executing a simple harmonic motion in quantum mechanics. I should see the expectation value of the position should execute a simple harmonic motion. Because how will I describe the classical harmonic oscillator, which I see moving back and forth by quantum mechanical arguments. So, I will have this operation and finally, I will have to make out that because I know when I observe I see the particle doing this.

So, I should get from my analysis the expectation value of the position should move like this exactly like a classical oscillator. Have you studied (( )) theorem go back and read (( )) theorem. The expectation values of x and p will satisfy the classical equations of motion. So, if the classical equation of motion for x is x naught cos omega t. The expectation value of x should have been x naught cos omega t. And that is not present here, if you take any eigen state any of the energy eigen states it does not satisfied

Sir even in the superposition also it could not satisfy, because the superposition also we get a definite state.

No this is this is 1 superposition I can have I will have some some superposition state.

That would give me a definite value of the expectation value.

Expectation value is always definite.

But, as you said that in the classical harmonic oscillator, it should go back

Yeah, but this expectation value can be function of time? This is what? This this 1which I have to find out. What is x average in this in this state? You will find it is a function of time, because x contains no no no we have not discussed the time variation and all yeah yeah sorry sorry ,we have not discussed this time, I will I will bring that next time I will bring it next time, yeah because this is only at t is equal to 0 you are calculating.

This is

Yeah

One stationary state.

Yes yes no not stationary. I will come back to it I have to I have to write write down the time dependence of the states, which I will obtain by solving the Schrodinger equation.

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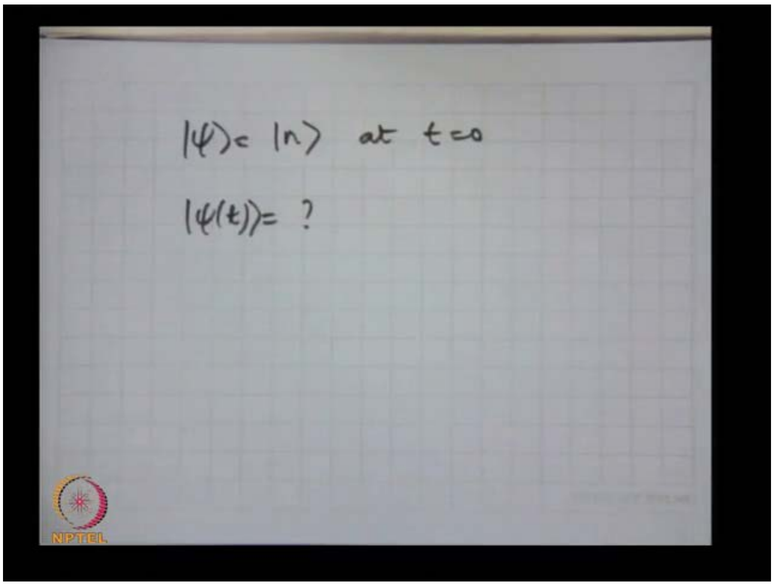

How will how will this state vary with time? Suppose, I have a state psi (no audio from 46:48 to 46:53) so, what is psi of t? Have you done this? What is it?

(( ))

Please go back and look

E to the power I e h e by h

Yeah. So, I will, anyway, I will bring that next time, and yeah this you have to introduce the time dependent, because this is at only at the initial time, and these states evolve with time both this we will stop here

(( )) the operator in to ket 0

Yeah.

That should

0.

Did not (( )).

No, because.

They can (( )).

There can be no negative energy. In fact, that is used in deriving this expression for the energy eigen values of n plus of h cross omega. So, a into 0 ket is 0 that is also apparent from this formula a into n ket is equal to square root of n into n minus 1. So, square root of n is 0 there. So, which have become 0.