Implementation Aspects of Quantum Computing

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Lecture - 21
Optical Implementation

We have been looking at various implementation aspects of quantum computing. We had looked at NMR to start with in detail. Next we will start looking at the optical approaches. So, in the first part of the optical approaches after we finish the basics of the tools that are used in optical approaches, we looked at the case where we were looking at linear approaches to quantum computing using optics.

Now in this particular week we will be looking at the other kinds of optical approaches which are invoked, and in order to do that let us start by looking at some of the interesting problems that have been looked at in this area.

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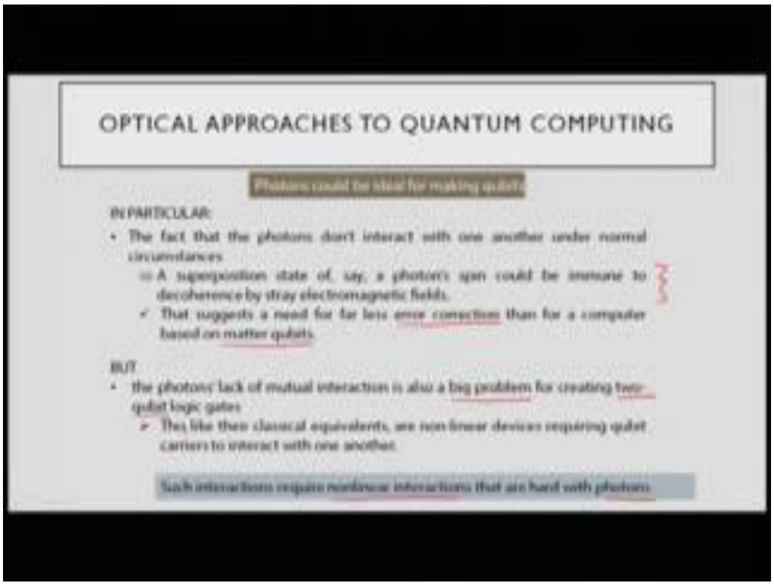

So, this week which is our week 7, the first lecture would focus on optical approaches other than the linear approaches to quantum information and quantum computing. So, QI QC is often a common nomenclature which is used. So, the full form is Quantum

Information and Quantum Computing. See the optical approaches to quantum computing we have been discussing in which where we have stated that photons often are essentially ideal for making qubits, because they can be transmitted most easily that is what was talked about when we were looking at teleportation for instance.

So, in particular the fact that the photons do not interact with one another under normal circumstances also has a very important consequence, which means that a superposition state of say a photon spin could be immune to decoherence by stray electromagnetic fields.

This addresses one of the very important aspects of quantum processing that we have been facing which is that, we have to worry far less about error correction then a computer based on matter qubits. Matter qubits are like qubits where we had like taken states of the matter and spins other kinds of properties and there because of strong interactions, we have to worry a lot about the error corrections and decoherences other kinds of things. However, this advantage which we have with photons, that is in known interaction character also creates a problem. The photon lack of mutual interaction is a big problem for creating 2 qubit logic gates 2 or multiple. This like their classical equivalence is non-linear devices requiring qubit carriers to interact with one another.

So, the lack of interaction is creating a problem because in order to create multiple qubits to interact, there has to be an interaction and this interaction process is sort of missing when we talk about photons. So, most of these interactions that we talk about require non-linear interactions that are hard to do with photons.

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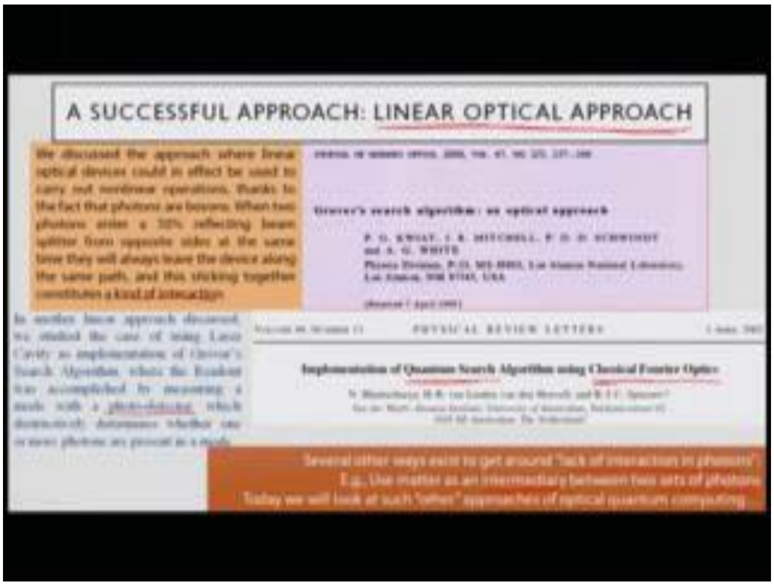

In the last week what we did was we looked at the linear optical approaches which is been a quite a bit of a success. We in particular talked about 2 specific cases; one based on the idea that we spent a lot of time on lasers. So, that one is on the principle of implementation of quantum search algorithm using classical Fourier optics using the concept of laser. And the other one which is also very popular is the idea of using linear elements, such as using 50 50 beam splitter where the photons entering from either side of the 50 percent reflecting beam splitter, at the same time would leap the device along the same path which is due to their bozonic nature and this ticking together constitutes a kind of interaction which is how they take advantage of this interaction to enable, even the linear optical approaches to work in such a way which can take advantage and allow us to implement non-linear interactions.

So, these 2 interactions that are we talked about essentially used the principles of the laser as well as principle of light interaction photon interaction being bozonic of nature. In particular one point also remember is that, when we do the final point of these studies for instance in the laser based approach the final read out was accomplished by measuring the mode the laser mode with the photo detector, the laser mode actually in this case if you actually remember from last week was the embedded data that we had for doing the processing, and so the readout process which was accomplished by measuring with the photo detector, destructively determined whether one or more photons were present in the mode and some based on the studies we eventually led to the concept implementation of quantum search.

There have been several other ways to get around the lack of interaction in photons, for example use matter as intermediary between 2 sets of photons. This is another approach which was popular since the 1990 however; this has added difficulties in terms of scaling up. These linear approach is also suffer from the scaling up issues because as we discussed in the last week. They scale in the linear way in terms of the resources and therefore, it becomes very bulky and large in these linear approaches. Similarly, in terms of intermediary of using matter between 2 sets of photons and things like that also have certain difficulties associated with it.

So, today we will look at some other or approaches of optical quantum computing and may be some sort of intermediary or some sort of other interactions of photons with matter which might be of use to advancing the quantum computing aspects.

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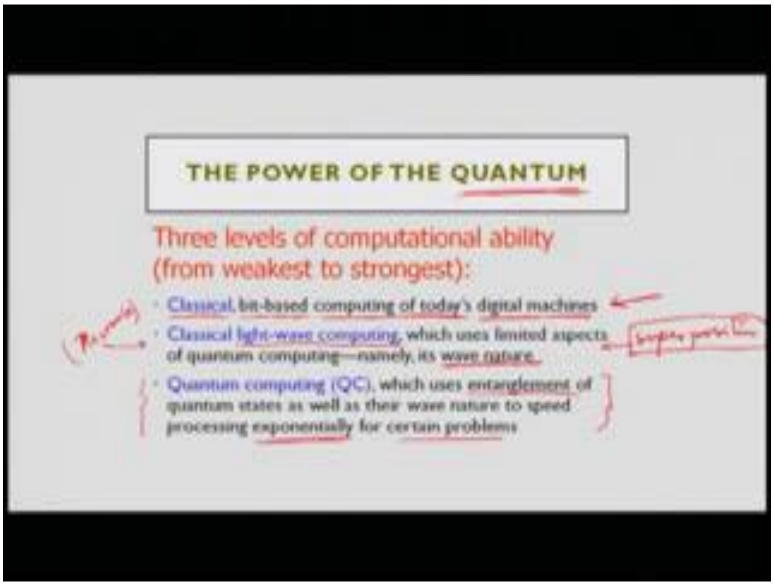

So, before getting there let me actually point out a few interesting aspects that we have dealt with over the last few weeks in terms of implementation. We have sort of realize that because of the way of the complexity of the problem in essential exist, there are different levels of how we can take the advantage of the quantum part of the problem in this case, there is some sense you can essentially discuss it in terms of 3 levels of computational ability from weakest to strongest.

The first one which is all optical can be done, which is an essentially a classical option. It is a bit based computing and this is essentially relying on digital concepts that we use today. The optical analog of this uses bits in terms of sending and discussing or transmitting data in terms of information and so all information that is encoded in fiber optic transmission for example, are still utilized, but this is ultimately classical where everything is based on the bits, highs and lows that we use today in terms of digital machines. We are highly familiar with this; In fact the computer that I am currently using also uses the same concept. So, and the information transfer process is done by fiber optics, where it is all based on the principle that we are doing classically.

Now, the second level of discussion that we have done while doing this optical approaches to quantum computing has often utilized light wave computing in some sense. So, it utilizes mostly superposition principles of a classical wave and it can be sort of like an analog level to some level and so it uses it is wave nature, but it does not really explore the entanglement part of quantum systems, which is critical in terms of giving it is maximal advantage. So, this is somewhere in the middle where a lot of success has been shown and many people and many of the efforts currently are quite happy with this kind of in between approach. The difficulty in this particular approach as of now lies in the process or lies in the resource, the scaling of the resources here can be very large in order to solve big problems.

So, although this is advantageous than the present classical computing and the resources required here are less than that required for a classical computation, but it still might not be as good as what we are looking for when we are talking about complete quantum computing, where the entanglement of the quantum states are also used in addition to their wave nature. And so there we can definitely get the exponential benefit of quantum computing for certain problems obviously.

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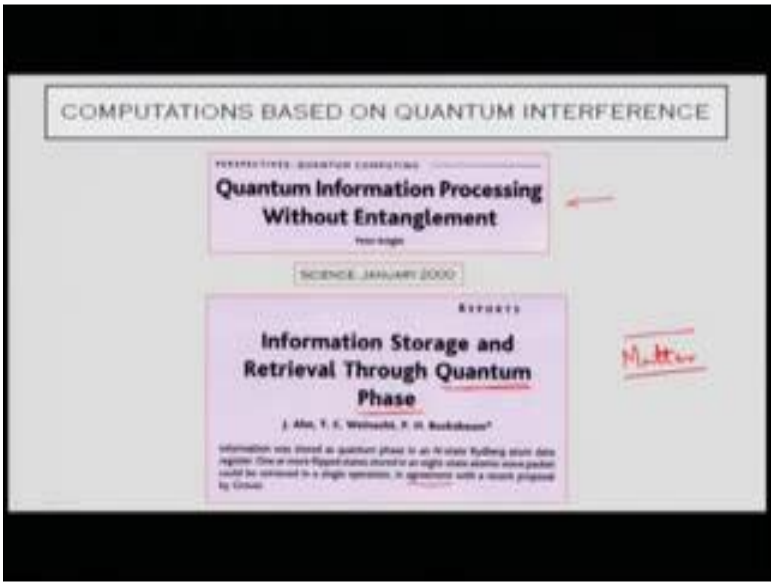

So, with this let us now see what are the other aspects which have been looked at, in terms of computations based on quantum interference there has been one more effort which I did not discussed last week, which is based on quantum information processing again once again without entanglement and this was presented in the year 2000 where the information storage and retrieval was done through quantum phase by using a atomic system. So, it sort of matter intermediate was used in this particular case, where the interaction with lighten matter in which the matter inter mediatory was used for quantum processing.

Now, in this case the phase, the quantum phase of the system was utilized get to the information content and it was shown that say for n state Rydberg atom data register, it was possible to get information and searching done in agreement with the Grover's algorithm.

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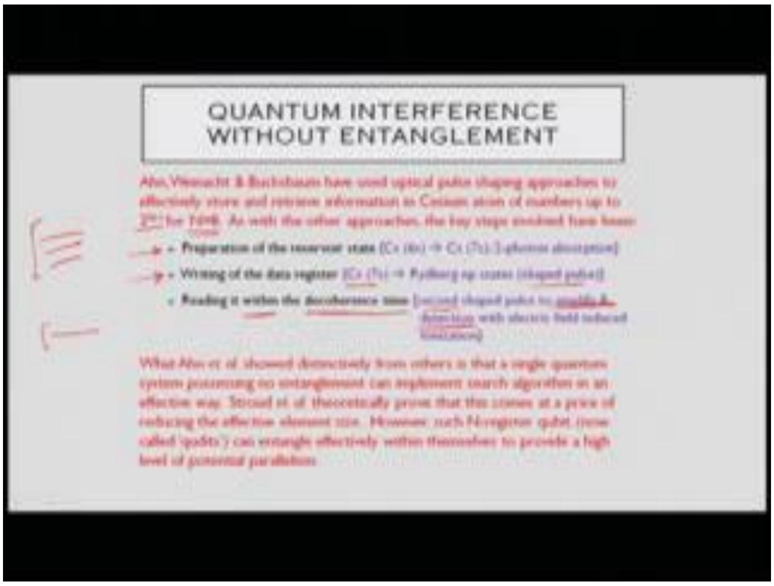

So in their particular work by Bucksburn and his group, they used this optical pulse shaping approaches which are described in a moment to effectively store and retrieve information in cesium atom of numbers up to 2 to the power n minus 1, and they could do only for n equal to 8 up to this number.

So, the key steps in this particular process has been similar to what has been for almost all other implementation processes, preparation of the reservoir states in this case is the high excided state of the cesium atom, it is a 2 photon absorption it is not a single photon process. So, it is a in some sense difficult to achieve. So, once it is achieved the state generated would be much easier to keep it there. Then is the writing of the data register in that step, where the state is sort of stable to some level and that is being achieved by using the shape pulses. In some sense this shaping of the pulses will discuss here would be the encoding of the data in the optical sense and that is being now transferred into the mid matter system.

In some sense of a quantum system and then reading it out within the decoherence time now the key element has been here the decoherence time of the system, which sort of a should be able to read it and that was also achieved by using a second shape pulse to amplify and detect the electric field induced ionization. So what they were able to distinctively show from the other similar approaches, at that time is that a single quantum system possessing no entanglement, because what happened was it was basically using one single atomic state, what atomic system with different state. So, what you could only do or achieve in these kinds of states as we will discuss in the next slide; is basically superposition's of a different states associated with their atom and there were no multiple atoms together which were working to create an entanglement system out here.

So, that way it was something which sort of was similar to the previous approaches of Wave approaches or Optical approaches or Linear approaches, where it was all done with superposition only and not with any entanglement. So, there has been similar as we discussed similar approaches earlier.

So, this sort of gives you familiarity, this is sort of similar in terms of the earlier approaches that we discussed last week of Wave quantum computing or Linear optical quantum computing. This is sort of similar to the earlier approaches of linear optical quantum computing, that we discussed last week and it also does not involve any entanglement as we discussed here.

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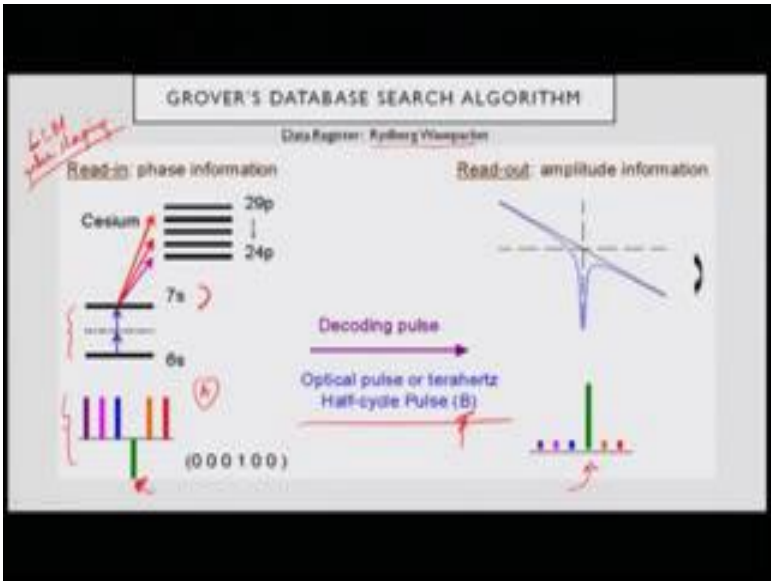

So, in a little bit of more detail this is exactly what happens here, there is this state which is generated is sort of met stable because of the way the interaction is needed for the state to be generated. This is a 2 photon interaction to produce that state and this particular state is therefore, not directly connected to the ground state that easily.

Once it is there the state has a encoding of this sort where the phase of one of the states is flipped with respect to the other. So, this is the read in of the phase information which is done to make sure that these states have been written properly. So, it is a Rydberg wave packet which is generated and that wave packet is then read out by another shape pulse, which would be able to ionize the system in such a way that the preferentially the state which exists or has the encoded phase is the one which will be amplified as a result this was optical pulse or terahertz half cycle pulse which was applied.

So, this is the initial pulse which read in the data a say and this was the other pulse which read out the data by using the ionization of the states which had this particular marked phase and in preference to the rest of them. So, generally the amplification happened and the Grover's algorithm search was being performed in this particular way.

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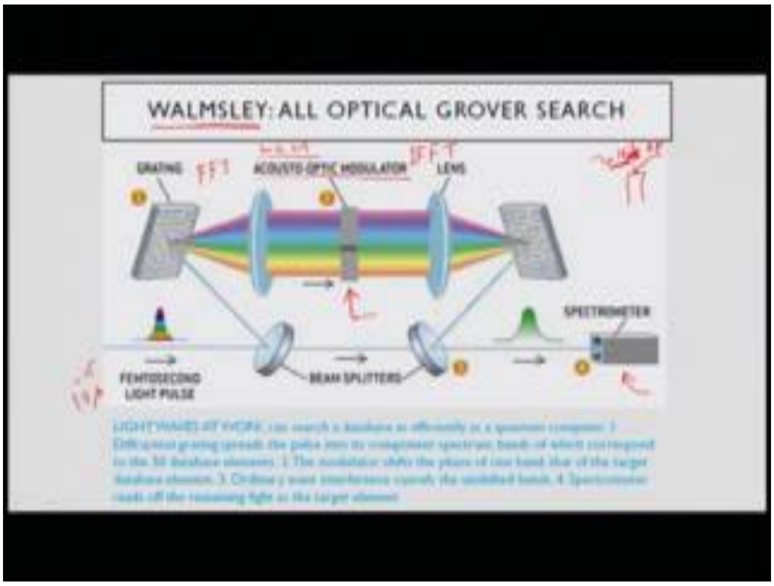

So, in this case the all optical Grover search essentially is based on similar approaches where earlier Walmsley has also discussed this actually about the same time on later. They used light wave modulation which is similar to and we have also developed in our lab here and I will discuss one of the techniques associated to this same idea. Where a very short pulse which goes through a Fourier transforming in the optical sense and once we are in the Fourier domain, there is a modulator in this particular case it is an Acoustic optic modulator.

The name of Acoustic optic modulator essentially means that it is a material device, which is being modulated by the use of radio frequency waves that is the acousto optic interaction, and it is like a little hammer working on the modulator and the hammer is being modulated with the radio frequency waves. And the radio frequency as we know is 10 to the power minus 6 micro second time scale and that is electronically much easy to modulate as compared to the timescales that we are talking about in terms of femto second timescale.

So, in terms of time the microsecond modulation is much easier to be achieved and that is why it is done in the Fourier domain, where the modulator is able to respond and produce interacting features which can then be preferentially allowed to go through or not, go through or provide a phase shift. So both phase and amplitude modulation is possible in this Fourier domain, which is then inverse Fourier domain. So, this is forward Fourier transform if you make and this is inwards Fourier transform which is happening because of the lens and the greeting pair.

Similarly, here it is a greeting lens pair and the end of it the input pulse is getting modulated, which can be read by using a spectrometer. So, this was also used by Walmsley, although this technique was originally generated and developed by us and I will get into that in a minute. So, these kinds of a light wave data was also used by the group, which we just discussed the Bucksburn group, where they instead of using amplitude modulation they used a phase modulation in one of the forms.

Now there are other ways of also doing this light modulation instead of you know acousto optic modulator, it could be a liquid crystal modulator; LCM. In this case the phase modulation is much more easily done in this particular case. And in the particular case of this experiment which was shown by Bucksburn, they used the LCM technique for doing the data encoding and that is why they preferentially did this whole work by using a phase concept, whereas in the acousto optic modulator scheme, both phase and amplitude can be modulated.

So, both these options have been used in different cases for showing that it can be utilized for doing fast data search in these cases, but as I mentioned that either way how we do it whether by using the light alone or by using; so this one is only using light. So, it is using superposition as we discussed earlier, this is similar to the linear optics except that we encode the data in Fourier domain and the other case is also a approach which is using the encoded data, but the encoded data is now been put on to the system concerned in this case it is an atom, which does the interaction and gives rise to the result. But the net result in all of these cases is the same, that it is essentially taking advantage of superposition. So, this is LCM based pulse shaping, but the advantage is they all can do pretty fast pulse shaping.

There are some (Refer Time: 20:24) and regard to the exact differences between LCM versus AOM, the AOM one is slightly better advantages in certain aspects versus the LCM ones, but the end of the day the principle is the same, that you go into the Fourier domain make the shape pulses and then you make them interact. And whether you do it call optically or by using a matter inters mediatory they essentially give rise to the same ideas.

So, these essentially reflect similar concepts as we have been discussing in the last week; however, it is important to realize that these connections are based on the principle that we are essentially doing mostly superposition principle work, rather than entanglement in most of them.

So, one other area where light can play an important role is also to look into the principle of decoherence, because there are most cases when these discussions are happened. The coherence part of the story is an issue which often goes away.

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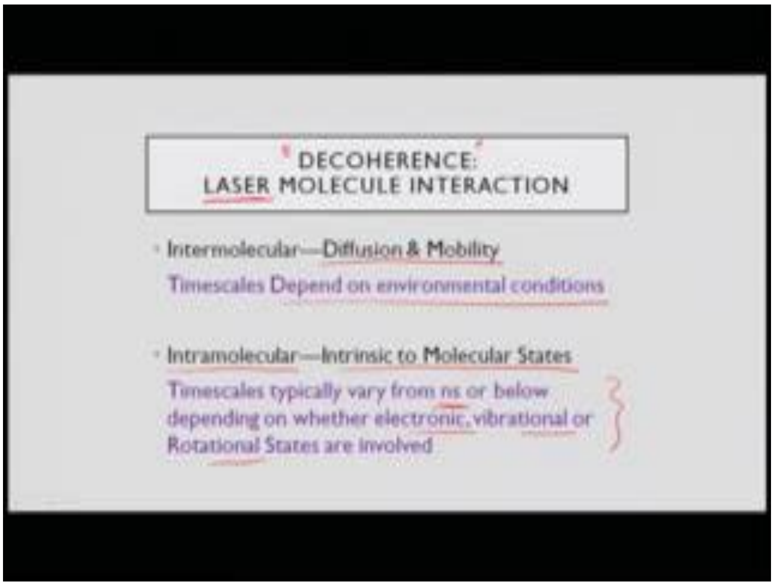

And similarly when we have a laser interact in some sense if we would really want to do a molecule interaction, which has a better chance of doing entanglement compared to an atom, because there are many parallel states and also when we have scalability issues molecular interactions can be better because it has richer number of states or in other words if you would like to have atoms coming together and interacting. Whatever way we look at it decoherence is an issue, which is important because it is the case where the information can be lost because of the coherence being lost in these cases.

So, in these cases the Decohence control is an issue which has to be important. In case of intermolecular cases it is something which can be controlled by using diffusion and mobility and the timescale depend on environmental conditions. So, this is something where decoherence can be controlled by this. So, in many cases by going into controlled environment like when the system is being separated out the molecules are separated vastly away from each other or the atoms are kept separately out from each other by large amount, this becomes an issue which can be easily looked at.

However, in most cases where you would like to see the information transfer interacting heavily which is one of the reasons why matter is in first place being used, that is you would like to have interactions to happen, so molecular states that way are very interesting because they have this intra molecular interactions which are intrinsic to molecular states. And these timescales typically vary from nanoseconds or below depending on whether they are electronic vibration or rotational states. And, so this decoherence can essentially wash way any kind of information processing that we would like to do with these kinds of systems.

So, bringing in matter with light interaction often creates this essential dilemma as to how this can be finally utilized for implementation. So, decoherence control happens to be a very important problem.

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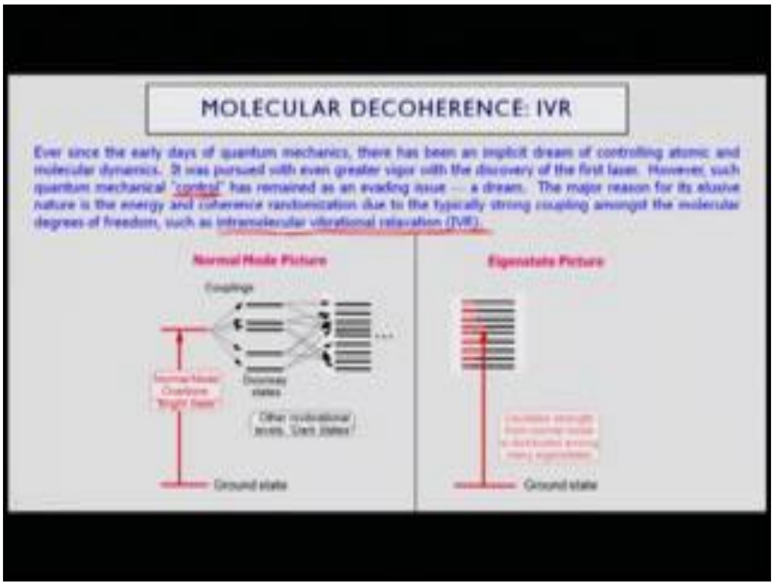

So, a model system in this particular case be always looked at in particular for the molecules in a way where, the picture is roughly equivalently stated in quantum mechanical sense and this is a parallel problem which has been looked at in many other areas of research, which basically states that if you have a specific excitation that is then connected to or can basically diphase away or decoher away from that particular excitation to other states, which are perhaps not optically connected, but still because of the way the construction is this is how they go away.

Then it can be equivalently looked at by either in this particular picture, where it is a normal mode picture where the state is connected to other states and so on so forth. Or in an equivalent Eigen state picture, where we diagonalize the matrix connected to this Hamiltonian, and as a result we get the oscillator strength being distributed over several states and so, whenever an interaction happens the energy is essentially distributed excitation is distributed to many states and sort of like the way packet picture.

So, irrespective of how the excitation occurs, there are many more states than a single state which gets populated and that is the picture which we known typically known as a wave packet. So, this has actually remained a big problem because this essentially has led to an area of control, where the control can be in terms of a any physical or chemical processes where which involves molecule to be looked at. And this has remained as invading issue as a problem which is sort of like the holy grail of many processes that have been looked at.

One of the simple pictures or the traditional pictures which has made a lot of impact in this area has been the idea of intra molecular Vibrational relaxation process. So, in most of these cases if these involve vibrational states what we are essentially looking at is, the states getting relaxed the moment they are being excited and as a result it is not possible to localize the energy and that is the randomization is an issue. And this is similar of a problem which is the big issue for quantum information processing using molecules or atoms even, because in case of atoms it is not exactly the same picture, but once the atoms are supposed to come together to interact and generate the information transfer in the way, which is missing in terms of photons not interacting the similar picture essentially works out.

So, either way we look at we have a problem looking at it which would be giving rise to a general area of understanding for this entire problem of how the coherence or the information embedded in the system can be contained to a long enough time so that it can be processed. So, that is the basic problem here.

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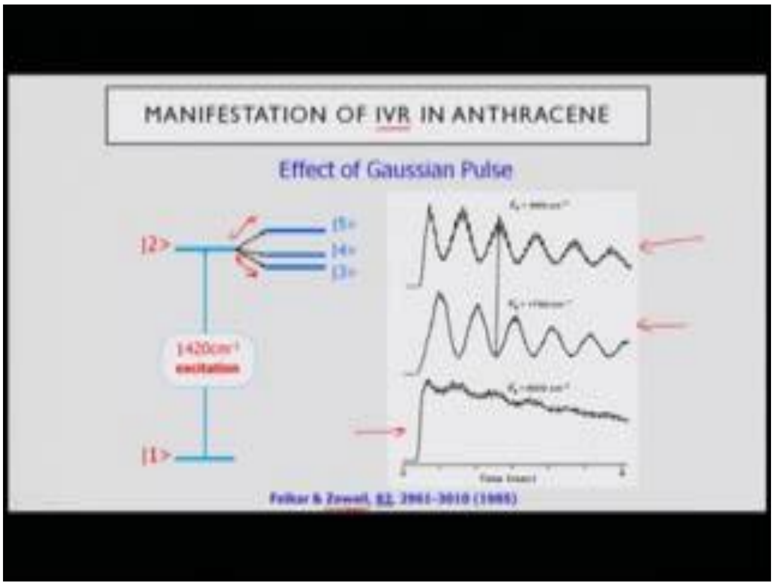

And we would like to present from the work which was based on some of the very famous initial work of Felkar and Zewail and many others in that region, but Zewail's work is in some sense very important because he was one of the pioneers of this particular process of seeing how things happen in real time and he had coined the term femtochemistry, in terms of looking at very fast processes and how they disappear and things like that.

So, he was able to also show that, in many cases although we often always expect the energy to just go away once we excide. There are cases where in the same molecule under certain particular experimental conditions, it is possible to see a recurrences of the state occur essentially showing as if it is not just a one way transfer, but the connection is in both ways, which by the way when we look at it quantum mechanical and we set up our Hamiltonian, this is what we are doing we are basically stating that these are double line arrows rather than single line. And so there is always a possibility of whatever is lost out here should be coming back. But in reality often the states are either so many or statistically connected to so many conditions, that this is not possible to see these kinds of recurrences.

But he had done some of these interesting experiments, where he was able to isolate the molecules to some level inside the conditions of gas phase conditions where recurrences could be seen within states. In modern day variations of these we have also seen situations where due to solvent sheets and solvent being around in certain objects and liquids, it is has been possible in liquid state studies also that energy or these kinds of processes can be looked at as situations where recurrences or these kinds of oscillating back and forth to the states concerned are occurring.

So, that way speaking this is a universally interesting problem which keeps on happening. And as I mentioned earlier this is an intermolecular Vibrational relaxation when you are looking exactly at vibrational states. So, the energy also corresponds to the vibrational energy. Just a interlude typically spectroscopes or those who are associated with these often talk in terms of wave numbers or electron volts because energy considerations in terms of these numbers are much better than considering something as wave length because, the connection to wave number is direct, so the energy is directly proportional to the wave number and so on so forth.

That is why it is a better concept rather than; so frequency, electron volts, and wave numbers are all the more popular energy units which are used for these kinds of cases.

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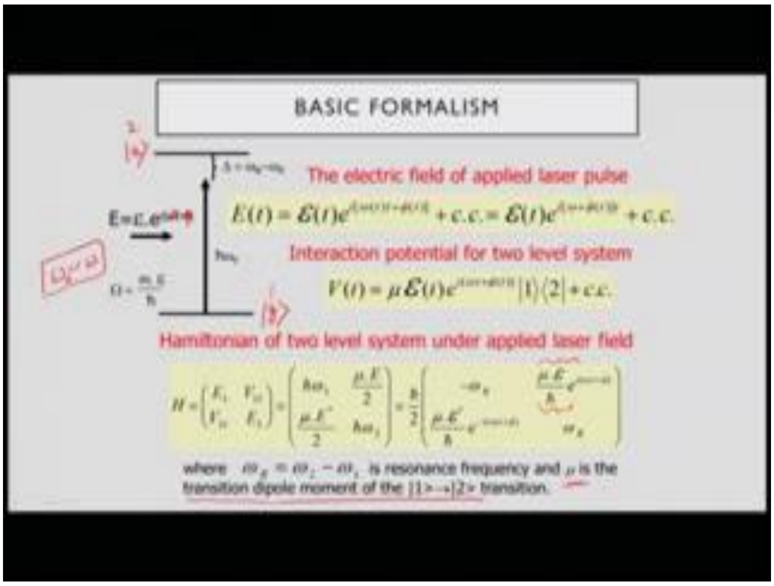

So, the basic formalism I think I might have actually discussed this earlier in one of the basic classes, but just in this connection let me actually point out to you what is happening here, we have in the simplest possible case of only just 2 states where we have one which is the ground state and another one which is just say the excited state, we have these conditions where the applied field has some kind of a frequency which is close enough to make this transition work, this is omega. So, they applied the electric field has a right kind of frequency that will allow this transition to occur.

And when these frequencies are close enough, so essentially omega 0 which is proportional energy of the gap, is close to the applied field radiation, then this transition will happen and that is the point where this is being looked at as the resonance and all that. So this can be looked at in terms of the field interaction and in the dipolar limit, the interaction potential of these 2 level systems can be simply written in these cases. So, I think in this case 1 is g and 2 is e; that is how they have been labeled. And for the simple 2 level system under applied field the Hamiltonian is essentially not just the energies of the 2 states along with the coupling terms, and in these cases the coupling terms that the dipolar limit is roughly the, field interacting with the dipole of the system.

So, is the transition dipole moment as we talk about this and that is the interaction term which makes this happen and the field can be then replaced into this and this particular term is very important mu dot e over h cross, which was what was famously coined by Rabi as the Rabi frequency, is that sort of kinds of like that. And this resonant gap between the 2 which is necessary for this transition to occur is also known as the resonance frequency. So, this is the transition dipole moment of the 2 of this particular transition and so on so forth. This basically looks at the integral of this connectivity between the 2 states.

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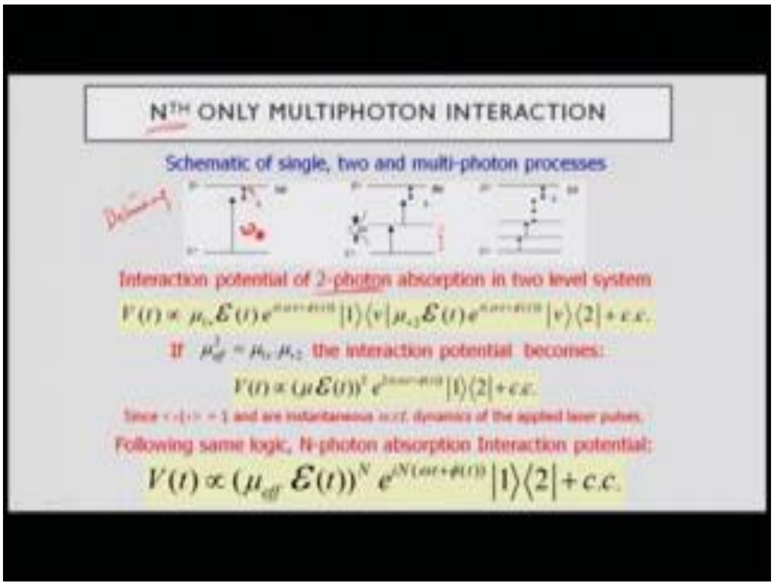

Now this can also be true for if there are n sort of connections because we have already talked about cases where there were 2 photons connecting rather than a single photon connecting. And in case only the nth transition is going to happen, n photon base transition is going to happen, and then the picture becomes much more simplistic because the all other processes are not going to happen. And this is typically true in experimental conditions because when you are supplying the energy were either supplying energies which are of one of these particular kinds of frequencies that we are talking about, this particular arrows represents some sort of a gap omega may be. So the gap is the omega naught let say and this particular gap is what is being looked at the delta is essentially looking at the gap between the exact energy provided and the little bit of a separation that might still be. And this is sort of known as detuning.

So, you are not exactly let say omega naught there is certain difference, but that may be good enough to do these things. And most of the time there is a bandwidth is associated with any kind of a particular excitation, so all these things can be taken care. And these kinds of interaction in the simplest possible case when only say the nth transition is happening in this particular case say 2 photon absorption is going to happen, while the single photon absorption is not going to happen. Typically, the orders of magnitude of these transitions to occur are so largely different vastly different.

So, the probability of a 2 photon occurring is so many orders of magnitude less than that of a single photon process is happening that, once a single photon is possible chances are of having a 2 photon processing is extremely low and so on so forth. Typically what we are assuming is that we are essentially providing frequencies or energies which are relevant to only of the much smaller level, so that they can only add up to produce this kind of excitation to produce. And in that case if only one of the process is happening the problem can be simplified even in this dipolar mode to a level where this can be looked at simply in these kinds of certain logics that we have discussed.

This is to encompass the fact that even instead of just simply using a single photon transition, we can extend the probabilities and the possibilities to hire the processes just as been looked at by say the Bucksburn group, where they use multi photon processes to do their ionization the kinds of thing; surprisingly most of these simple theoretical, and developments sort of work quite well to explain many of the experimental results.

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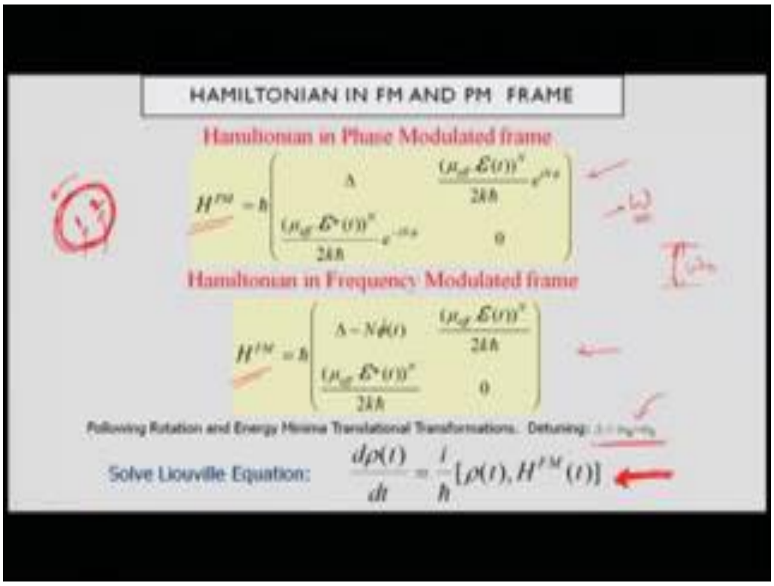

So any way, the Hamiltonian can then be transformed into whether it is in a frequency modulated frame or a phase modulated frame. Once again some of these have been discussed earlier in some of the basic lectures where it essentially means that we are now considering the fact that the relative motion of the system based on the applied frequency of the system are going to be put at the same level.

In other words it is like going to a rotated frame of reference given that we are talking in terms of the same frame. So, if you are looking for instance events on earth in relation to each other on the earth, then all of them are rotating at the same frequency of the earth's rotation. So, the entire process of the rotation of the earth can be essentially taken away from this and everybody on that particular rotating object can be, every calculation can be done with respect to say the frequency of the rotation per say. So, this particular rotating frame reference can be utilized in case of applied field to an atomic system also, where the frame of rotation is now taken as the as the applied field.

For instance, if the if the system seems to rotate at the applied field which is omega, then all it remains is the detuning from that frequency with which this relative motion can be looked at. And that is why it can be simplified to a situation where it is considered to be the phase modulated case or an additional case, where it is being looked at in a condition where it is further simplified in to a frequency modulated frame.

So, these are all essentially mathematical transformations which simplify the problem to a way so that they can be looked at easily. And, once these frames of references are taken these are very important when people are interested in looking at shape pulse interactions mostly, because then the modulation process defines us to whether you would like to use a frequency modulated frame of reference or phase modulated frame of reference, irrespective of the choice the results would be the same. And the final minima or the maxima or the translational transforms can be found and this is how the detuning. So, I have basically put it as a difference because it is irrespective of whether the exact gap omega naught versus the resonance energy or the applied field that is been taken or how it is been looked at is irrespective the signs are not very important, but it is important to decide which one is being looked at when this is being developed.

So, at the end of it once this is done in order to take advantage of the statistics of the problem, is best to use the density of states or density matrices rather than use Schrodinger equation although they have essentially the same form in some sense and in terms of solving this equation. This if we replace these as size then it would go back to almost the Schrodinger equation that we know.

So, it is essentially solving the well known Liouville's equation in that sense which is a statistical version of the problem that we have looked at simply by using either one state or so. And hence these are multiple states which are being looked at. So, this is the right way of doing the solution and once this is done it is possible to modulate and model these kinds of systems.

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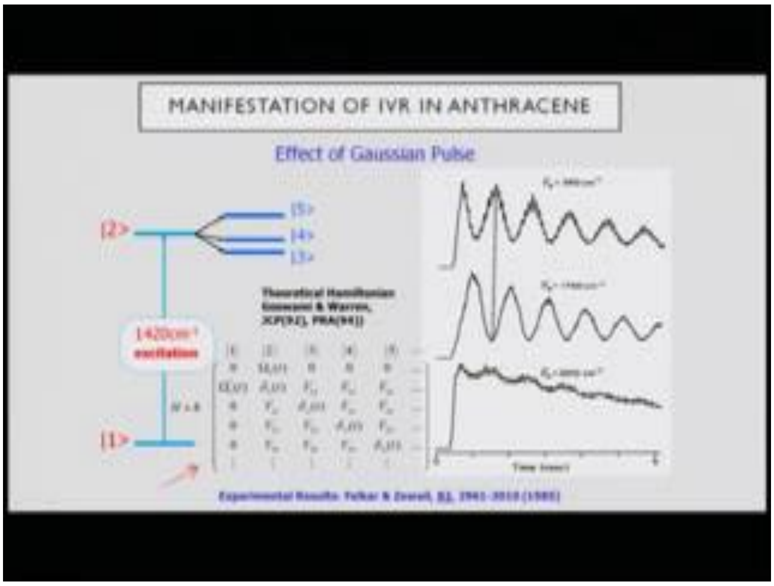

For instance, in this particular case since the Hamiltonian could be drawn from these experiments where these coupling constants and the gaps between the states could be come up from the spectroscopy done, these were possible to model and that is what we had done when we looked at it.

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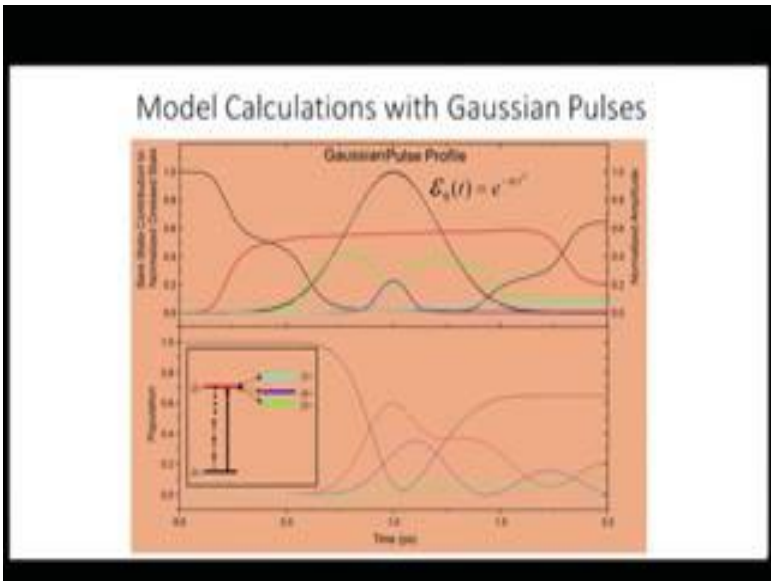

And we were able to look at it how things change when we go from the case of being a simple Gaussian pulse profile. Now typically a Gaussian pulse profile is something which is thought of coming out of a standard laser system and because of the way how the system interacts and how the laser is essentially being set up. So, it is either a Gaussian or a hyperbolic secant either of the 2 beam profiles in time which comes out from a laser, mostly it is easiest to consider Gaussian because the Fourier transform of the Gaussian is also a Gaussian. So, the spectra in the time can be correlated very easily.

So, in most cases it is the profile is considered to be Gaussian when nothing else is being done to the process. And so doing model calculations make sense when we first do it. This is basically looking at how the system involves in terms. So, as expected the population of the ground state starts off at some point and the ground state is full and then it actually goes decays and then because of the coupling going back and forth, it can actually get coupled and some of the population can come back and it can decade and so on so forth.

Similarly, the intermediate states 2, 3 and others can get populated. Depending on the coupling constant these things keep on changing. So, at any point of time if it is randomly looked at there will be populations which will be existing in many of the states and so and so forth. So, basically there is almost no control over the systems, but it is possible to have oscillations as we have been seeing in some of the experimental cases.

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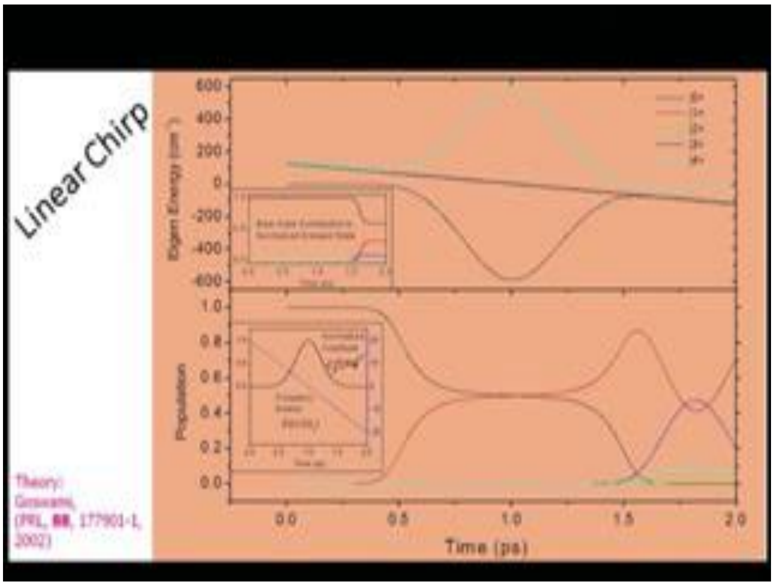

However, if you use specific shapes of pulses, for instance here it is a simple linear frequency sweep which is being provided. So, it is basically quadratic phase shift which is happening within the pulse then it turns out that it can adiabatically change the state of the system from ground to the excited irrespective of the fact that there are other states involved. And so while the system is being radiated only the 2 states can be coupled while the other states cannot be coupled. And this is actually a very interesting condition.

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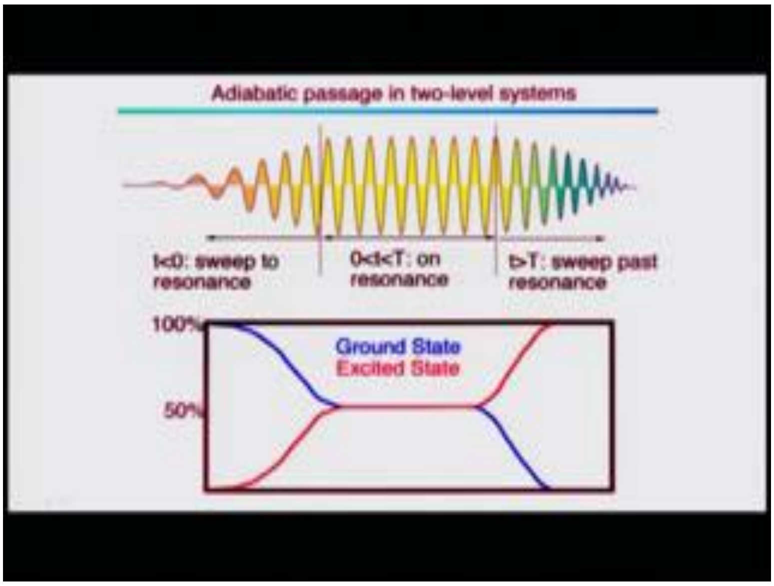

A principle which comes also is known to occur in NMR, because in those cases this is one of the simple ways how the spin system is being transferred from one to the other. In generally speaking this system is taken from far of resonance 2 resonance and then past resonance. And for a simple 2 level system basically you take it all the way to the excited state because the character of the state changes from ground to excite as the system undergoes this goes through this resonance condition. The character of the state changes as you go through this and it is possible to do this.

So, it is known as adiabatic passage although it is typically also known as adiabatic rapid passage because this has to be done faster than the decoherence of the states involved. In NMR it is actually not that difficult because the states that we are talking about are having a long enough lifetimes and so it can be looked at easily. So, it is simple adiabatic passage they are, but in optics it is importance is to consider it as a rapid passage because the lifetime of the states involved might not be long enough to go through this.

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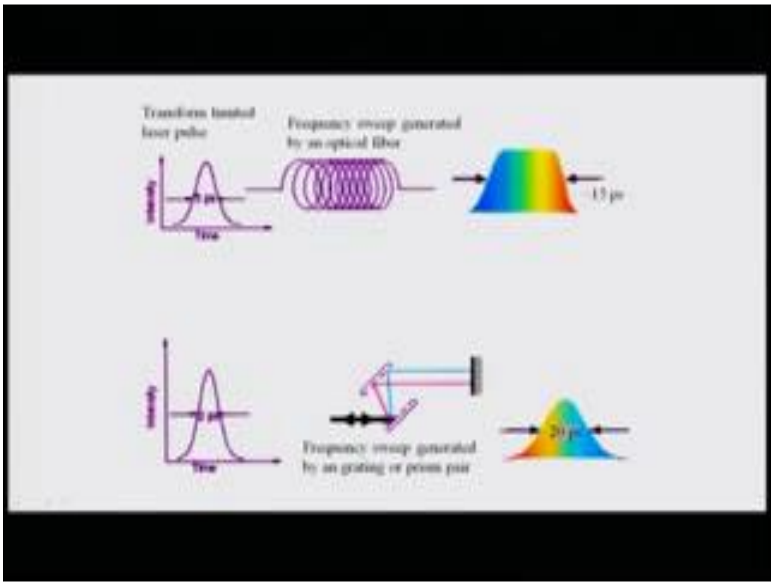

So, these have been achieved initially by using simple frequency sweep generated by the optical fibers or by using a grating or lens or prism pair or such that the frequency content within the pulse is being continuously swapped from blue to red or red to blue, and these have been applied for these kinds of applications, and has been shown that it is possible to do with this in terms of making the population change for one to the other.

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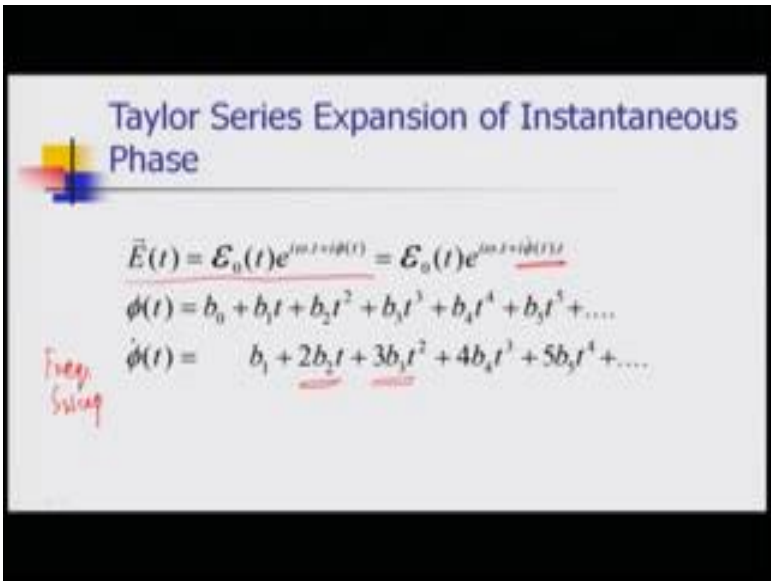

In order to make this look more generic, it is possible to make a Taylor series expansion of the instantaneous phase of the field that we have been discussing about. So, the electric field in general looks like this as we discussed with the phase and the frequency of the applied field. And that can be looked into the phase component part in terms of the instantaneous phase, which is either going linearly or quadratic ally and so on so forth; so the frequency sweeps. So, this is our frequency sweep that we are looking at, which is basically the first order derivative of the phase which gives rise to linear chirp or a quadratic or so on so forth, and that is the one which is responsible for the property of the system as we discussed.

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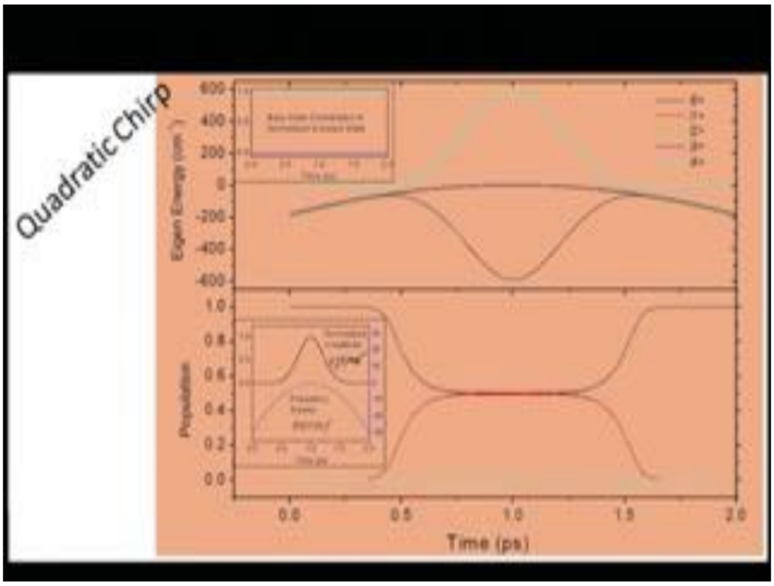

Similarly, instead of looking at a linear sweep if you look at a quadratic sweep. It essentially takes the system all the way to resonance where they are coupled and then they can go away completely, when they are brought back to the original condition. So far from resonance to resonance and once again far from resonance, but not in the opposite direction but in the same direction, basically make sure that the state can evolve from ground to the superposition condition back to individual cases.

So, in some sense this is a situation where you can see while the field is on a complete interaction happening between the states, but there is they go back to the original states when they are done. So, in some sense laser matter interaction in these cases are showing specific interactions which can be utilized in the sense that we are talking about.

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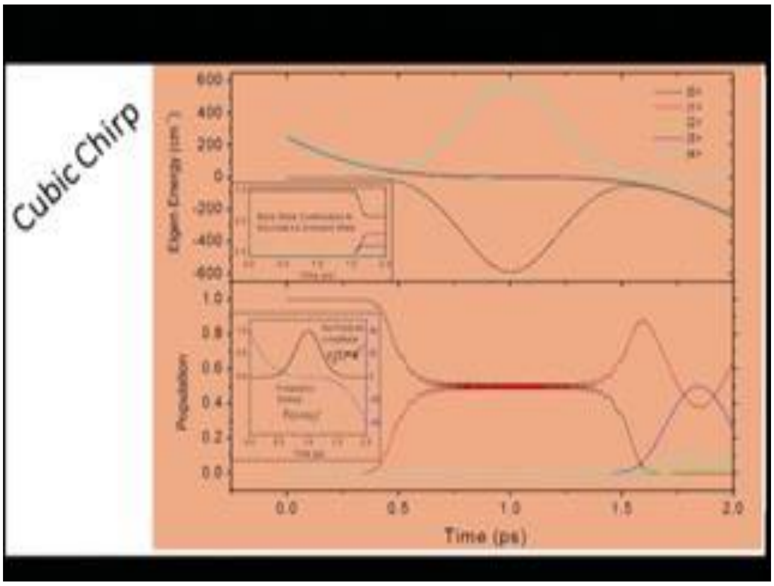

And similarly the cubic chirp can also be something where it can interact and then it can go to the opposite sense to some level. But generally during the period of the pulse the interaction is such that they are the 2 particular states can be kept coupled strongly with each other with equal contribution from both of them, while the rest of the states are not involved.

So, the bright state and the ground state; the bright state in the sense which is optically coupled are the once which get isolated from the rest of the system. So, in some sense while the field is on, we are able to isolate the optically coupled state away from the rest of the states which lead to decoherence. So, in some sense we are basically saying that there is no possibility of decoherence under these conditions for any of the chirp that we are looking at.

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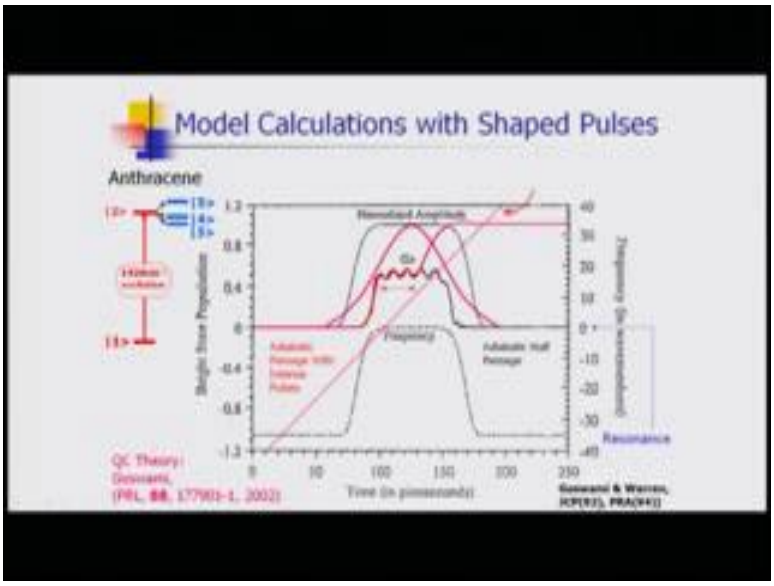

In general this was one of the things that we were able to point out with this work that given the previous level of discussions and work done in these kinds of systems it is possible to sort of say that, there exists a region of a which it will be possible even for simple shaped pulse like a linear sweep, there exists a region over which the 2 states can undergo a complete coupling between each other in such a way so that it is completely decoupled from the rest of the states which create decoherance further.

Now, the problem is generating these other very complicated shaped pulses, which can give rise to much more interesting conditions like adiabatic half passage or others, it is very difficult. And we also know that creating smooth variations in these kinds of frequency sweeps which are higher order conditions to produce pulses which will have frequency go to resonance and then back away from to the original condition is very difficult. Whereas, the linear sweep cases have been experimentally determined and shown. So, even under those conditions under certain sweep rates it is possible to show this kind of results which were very exciting to be showing at that point of time.

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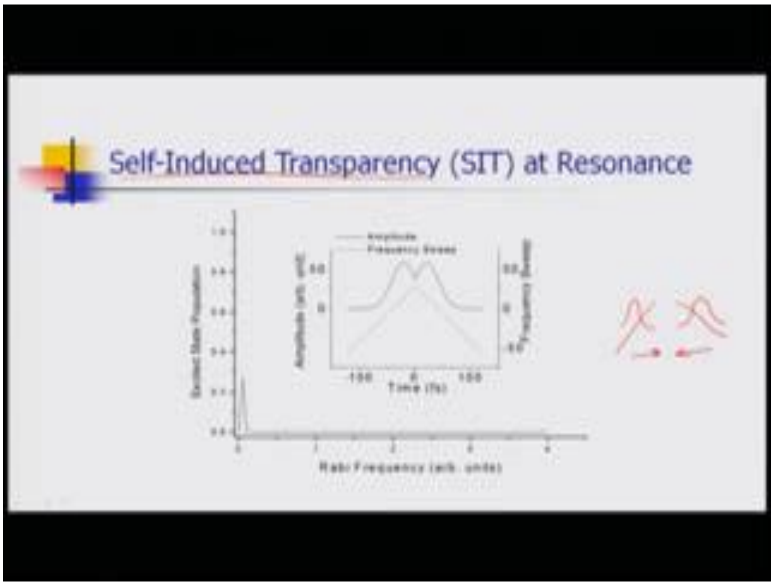

It could also be used in terms of multiple pulses if they are brought together close enough and that was another case where we were able to see if we could use 2 pulses which are linearly swept say and brought together in such a way so that they also produce cases where there is no excitation possible.

So basically this is self induced transparency, basically saying that we can take cycle the population in such a way so that there is no population net available at resonance. So, it is similar to their earlier conditions that we have been discussing. So, that they produce a coherence or 50 50 connection at resonance time at the point where they are perfectly overlapped and before and after there are no changes which happening.

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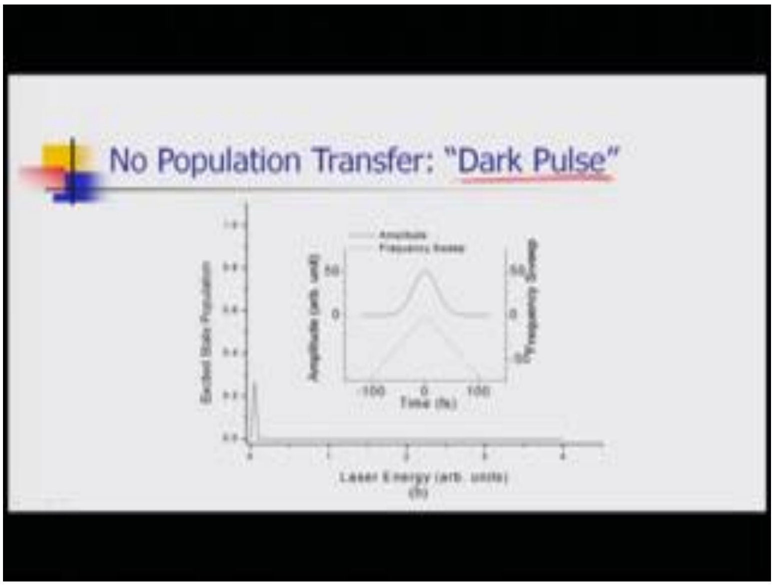

So, this is one example of producing no population transfer and we can often call them as a dark pulse, which is the condition which has been shown here. These are cases where the frequency swept is kept in such a way so that they come and go almost each other, in some sense. It is much easier to when you have 2 pulses coming from of opposite kinds coming together. However, in a single pulse producing in this would require a pulse shape or which is going to be quite complicated, but it should be possible sometime to find out these kinds of shape pulses.

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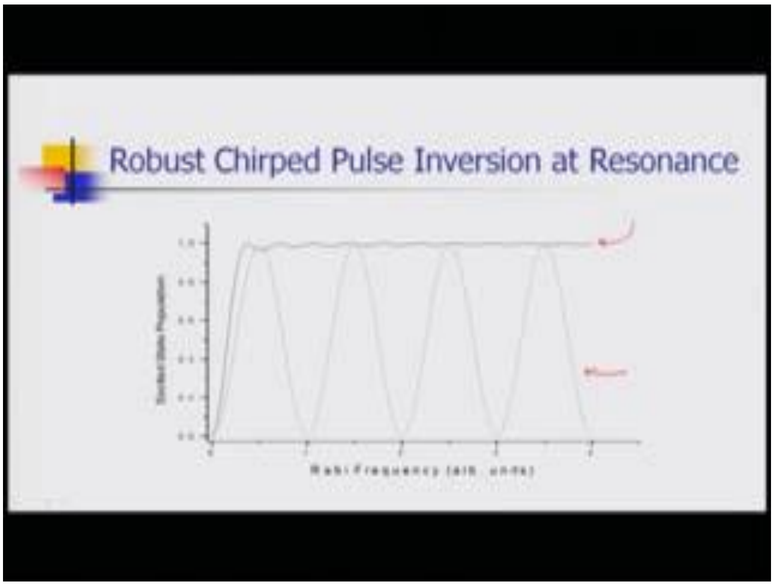

In general the basic point of a pulse shaping system is to say that irrespective of what happens when you have a adiabatic conditions satisfied where the population can be put to the excite status and nothing else happens, versus the case where an oscillating condition excess when a simple Gaussian pulse is been used, because the population can go back and forth between the ground and excite states. So, that is typically the condition which we know which happens at resonance.

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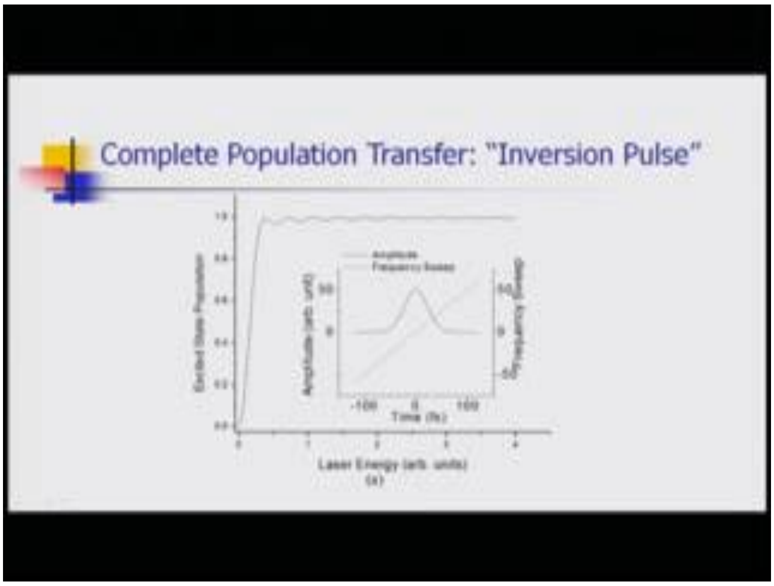

And the other kind is to, so one of them is sort of like the inversion pulse whereas the other kind is sort of like a dug pulse, where there is no population transferred net happening as a result of the presence of pulse also.

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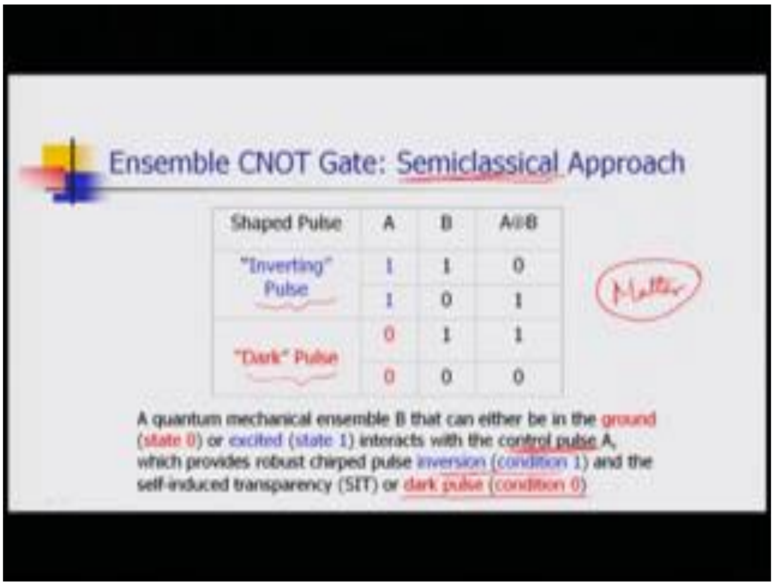

So, bringing them all together it was possible to sort of provide a semi classical in sense of a CNOT gate, where these kinds of pulses which were inverting versus dark, which could be put together to produce a quantum mechanical ensemble that can either be in the ground state or excited state interacting with the control pulse, where our control pulse is the optical pulse provides robust pulse, chirped pulse inversion which is the condition 1, and the self induced transparency or no inversion or no light population transfer is the dark pulse which occur.

So, this was another way of looking at the implementation of some of these simple ways of having a matter interact with the applied field and have this kind of overall interaction result in quantum processing that we are looking at. The advantage of this particular scheme however, is the fact that this really does not make it such where there is a requirement of entanglement or superposition explicitly being asked for.

So, it is being questioning one of these is not really clear. So in somewhere this is a semi classical however because it is essentially using the condition of the controls which are optical completely, but the state which is being used are of the matter. So, the matter inter mediatory in some sense in these cases are all quantum like. So, that is the reason why this has become quite interesting in terms of looking at it.

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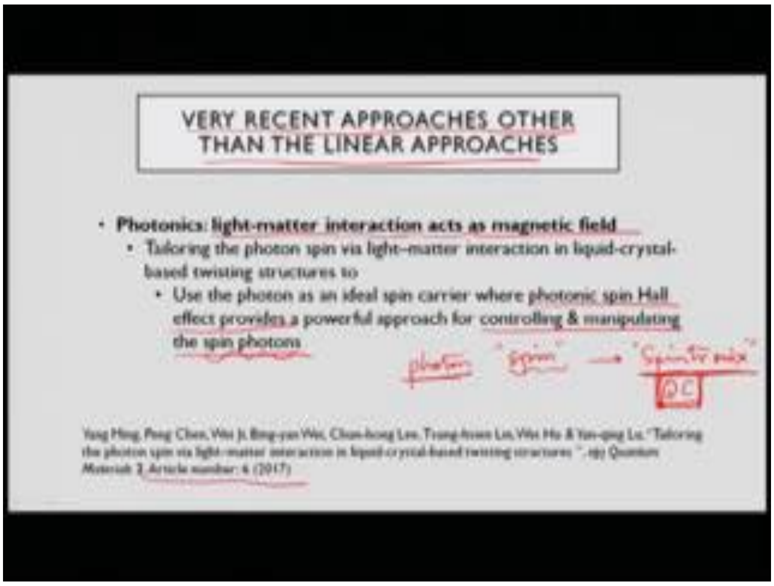

So, there have been some very recent additional looks into these optical approaches, which have been quite different from the linear approaches to start with, and some of the other approaches that we have been talking about. And one of the most recent works which has happened in very recent times is the use of photonics or light matter interaction where it has been used as a magnetic field, to result in producing states which are controlling the spin character of the photon.

So now, photons can also be treated as the concepts, where the spin is being used up and so the photon spin can be used as a important device and so it is in when we talk about photon spin rather than the other aspects, then it is more to do with the other area of spintronics because spintronics is something where anything to do with the characteristics of spin of a system is being looked at.

Now, this spintronics approach to quantum computing is an entire different area of topic where we will be discussing a lot of issues associated with it is implementation, and this particular approach is very interesting and it has come out quite recently this is just an article that came out last month. And, it sort of couples the principle of the photon spin in terms of concepts of spintronics with optical Hall Effect.

So, it is a photonic spin hall effect, which provides a powerful approach of controlling and manipulating spin photons. And this is kind of very interesting because once again in terms of other matter spins, there are always complicates in terms of their difficulties of using, but with light and photons this will not be.

So with this, I would like to conclude today’s lecture and let me say that from the next lecture on for this week we will be focusing on the problems which we have been always saying will look at. So, all the earlier problems that we have given to you as assignments will be solved from the next lecture or in this week.

Thank you.