Implementation Aspects of Quantum Computing

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Lecture – 24
Application of Ion Traps in "QIQC"

This week we are continuing with the understanding of implementation of aspects and we had into the third major implementation aspect that we are looking at. We introduced you to the ion trap scheme which has been one of the very important and successful approaches of quantum computing.

So in terms of the approaches that we have discussed before this, the major aspects were in terms of NMR, then we came and talked about optical schemes, and then we also mentioned that optical schemes had been utilized in conjunction with many other approaches; so we went up to a certain level and then left it. And then we entered one of the major advantages or applications of quantum computing that implementation has been which is the ion trap case. In this particular ion trap case, the advantages have been that it represents the simplest form of qubit representation which is the atom itself to start with or its corollary which is the ion that we are looking at.

We discussed how typically this has been utilized in many different ways. In this lecture now on, we basically look into the various different aspects of ion trap which have been utilized and how it stands in at present times in terms of its implementation and as well as its advantages into the future.

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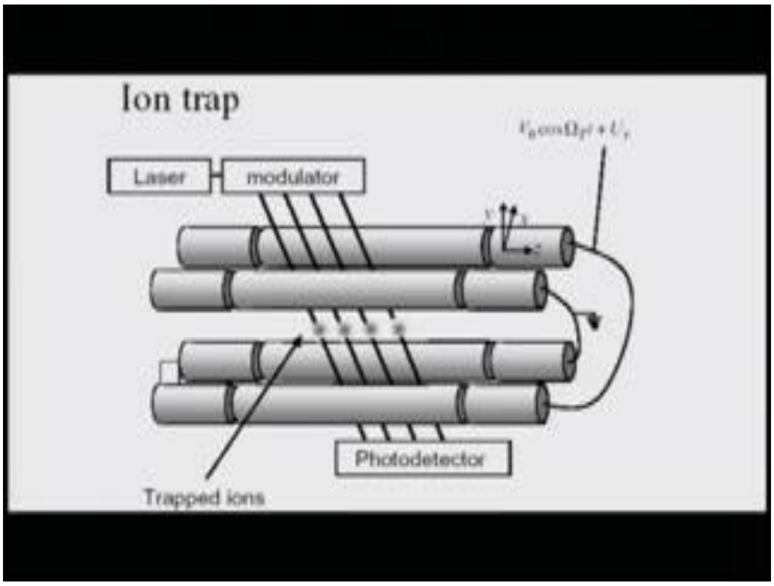

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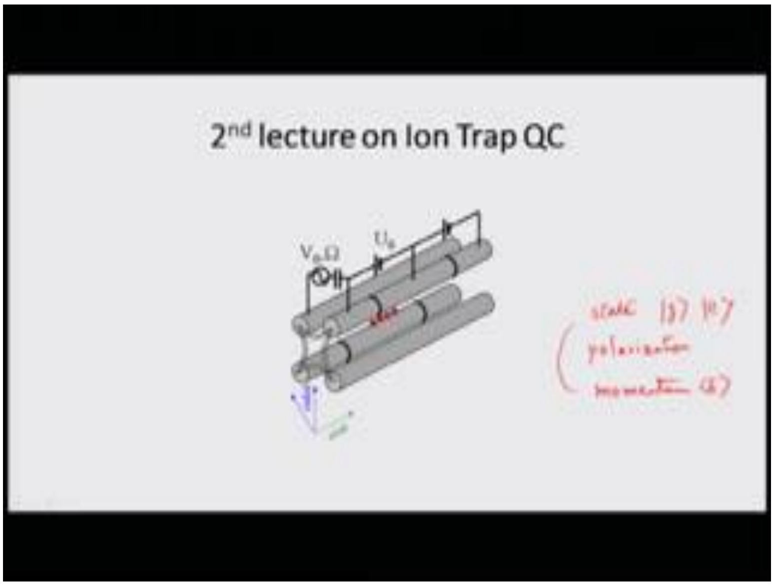

With this let us look at into our ion trap issue. We basically know that the trapped ions are generated inside a setup where we have these RF being applied with oscillatory fields so that the trapping condition is achieved and we are able to put multiple ions in relation to each other so that their independent states which basically represents the internal property of the system as well as the proximity. Basically, there were 2 different aspects that we looked at; one is the principle of the individual internal state of the ion that we are talking about, and secondly is the relative position of a bunch up ions that we are looking at.

That is how we have been discussing this issue of the ion trap and how it has been taken advantage of. In some sense, it is say the state of the ion that we are looking at. That is internal state whether it is in the ground state or excited state. Then the second one is the polarisation very often that is also some times which are used, polarisation of the ion state. And the third one, which is often used, is the position or the relative motion of that so that translational, so it is sort of related to the momentum or energy in that sense also.

Basically many a times these 2 are coupled in order to get advantage of multiple quantum bits been encoded at the same ionic conditions. This is how the gates and the ions in the ion trap have been utilized. And roughly speaking we showed how the addressability of these ions can be achieved by using lasers which can then be modulated to be off and on and that additional to the condition of the ion which is being placed with respect to its property as well as its relative position can all be put together into use when we look at the implementation of quantum information or other aspects of quantum into the ion trap condition.

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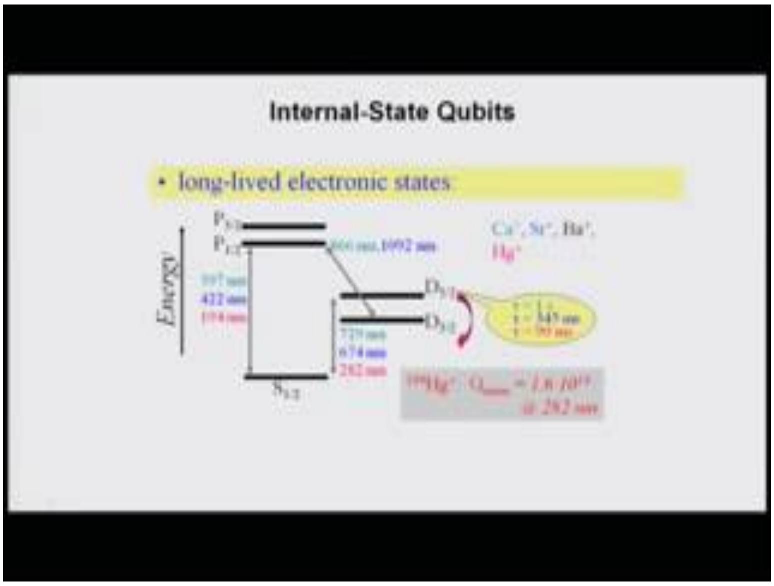

With that diagram, now we also discussed some of the major candidates for these ion states and they are mostly candidates like calcium's, strontium, barium, mercury, each of them simply ionised so that we have 1 electron available in the outer mode state which could be then utilized as available entity which could also be used. And these are states which have long lived so that is why we have the advantage of keeping them for a very long period of time.

We also looked at it that under conditions where we keep it at, we can actually isolate it to a very good extend then the life times can be extremely long. And so that has an advantage many of these operations. So one of the principles which advantage have an advantage in this and trap case the long lived electronic states that we are looking at.

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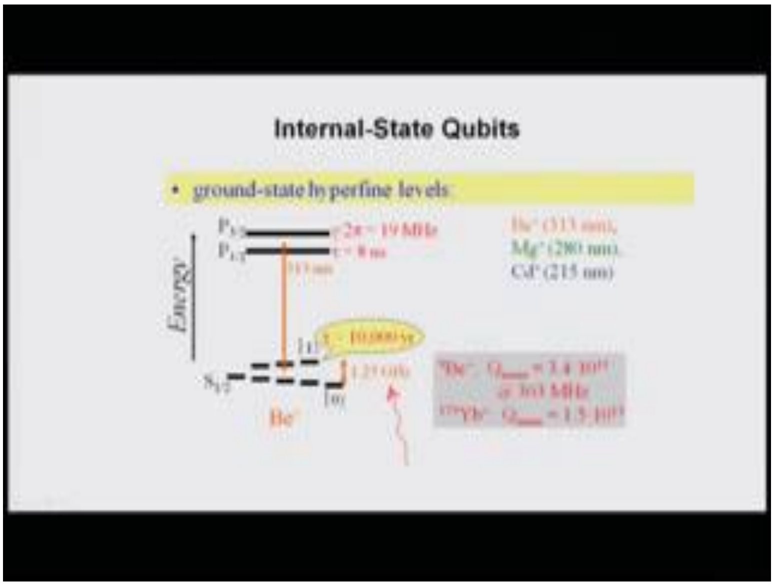

Also there are many of them which have hyperfine ground state levels, which are very very long lived and that is another place were the addressability of these states have been achieved by using say RF or megahertz or gigahertz pulses which can radiation, which can then address these states and these states are say stable to for example, in this case for some of these ions that we show in the range of over 10,000 years in times of the stability of the state that you are going to create with respect to the starting states. That is the long lividness of these states are extremely advantageous when we are looking at the implementation aspects in terms of quantum processing as we are been discussing.

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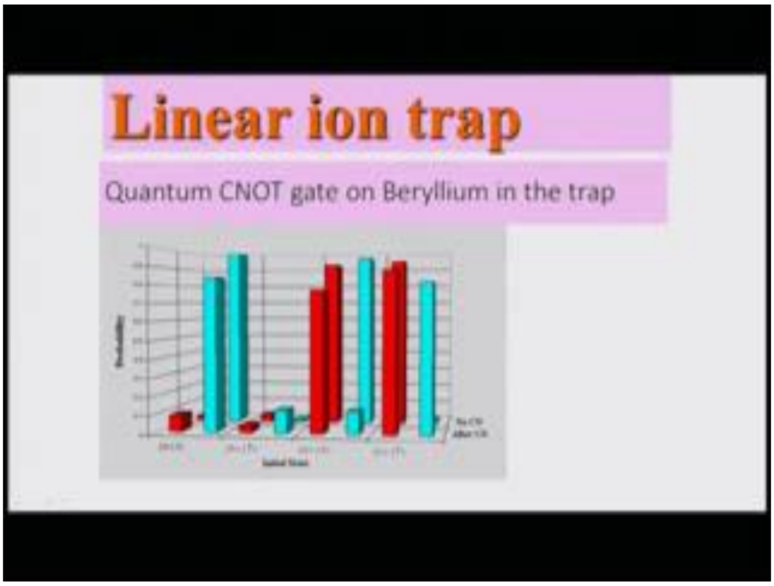

One of the examples which were utilized and used was the CNOT gate for example, on berylliums ion in the ion trap and this was one of the examples where after the control not what happened, before the control not gate apply application what happened. We are coming to this in a minute, so this sort of like shows that these traps have been utilized.

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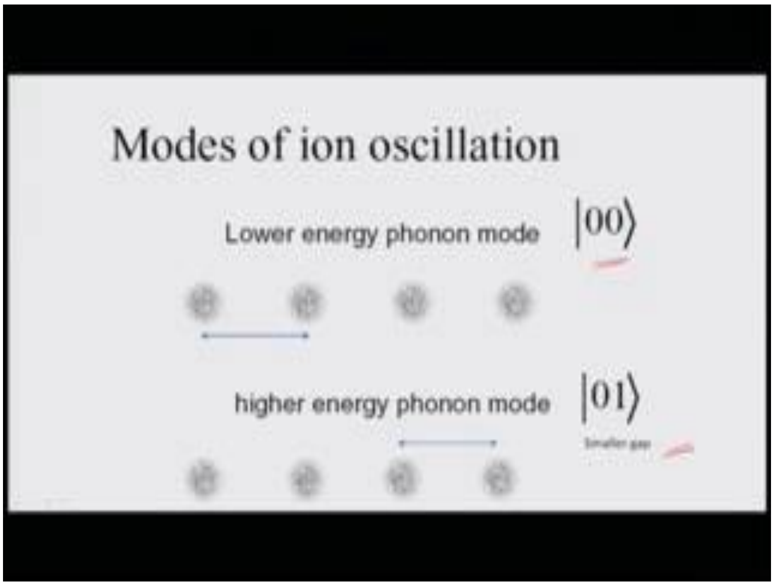

The other property which we were discussing at the very beginning is the mode of the ion oscillation. There can be the lower energy phonon mode which is due to the relative positioning of these ions with respect to each other when they are further apart, then it is the lower energy phonon mode, when they are closer to each other then it becomes a higher energy phonon mode. And that is how you can get these other couple states which can become 2 qubit condition instead of the single qubit which is due to the internal energy state of the ion per say.

So the interaction which is between the ions, which is the phononic interaction for instance in this case, due to their motion and oscillation is one kind of mode and that can be addressed in addition to the internal state of the system.

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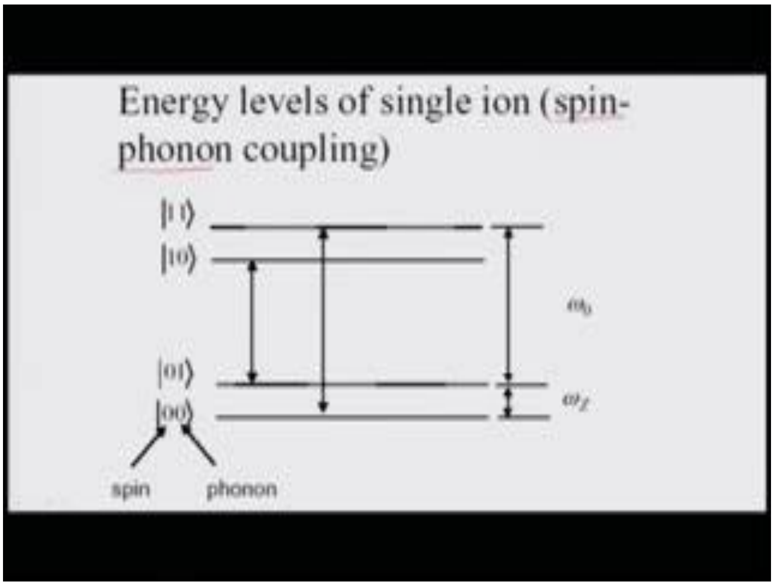

For example, here is the energy level of a single ion spin phonon. Here we are talking about spin as well as the phonon coupling conditions. And the spin of the ion is thereby connected to the phonon state because of the oscillation which is due to relative motion versus the spin condition of individual ions which can be kept at one kind with the others and that can be addressed and that can be utilized.

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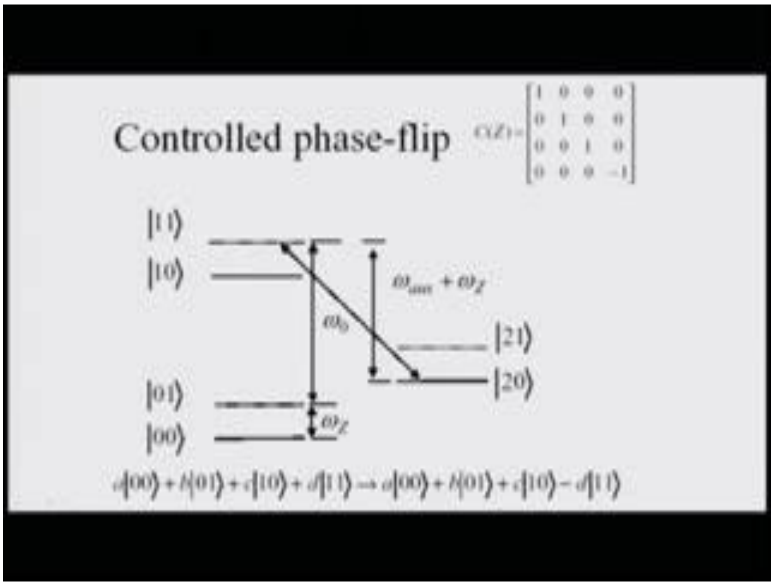

And this is a case where the couplings which are there as result of this can be utilized to do a f control face let in this kind of way 2 qubit operation. Many different operations of these kinds are possible. And this is very simple in terms of operation because this mimics the classic case of the theory that we were discussing at the very beginning of this course, where we were is in some sense is the text book criteria definition of many of these gates implications on single qubits and 2 qubits which we were initially introduced.

In these particular aspects of using ion traps help gets it so close to that, and therefore ion traps were one of the natural early sources and advantageous it has been happening with this case.

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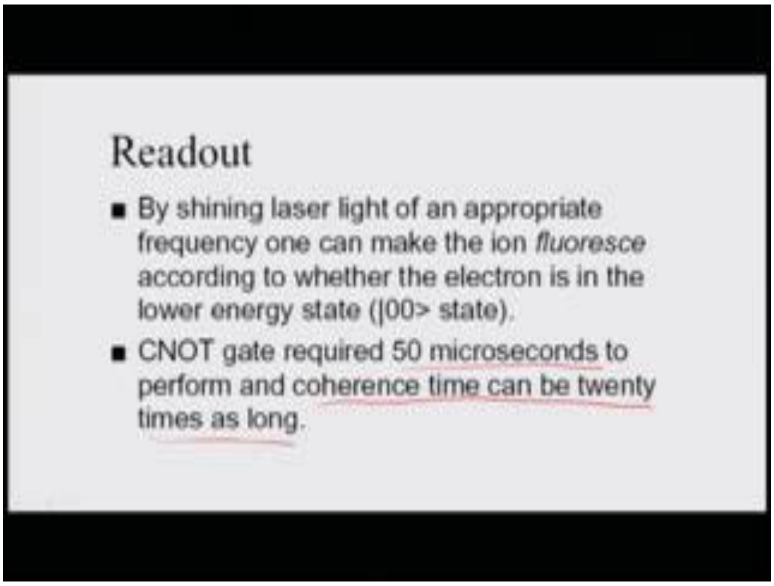

And most of the time the read out is done by shining the light of an appropriate frequency where the ion fluoresce. Many cases the read out is essentially done by shining a light over an appropriate frequency that reads out the property of the system by making the ion to fluoresce according to whether the electron is in the lower state or in lowest energy state or not.

The CNOT gate applications for instance required about 50 microseconds to perform and the coherence time as we were discussing can be 20 times as long. And so these kinds of systems are very effective in terms of an application of the gates because the times scale are not much of a problem.

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Here is an example case of the implementation of the Deustsch-Josza algorithm using trapped ions which shows the suitability of ion traps in quantum information processing relatively simple algorithm and it uses in this particular case using only 1 trapped ion.

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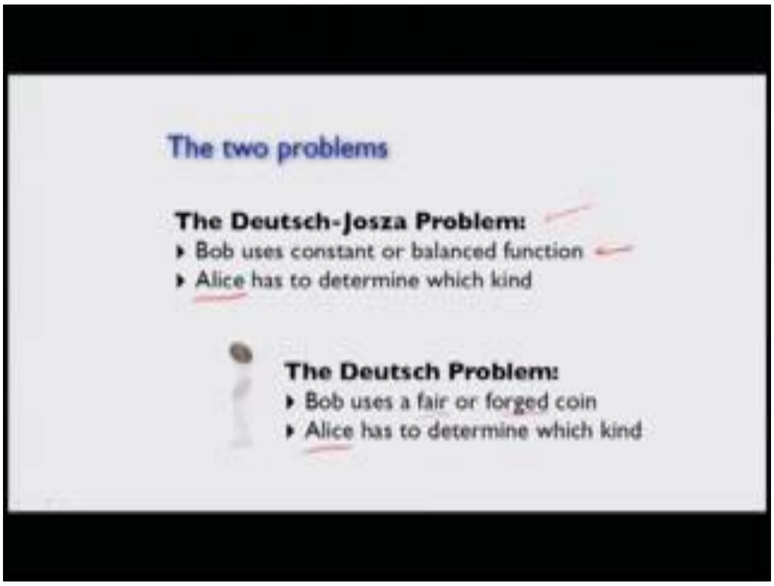

The 2 problems which are looked at is essentially the more common D J algorithm or the Deutsch-Josza problem, where the individual concerned is going to use constant of balance function, and the other individual is supposed to determine which kind the individual has used. Basically, it is the job of the reader to be able to find out what the function is being used by the person concerned.

The other problem is to use the Quantas problems where Deustsch problem, where Quantas is whether it is fair or a forged coin is been utilized has to be determined by the user.

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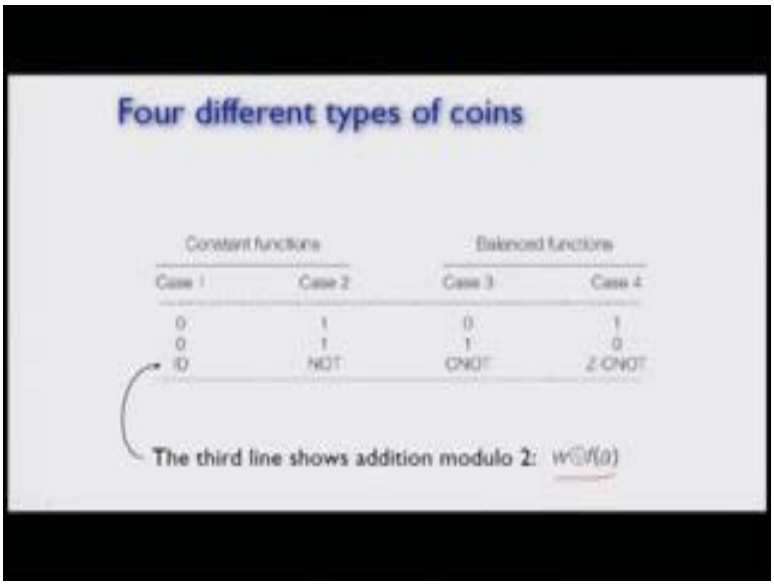

There are 4 different types of coins that we are looking at it here. Essentially we have these as defined earlier in terms of D J algorithm and Deustsch algorithm that we are essentially looking for constant functions versus balance functions. And there are 2 cases for each of these which make these different types of coins we are talking about.

And what we have is, in one case we are using the third line is essentially finding out the addition module 2 of the 2 which we are looking at, we are applying the application of these individual functions and then we are looking at the result accordingly.

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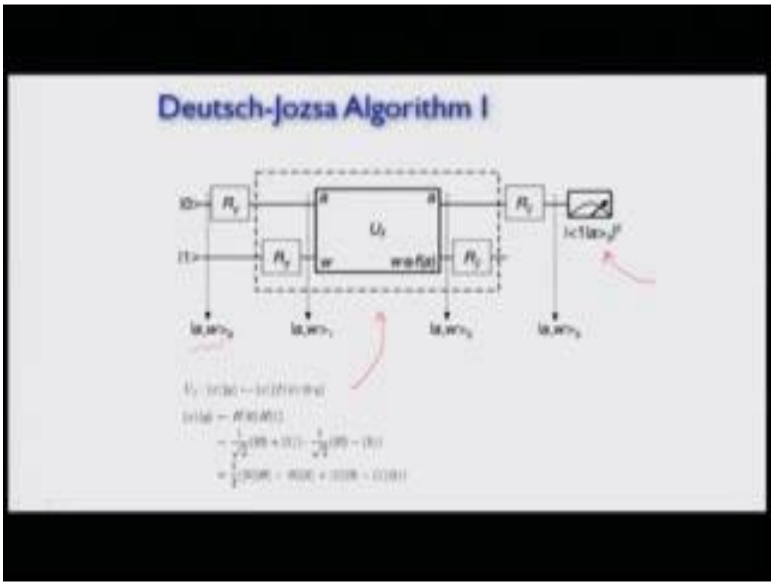

The implementation aspect therefore is essentially solving this particular diagram in which we have the input, these are A and W which we are inputting. And accordingly we are looking at their different aspects as we go around and before we finally make the measure. And there are these unitary transform case that is being applied, which does the addition module and that is what is been used.

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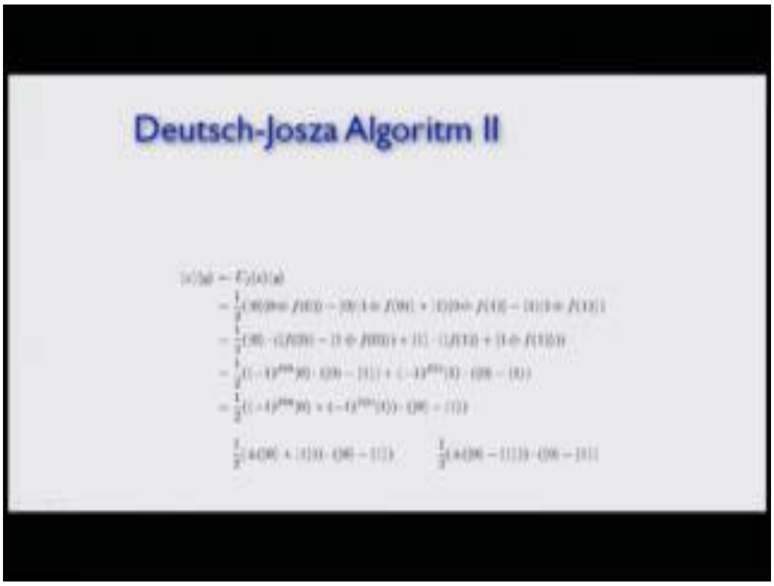

The Hadamard Gates are the ones which are originally being utilized to get to the initial condition which then is going to have the unitary being applied to it to create the addition module which would be of these different kind as we look at it.

And we basically can do both this algorithms in with the help of just a single ion in this case, because we can have the different modes of the ion coupled to each other and get this done.

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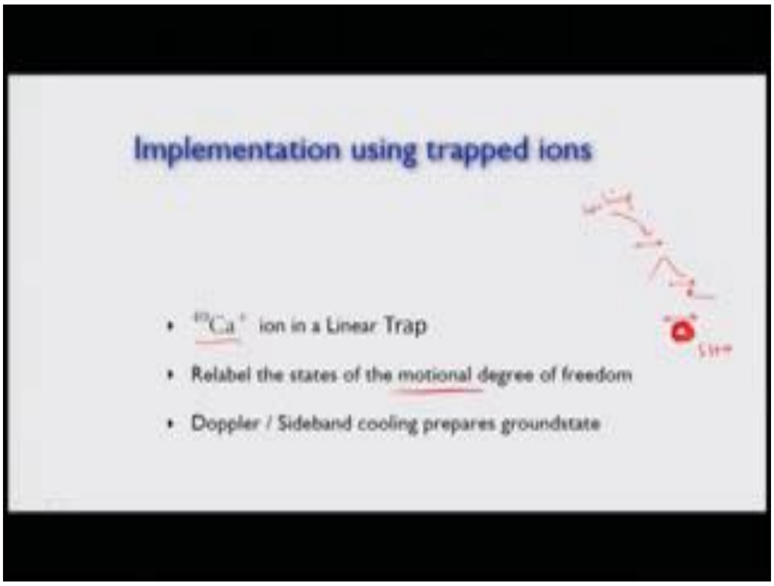

Here is an example, which has been taken in case of the calcium ion inside the linear trap, where the states of the motional degrees of freedom are being relabelled as the states of the set. This motional degree is essentially the condition of the ion within the trap. Roughly this is the one which is like this simple harmonic oscillator condition of this trapped ion. So that is the one which is to be set up in terms of the degrees of freedom.

And the Doppler side band cooling is way where which prepares the ground state. Typically whenever a laser interacts with this kinds of a trapped ion, depending on whether the leading edge is doing the job or the trailing edge does the job which is what is meant by the Dopplers side band, but the leading edge creates heating whereas, the trailing edge essentially does the cooling and that is how the ion is cooled. The idea is to make this motion minimal as it gets cooled. And this is due to the interaction where the momentum of the particle of the ion is getting decelerated because of this interaction with the applied this of it.

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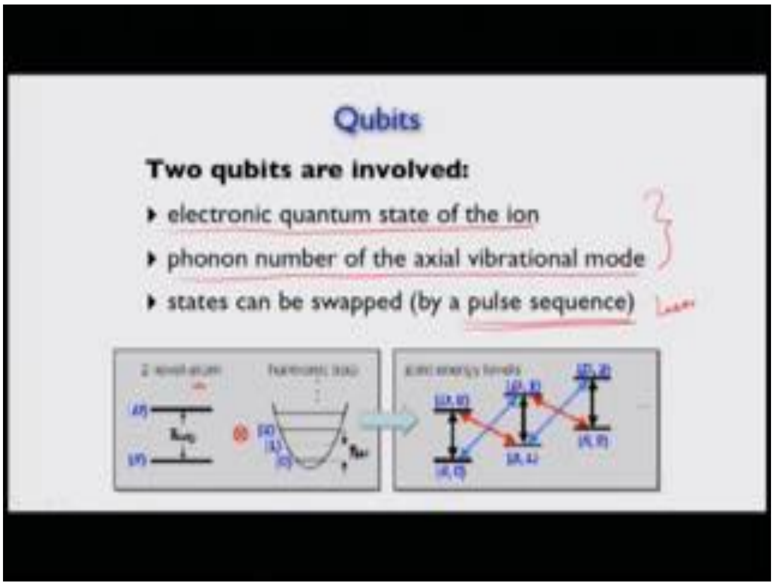

The 2 qubits which are involved in this case as I mentioned is the 2 level atoms in itself, which is the well in this particular cases the atoms slash ion, is we are looking at calcium ion with 1 electron in the exited outer mode shell. In some sense is 2 level system with the lowest possible excitation, the lowest energy outside the core shell is just going to have electron which is then corresponds to the ground state and then the next level up is the excite state.

In spectroscopic terms symbols we have the S state and the D state which we are looking at this particular case for the calcium ion. And it is then getting coupled to the harmonic motion of the trap as we just discussed which the one is where we have these 2 states being coupled. The electronic quantum state of the ion as well as the phonon number of the axial vibrational mode are the ones which gets coupled because of these particular principle and they are the ones which are being put together as our qubit system. These states, which we generate as result of this coupled states can be swapped by their help of a pulse sequence, as I was discussing and there. This is the reason of the use of a laser or RF, it depends on which particular condition we are talking about mostly it is the laser which is used for the traceability which is what is going to address these joint energy levels and make these states be swapped as a result of the interaction with the laser parts.

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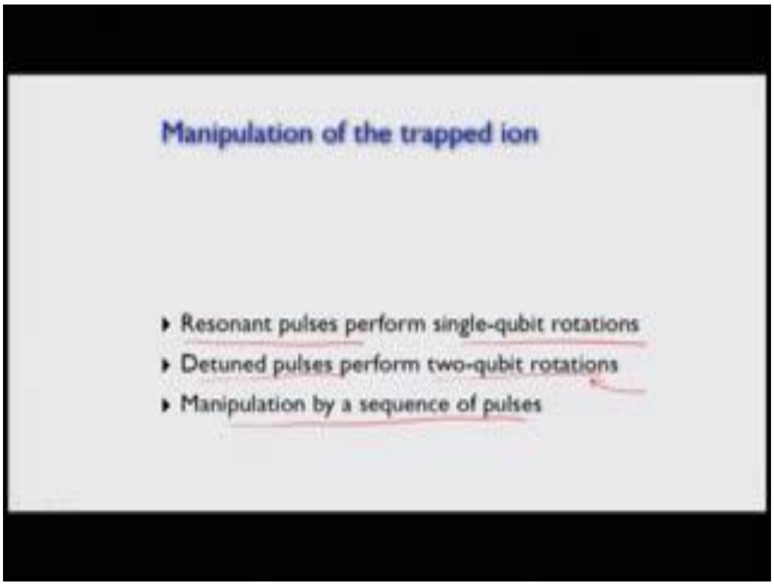

The manipulation of the trapped ion results in reasons. So we have these resonant pulses which perform the single qubic rotations, whereas the detuned pulses perform the 2 qubic rotations. Thus we have this detuned pulses which we do the 2 qubic rotations because the detuned pulses will essentially have the Doppler effect of sort of cooling the system or heating up the system. That creates a situation of having the 2 qubits, whereas the resonant pulses are going to either take it from one particular S level to the other particular sorry, one particular spin condition to the other particular coupled spin conditions.

This manipulation is achievable by sequence of pulses which is what is utilized for getting the states.

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The main sources of barrier in these kinds of experiments have been that the phases introduced by light shifts of the lasers may not be appropriate. And the system may leave the computational subspace, because if the trapping fails for some reason or the other then for a particular ion let say then it would leave the computational subspace. These are the 2 cases, but in most cases, these are pretty controllable so once in a while these are the error sources that can come.

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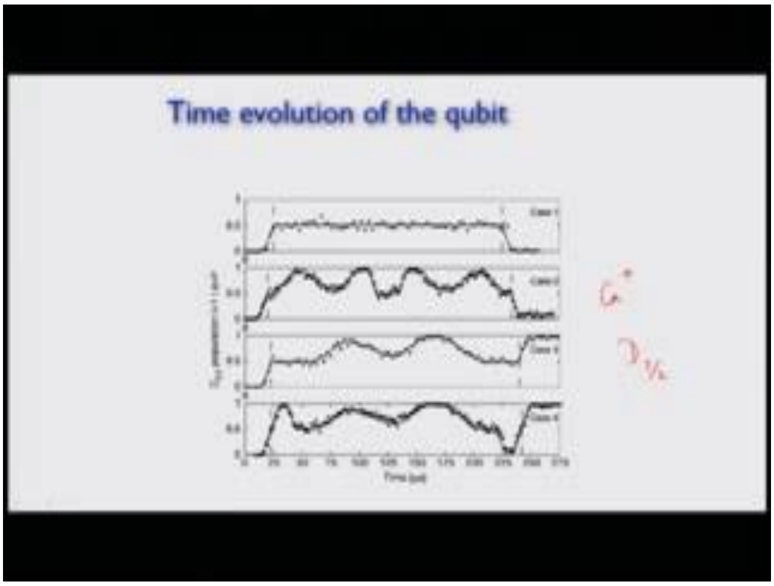

Typically, this is how the time evolution kind of shows up in one of the typical experiments which where it was first depicted years ago and that was shown that these different qubits that have been prepared by these conditions for these particular case of the calcium ion, can be spin in the vibrational mode which have been excited and looked at as a part of this. Basically the D 5 by 2 states is being looked at by this particular technique.

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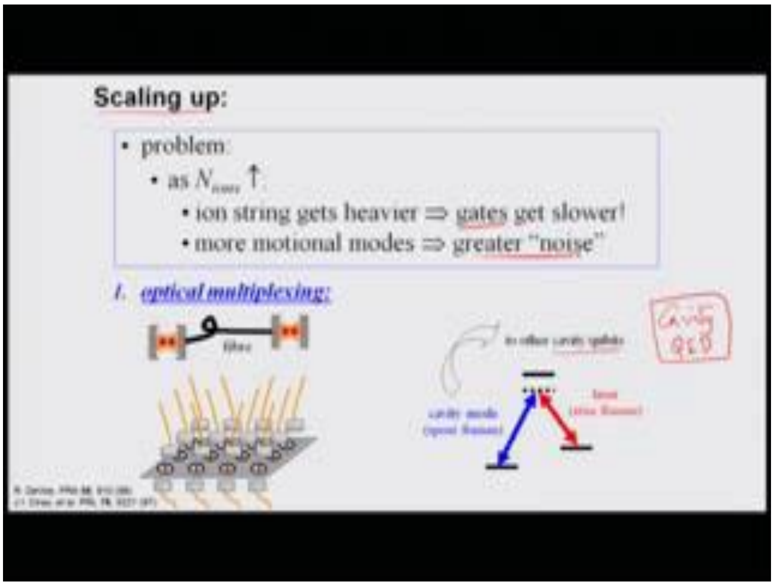

Now, as we discuss in the last case it is only a single qubits system, I mean single ion system which has been subjected in effect, which has been subjected to a coupling of 2 different parameters or 2 quantum conditions under the conditions that we are doing experiments. If we want to have lot more ions being put together in this kind of symatic, scaling up has a many different issues to worry about. As the number of ions go up the ions string gets heavier the gates get slower because now we are talking about phonon interactions of the large mass and the interactions become slower and therefore the effectiveness of the gates which are going to do these changes will become slower.

And there are much more motional modes to be to be taken care of which means that there is a greater noise condition. So that is basically saying that we have difficulty in cooling the system because we have lot more states which are already getting rise to as a result of the size of the system. So, optical multiplexing always helps in these cases. For example, here is an example where if the system put in such arrive at these independent trapped system can be individually addressed by using fibre optically coupled lasers. Then they will have better capability in terms of addressing them. That is one option; the other aspect which has been also looked at is to use the cavity mode of the system. This is more to do with the cavity coupling of the system with the ions that we are now talking about and these can be connected by using cavity modes and the qubits.

Now we have not really studied much about the cavity Q D aspects also. That is another way of looking at quantum computing. Once we again revisit the cavity Q D kind of problem. We will perhaps have a space where we can see how the cavity coupled condition of the ion trap with the cavity modes can also be effective in terms of producing or enhancing or scaling up the problem. Everywhere, what we are essentially coming to understand is that it is not just one particular way of looking at the problem that we are interested in whatever more ways. We can couple the system and have more different approaches that we have used, if we can couple them then they are going to gives us better answers and therefore, we have often utilized the principle of the already existing optical approaches let say in addition to the ion trap.

Similarly, we have been using the other approaches of teleportation adaption which are often available very affectability in the optical approaches into these different modes.

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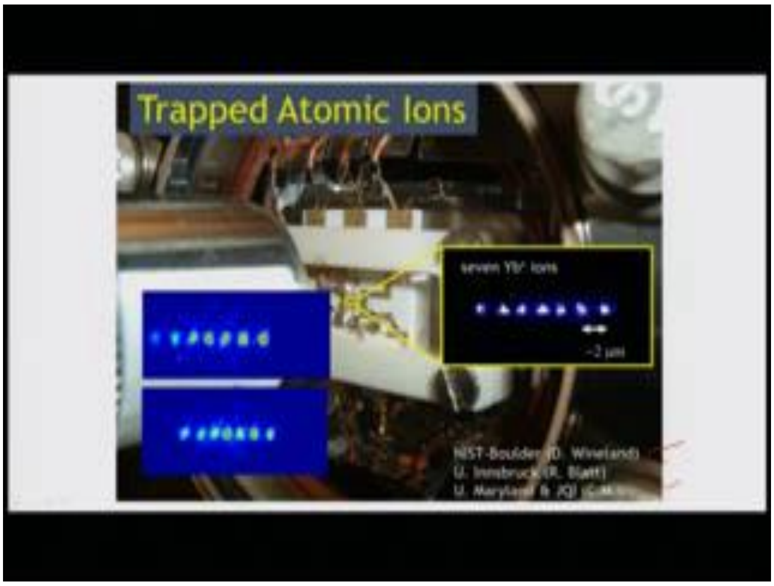

Here is some works which have been done very heavily by these groups. In fact, the Bose Einstein group which receive the noble prize in (Refer Time: 22:05) does a lot of work in this particular trapped atomic and ionic qubit system, they in fact were one of the first to demonstrate many of the events that we have also discussed here. There is a University of (Refer Time: 22:05) group and University of Maryland. There are many groups around the world which are looking at it. And this particular work were ytterbium ions 7 of them were coupled together and utilized is a very important aspect of trapped condition and here is an experimental setup condition which was utilized while this particular experimental approach was done. These are the 7 qubits and they are separated by about 2 micro metres from themselves.

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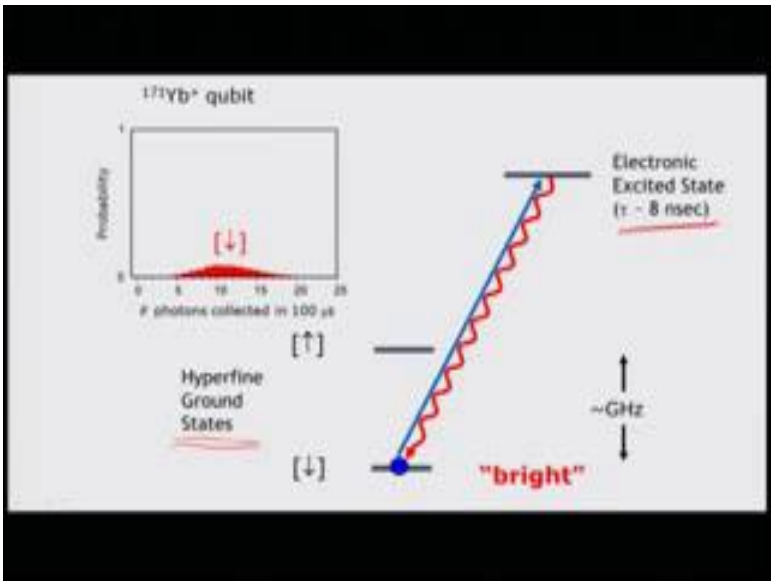

In this case for example, this ytterbium qubit photons can be collected in about 100 micro seconds, every time they are in one particular state or the other is hyperfine ground state. For example, of these particular ion can have excited electronic states which can then flurries back and this is a bright state coupling.

So, we have these 2 different spin conditions which are then being satisfied. The spin conditions are provided by the hyperfine ground states which Y I excitation to the electronic excite state it can be made to go one way versus the other. That is one approach of showing how the ytterbium qubit works.

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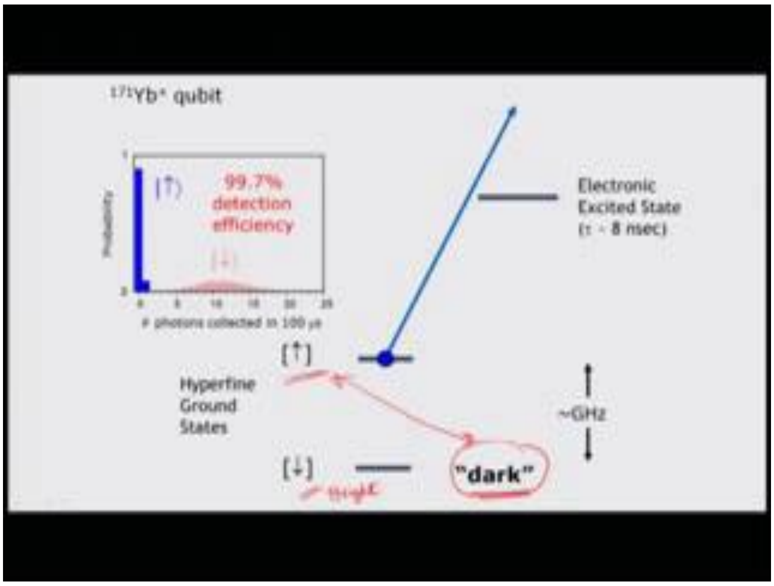

The other thing is that when once the higher hyperfine state is populated then then that is not coupled to any of the excite state. That is sort of known as the dark state because in the previous case where we looked at the bright state there was a coupling. So, the light could essentially the excitation would essentially bring back the light and that coupling could be seen, whereas in this particular dark state there are no photons to be collected as a result of that most of the probability is the fact that there is a no D coupling or like de coherence or like there is no state which is going to result because this is not a coupled state.

Excitation whenever only if this particular spins state is populated then it is the bright state, whereas the excited the other rotational state is populated then it is the dark state. This corresponds to the dark state and this corresponds to the bright state.

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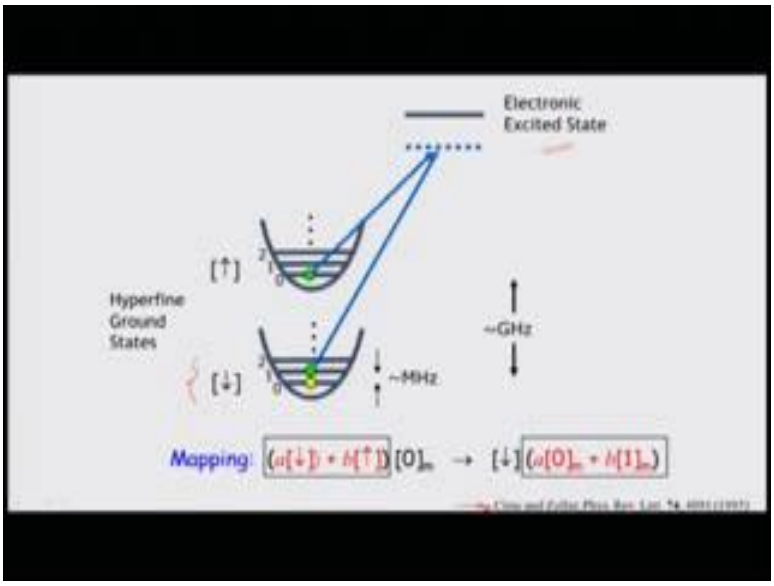

These hyperfine ground states are the ones which are sort of utilized for getting into these states which have been put together in terms of the mapping which are shown here. For example, a combination of these a states from one particular hyperfine spin condition which is of lower energy is being utilized with and to the electronic excite states to produce a coupling between these 2 different states. And these can be mapped by using this kind of approaches as has been shown in this particular diagram.

And if you want to learn more about it, you may want to look up the original paper by Pregan solar in 1995, where they have discussed this entire process in detail for this particular class. We are not going to go into these kinds of details because that takes a lot more effort than what we are actually trying to show.

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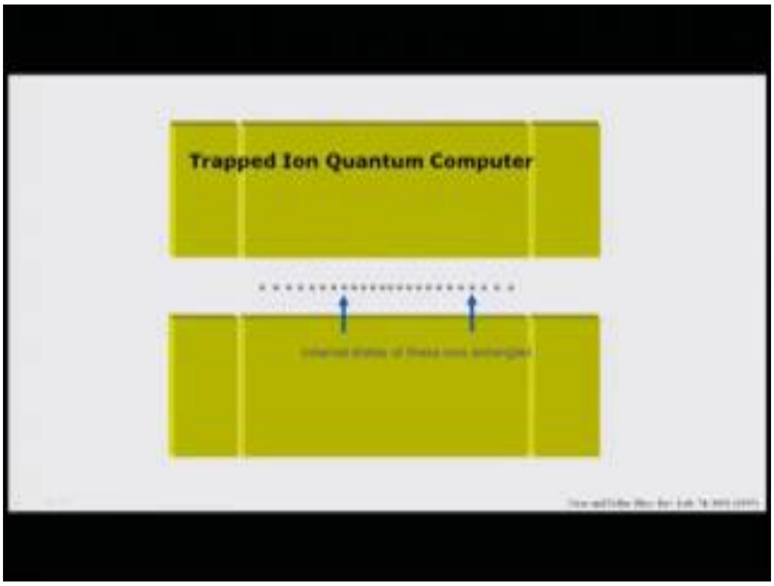

In terms of implementation aspect, here we would like to actually just suffice to point out that the laser beam is essentially looking at by a motional condition of the trapped ion in the system which is then being excited by the laser at different positions. And by looking at these lasers interactions we are able to do the interactions which are going to make them the internal states of the ions entangled in one way or the other.

This is basically the principle as to how the experiments work, once we accept the fact that the states are going to be coupled by using the laser which is going to bring them come closer. Here for example, the coupling between these states which I just showed with the laser again which I will again show you is possible due to these states getting coupled and that is the exact thing which is been shown in this cartoon where initial a laser essentially put some of the this study here.

And then there is other coupling which is done by the other state and finally, the third one puts it on together such that the internal states of these ions get entangled. This is an similar to the to the initial I J states of the ions that I had shown in the last lecture where to at the very beginning I was discussing as to how the ions of a particular set can be coupled in these kinds of scenario. This is actually a practical application of that initial opening few slides where I had shown, how to address different ion sets and then have them coupled.

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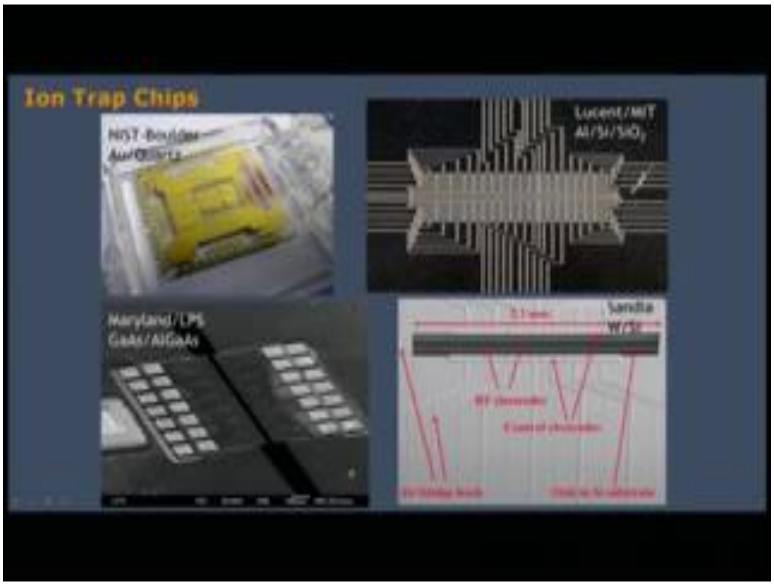

Ion traps have gone from being just very complicated objects being under vacuum and other kind of difficult conditions to states which can be addressed in terms of chips, which one put under appropriate conditions and they can be again addressed and brought back to the similar conditions. Here are some ion trap chips we have been showed, these are the studies from different groups where they have essentially put together, how they have done this entire process in solid states conditions where these channels.

And these were conditions were these injection points are the ones where the these trapped ions are been placed and they are traverse and they are addressed and that is typically how these different systems are and as you can see that they are very small and miniaturised, 100 micron gaps in one direction in this whole device is about. In this case for example, in sandier is about 2.2 millimetres. In lucent also you can see these are these are all the technologies that they have developed over the years and they are very well addressed can be utilized in many different cases.

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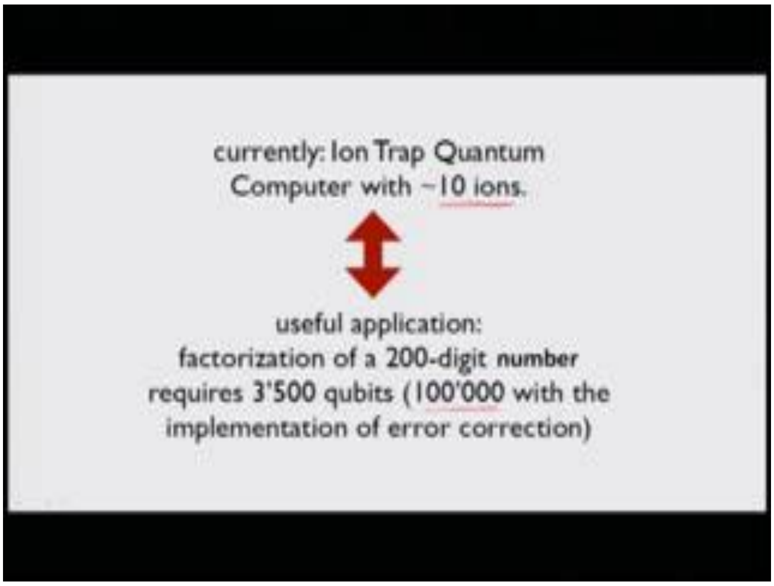

Currently the ion trap quantum computer that we are looking at is up to about 10 ions that we are managed to see. In our particular presentation here in this class we have shown experimental set ups with about 7 ions in place. However, for actual useful applications, say for example, factorization of a 200 digit number, there would be requirement of about 3500 qubit and if you would like to implement that with error correction there should be about 100000 qubit.

It requires a lot more scaling up then where the current condition is for the ion trap case although it has been excellent start up point for demonstrating. Some of the very classic of the text book style concept principles for quantum computing, it needs to be scaled up and. There have been lot of applications or at attempt.

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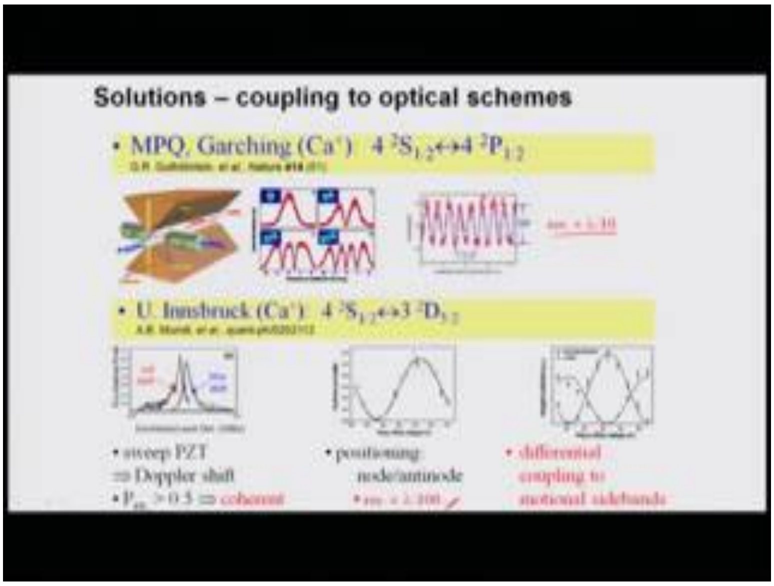

One of the cases in terms of scaling up for example, these are solutions that we found in many of the literature cases. It has been related to coupling for example, to optical schemes which has been attempted by Maths Plunk Gaussian, where they use the calcium as we discussed in this particular case. The case of the maths plunk institute quantum optics or Gaussian they used as calcium ion as one of the ion trapped condition and they were able to address the calcium ions, but using the optical light sources and that was one where the resolution was limited by how far or how far away these ions could be put together and the resolution there is about lambda over 10 which is quite a good resolution. The (Refer Time: 31:45) for example, with the same ion and has been addressing this by using laser detuning and that they have been utilizing the cooling principle and that particular one has resulted in over lambda over 100 resolution. The resolution is much better when it has been utilized in terms of the Doppler shift condition because that is the one which is using the advantage of cooling the system. And it is essentially is looking at differential coupling to the motional side bands of these kinds of motion.

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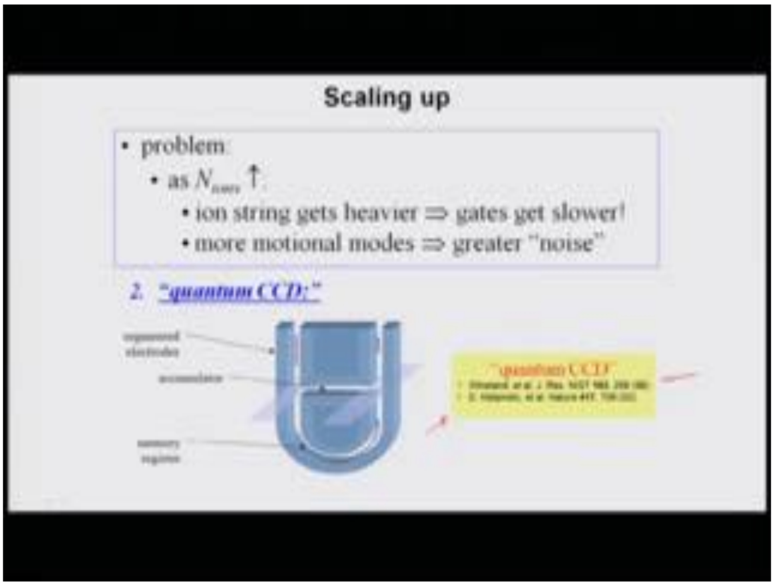

In terms of scaling up we mentioned before, it would be perhaps be interesting to see a C C D couple coupled device for instance, where the charged coupled device kind of a condition were these segmented electrodes, which are necessary for manipulating and motion of these ions are being put together in such a ways that they sort of look like a coupled condition and in these kinds of charged couple conditions which is the work of this particular groups where they claim that they could essentially use the idea of a C C D to making in to a quantum C C D by using the segmented electrodes to bring the ion trapped ions into these condition, where they would be creating the accumulator and they would be keeping the rest of the ions waiting for action as memory.

Once you have encoded them and kept them. This particular works for ion traps because as we have discussed ions traps have very long coherence times that they can be kept as and their interactions and their times scales that we have been discussing of the D case are very very long and this particular approach of design condition where we are setting up states like this and their being cooled or interacted by using lasers or RF or other ways of addressing them are been done in this accumulator or these other places where they can be made to work with. And this is a design condition which can be provided which has been provided by this groups and if you are interested you can look more into these papers to realize or understand a little bit more on this area.

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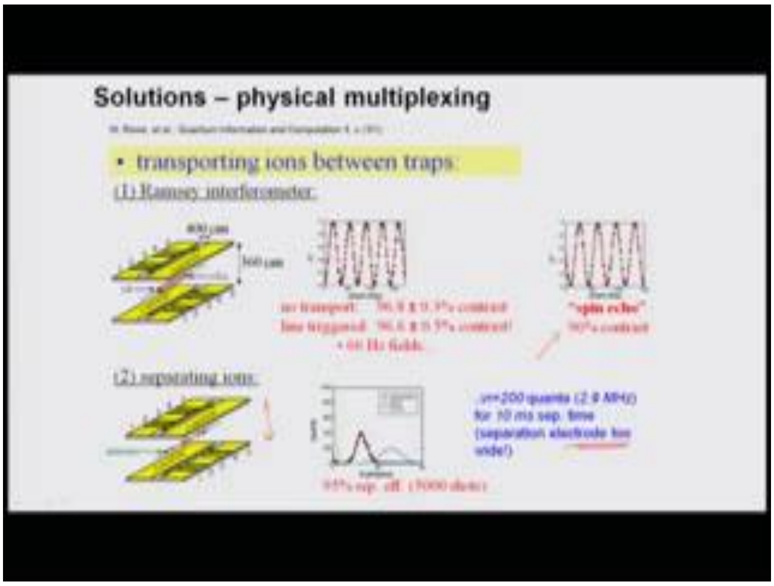

The other interesting way of scaling up the problem has also been using physical multiplexing aspects, where the ions have been transported between traps so that they can have a larger number of traps which can be put together and trapped ions which can be put together and they can then be subjected to the different RF or laser conditions to achieve the kind of information processing that would be liking to do that or put in information and manipulating them in terms of data registers.

That is another approach which has been used where there are 2 different cases, one is to by using introformatic approach and the other is by separating the ions by using RF electrodes. In either case, generally the N result is the fact that you are applying lasers to kind of see how they are going to interact and they can be made to work if the separation is made too large. For example, here separating electrodes has been made too wide, then it will not be possible to get the results effectively and these are the kinds of work which have gone into these kinds of experiments to show what is the good condition what is the bad condition.

In case of introformetric cases, it has been shown with say like about 96.6 percent of success to how this course or like transport versus spin ago is one of the conditions which are used for seeing that the D coherence is minimized and that is with 96 percent contrast ratio. It means that the coherence is maintained in terms of the transform. And it is important to realize that these are the processes that have been utilized over these years to see if this concept of multiplexing the ion traps and their conditions can be improved.

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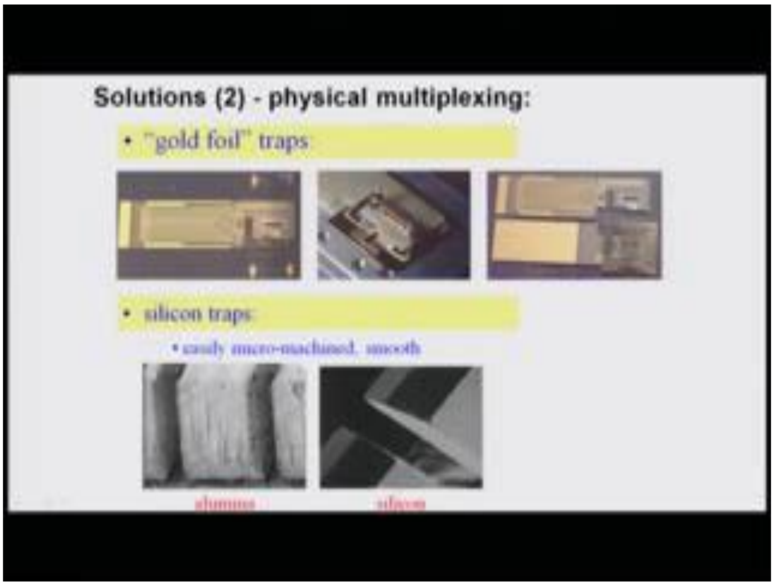

This is sort of look like how it looks like, when you are looking at these physical multiplexing objects they can be utilized in gold traps silicon traps and solid states devices alumina silicon and this is how they have been made to go forward.

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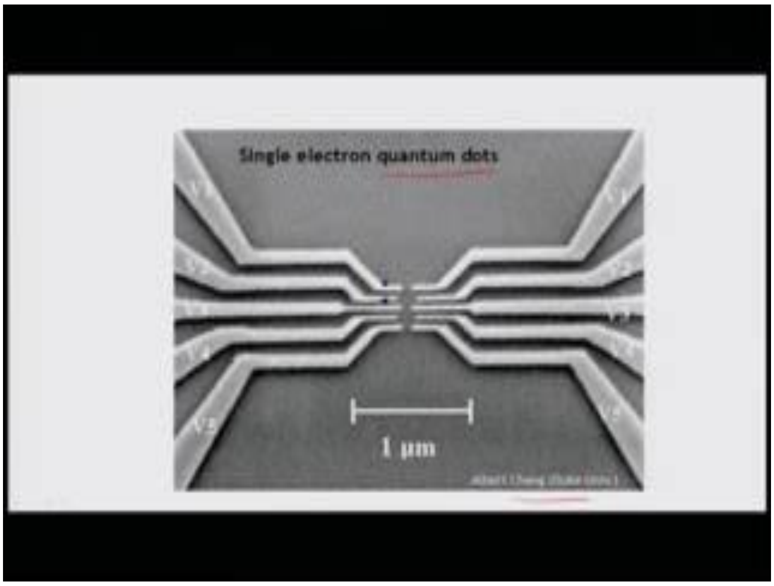

They have been also efforts in making single electron quantum dots which can act like these devices, where the traps into a trapped condition and this is the work which has been done by a group in Duke university. In order to say that they can actually generate single electron quantum dot conditions and that can also work almost as a these kinds of ion traps trapped and conditions, but this is again one of the other cases where different object is being mimicked to be applying to these kinds of applications of quantum information processing and coupling of the different concept, but it is important to point out the different aspects of applications have been put together to make the progress.

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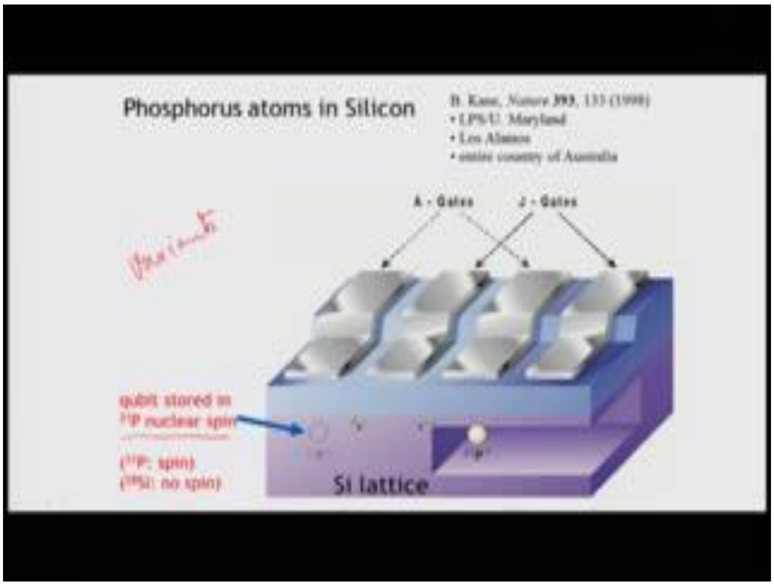

More work has happened in terms of utilizing the say, host atom in different kind of lattice and where the host atom is essentially acts like an ion which is sought of trapped under these conditions. These are like solid states conditions where these are achieved the qubit is then stored in say for example, in this case the phosphorus spin, nuclear spin inside the silicon lattice.

This is sort of like the condense face version of the of the ion trap, where we were still individually addressing these ions or the atoms that we are talking about, but in a different format and they can then be addressed by using different electrodes, which are then be put together to be placed in different ways, voltages and registers. These are different ways of addressing these particular variance of a the very original idea of using ion traps, but it is not exactly the same way that we have been starting on the idea of ion trap.

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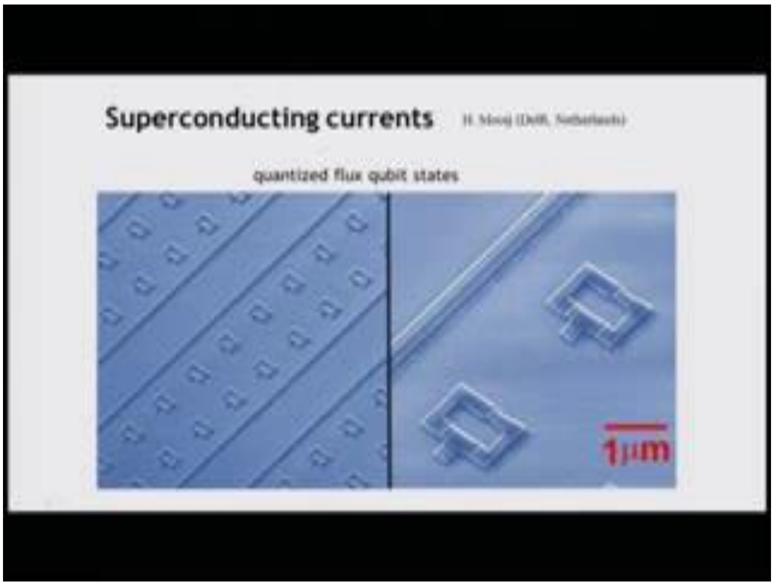

There have also been concepts, which arise from this very basic principle of ion traps to go into super connecting currents were the quantise flux qubits states of super conducting states have been utilized. Once again it is again a deviation from this in principle, but again its utilizing the atomic modes and atomic conditions.

And therefore, it is somehow related to how these quantum information processing started off a ion traps. All of these have been summarised in one of these reviews which came out some years back in nature where they were discussing about how the qubits at that point of time have been looked at, it is catching the bus catching the quantum bus kind of an idea.

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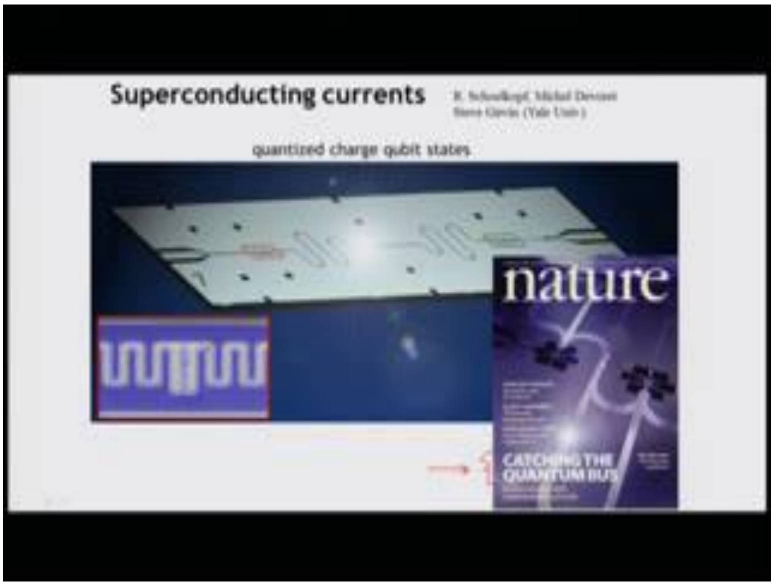

Where, they were able to transport and talk about charged qubit states, quantised charged qubits state based on these principles and since they all have ionic behaviour. They sought out are connected to the original concept of the ion traps.

However, let me also point out that this is not exactly the way how the original ion trap principles evolved as I have essentially showed in the beginning of the in the rest of the presentations here.

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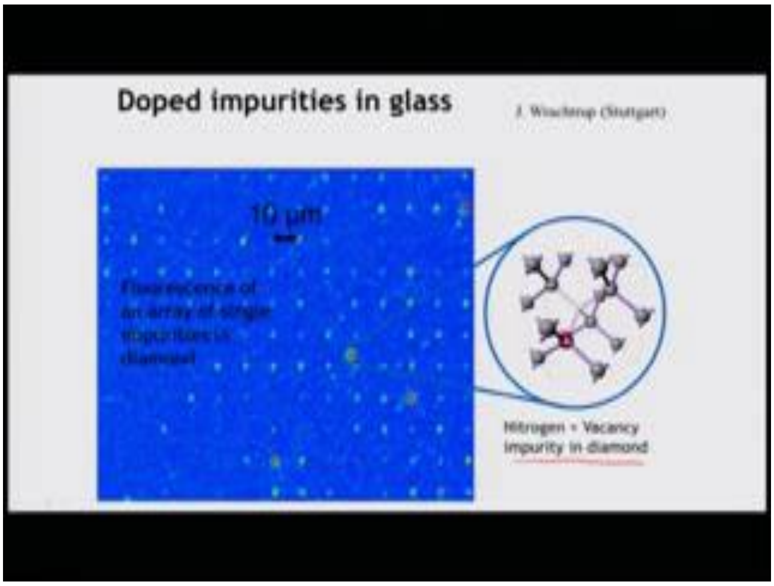

Another useful solid stating implementation of this area has been the principle of utilizing doped impurities in glass for instance, this is the this is been looking at a glass which is a which has been doped with impurities which are florescent and these florescence of these arise of single impurities in diamond in the glasses structure has been utilized for this kind of cases where the nitrogen plus vacancy impurity in diamond is the one which has been put forward as another idea of utilizing it.

Most of these invoke the principle of ion traps and or address it to sort of out explain the way, how they are going forward about it, but generally speaking and the original idea of ion trap is the one which essentially uses a very high, very different conditions and sought of the principle of cold atoms and things like that which brings us to the principle of the original ion traps.

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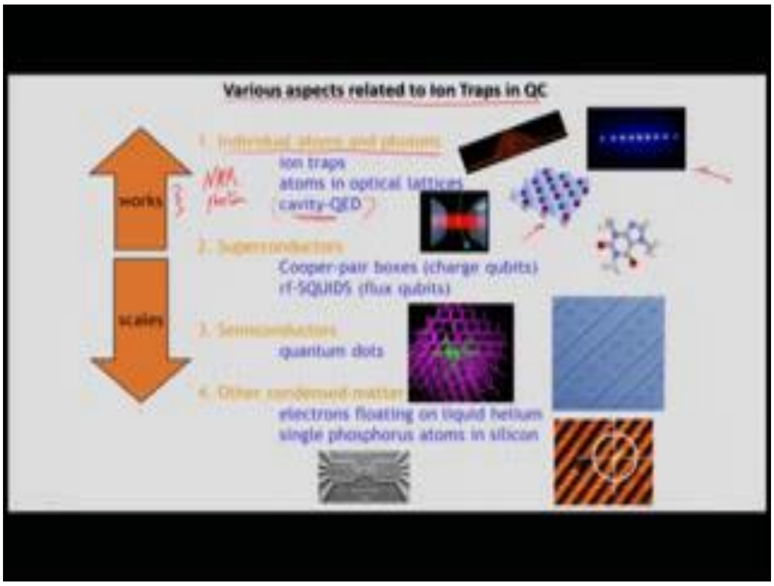

If we look at it this context various aspects related to ion traps in quantum computing, this is what we have in principle where the where the idea of the individual atoms and photons doing the job is where we have concentrated and discussed over the last few weeks, where we have shown that the ion traps or the attempts and optical fields. We have not quite discussed the cavity q d part, but we have alluded to here and there, where it essentially shows that this can be worked on. And they can be also looked at in the present context in terms of these lattice structures either because the ions are getting trapped or presented. In this kind of a fashion where each of them are addressable, in this form or in the solid state form where they have been put together in one place of the other and they have been entrusted in this particular ways.

And there have been other difficult principles, which we have not yet addressed, but we showed some indications where these principles have been extended to and we are with the claim is that they separately, they seem to scale better then these working condition cases. We also looked at another working case which is the NMR case in this case and NMR and photons by themselves. We will put them under the working conditions whereas, these others scaling condition ones are the ones which are being proposed and looked at more in recent years because they are seemed to stem towards a direction where they would perhaps scale better.

In the next few weeks that we have left we will perhaps go a little bit more into these newer concepts of the work that has been going on in terms of implementation of quantum computing. We might actually spend little bit time later, just to give you one of the other historic principles which has shown that quantum of computing work in terms of cavity Q D, but generally we will spending more time on principles where scalability issue seem to have been of some sort which we are going to address in the future courses future part of the discussions.

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Number cruncher turns 50

1st electronic computer feted

Granddaddy of computers turning 50

Before I close in this particular week, I would like to point out that although presently the picture of quantum computer and information processing and the way how things have been are looking not quite as what we aspect and it also looks to be a something of the extreme future. This is a cutting from a newspaper which came out in exactly when the first computer in any Eniac turned 50 at February 12th 1996 was the day in was when this newspaper came out because a 50 years before on the same day the Eniac was first put to action and although the electronics people said that there were too many vacuum tubes and it would never run.

The mathematics people said there was no problems complex enough that the computers were needed. That was the thing at that time where the Eniac team had to work on to get it to work. And this one fully of operational was filled by if 30 by 50 foot room in terms of the scale as to how this look like and the current day power of this particular machine is worse than a present calculator that you have in your hand and yet this was the beginning of the concept of the computer that as we know today.

And if in 50 years computers have gone through a huge revolution as to what we know today, there is a lot of hope still that these different implementation principles. Although, they have far from being what we expect or want them to be would in the future someday, become one of the major horsepower of computing perhaps which as we are discussing is quantum computing with that.

Thank you very much, and see you next week.