Implementation Aspects of Quantum Computing

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Lecture – 31
Understanding Implementation Issue from the Basics-I

In terms of quantum algorithms, it has been an integral part of the implementation that we have been discussing.

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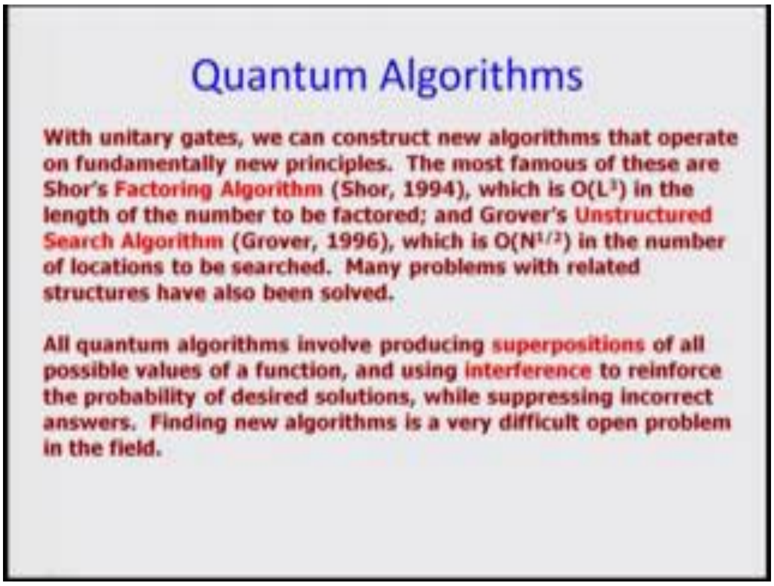

And in most of these cases with unitary gates, we have shown the construction of new algorithm that can operate on fundamentally new principles. Generally speaking the most famous of the ones that we have often used in terms of implementation has been Shor s algorithm, and the Grover s unstructured search algorithm. Both of which have been featured as the most important algorithms to be implemented in terms of quantum computing. Although one of the first ones, we often have manage to show in terms of implementation for the rudimentary computation has been the (Refer Time: 01:00) algorithm.

Algorithms have played a major role in the development of the or actually in the way that the implementation is appropriately working or not. That is sort of like a check point also, in terms of the quantum computer. In terms of the quantum computer implementation, quantum algorithms have in fact played the major role in proving that the quantum computation is properly working. Many problems related to the structures of the algorithm have also been looked into has the developments for the implementation have been taken care. The basic logic behind almost all algorithms have been in terms of producing super positions of all possible values of a function and then using interference to reinforce the probability of desired solutions, while suppressing incorrect answers.

Finding new algorithms has been very difficult task and open problem in the field. However, the algorithms by themselves have often acted as a check point for us to make sure that our implementation of quantum computing is going in the right direction.

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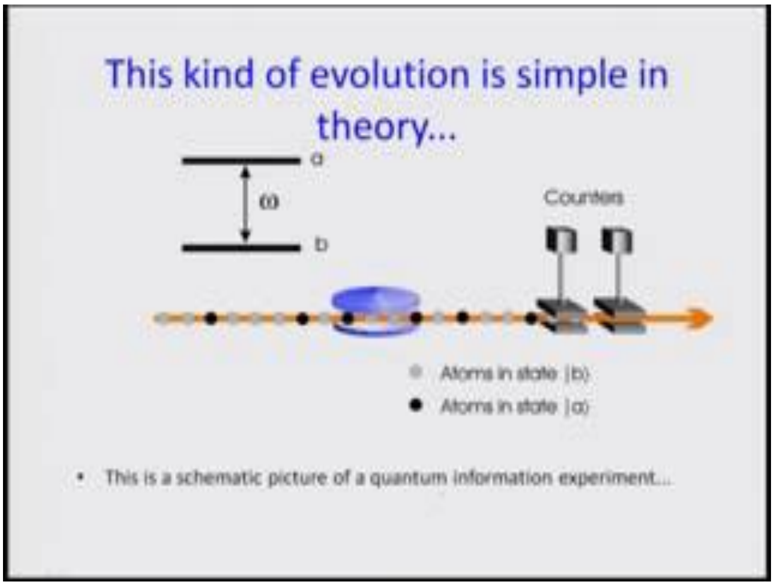

It also has played very important role. As we know the evolution of theory seems to be quite simple, you have a certain set of the states that we looking into in terms of the quantum states which are digital and have their proper values encoded in terms of being in a particular state a or in terms of being in particular state b. And in simple procedures the detection or the measurement procedure just involves finding out how many are on what kind of state. In some sense, the schematic picture of an information processing can be very simple in theory.

It is in analysis to the digital communication network, it could be thought about as streams of information in terms of quantum steps of a particular kind in this particular case being a or b or in between whatever their property b is been transmitted and the counter is going to finally, just measure it. In practicality however, the typical picture of a quantum information experiment can be as complicated as this.

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This is one of the optical approaches and the photo of an actual laboratory works on optical process to quantum information processing. The photons have been counted and the same principle. However, it is a real big complicacy in terms of the actual implementation in the laboratory. The reality of the implementation process is often quite much more involved than the theory.

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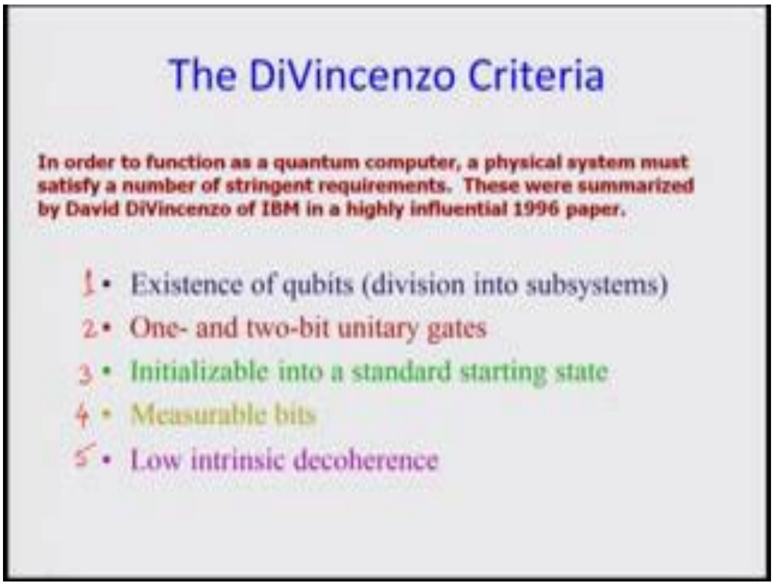

1 of the most important properties when we have been discussing implementation has been the concept of the DiVincenzo Criteria to be followed. In order to function as a quantum

computer a physical system must satisfy a number of stringent requirements. These were summarized by David DiVincenzo of IBM in a highly influential 1996 paper. And in terms of implementation we have always followed these criteria and I list them here once more for clarity and making sure that we remember this and that is the first one being the existence of qubits.

So, identification and existence of qubits so that they can be made into the process, that is the first part. Existence of qubits division into subsystems and the second part involves one- and two bit unitary gate developments. The third one involves initializability into a standard starting state for the system concerned. For example, if you are chooses a subsystem, say the ion trap system, then the first property of the ion trap is to make sure that it has the proper qubits available, which can be isolated into a proper subsystem. Then see that implement ability of a few qubits unitary gates are designable and possible. Then the other most important part is the initialization into the standard starting state.

Finally, the availability of measurable bits are extremely important and the critical part of this entire process lies in the low intrinsic decoherence of this entire system. Otherwise the competition process cannot be completed and it is important that all this criteria we have taken care.

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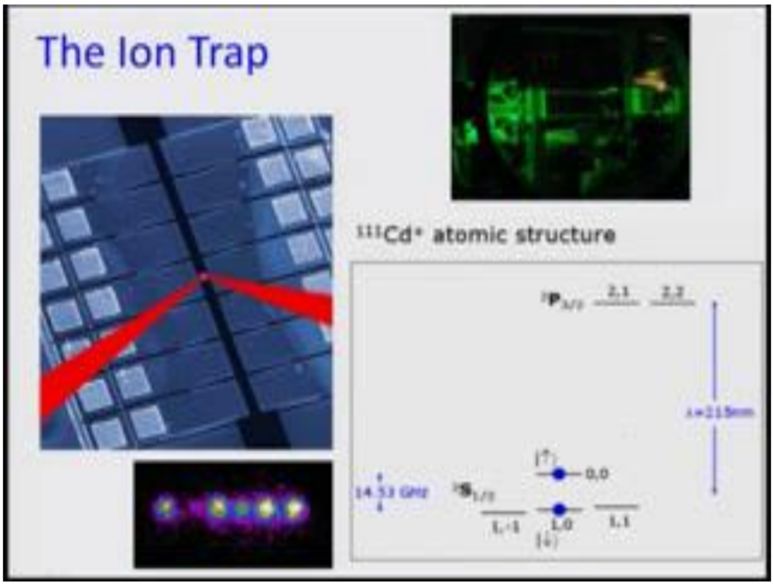

In terms of the ion trap, we have discussed many cases in the earlier weeks. For example, the cadmium case, there were the 2 states which were separated by 14.53 gigahertz. The 2 spins states of this is to half state, being one going downwards, the other going up at the ones which were used for the ion trap condition and is the superposition of these 2 states which created single qubits and depending on how they interacted with each other in terms of their, when they have set up in the trap, it was essentially used as the ion trap qubits.

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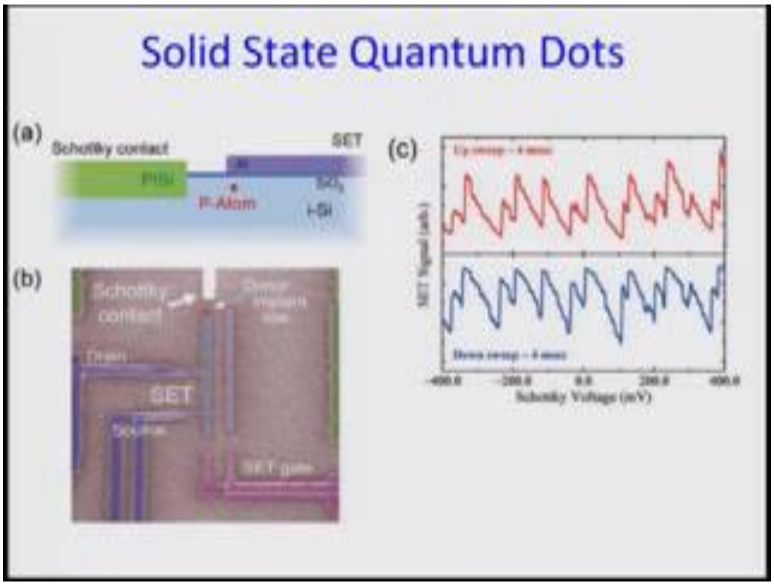

We have also discussed about solid state quantum dots, where the defect would offend be utilized as a way of doing quantum computing. In the, at the contact point say the Schottky contact point, there is a donor implant site, which was utilized as a single atom picture so that this gates could address them and be available for the operations to go on. Here for examples, this switching voltages and the measured gate changes where found out by changing as the upward sweep, it could track the process as you go upward versus downstream process and both of them about in terms of 4 milliseconds cycle, they kind of tracked opposite to each other as the system was undergoing this upstream versus downstream changes.

The system essentially tracked each other in the way of doing this processing. There are approaches where the solid state quantum dots have also been utilized and thus one of the places where implementation has been looked at.

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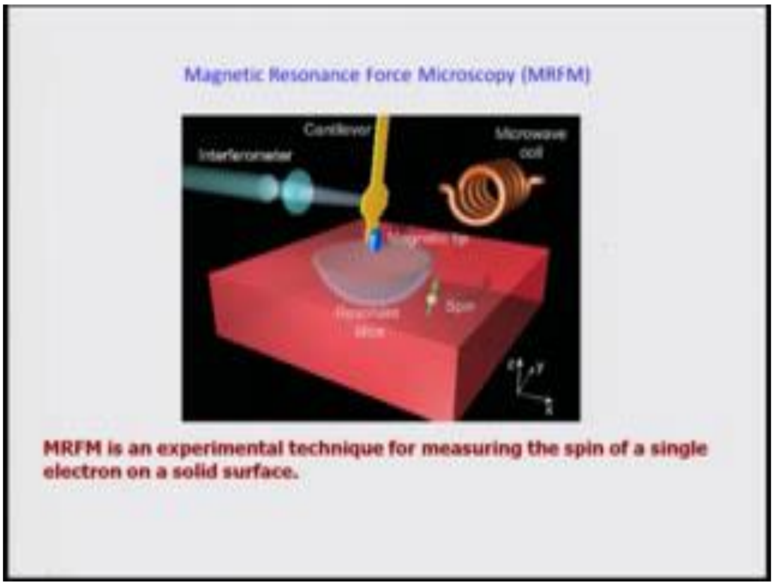

The other important implementation is an, is also the idea of using the magnetic resonance force microscopy and which is an experimental technique for measuring the spin of a single electron on a solid surface. Generally in almost all this approaches we have been using the spin of the electron as our approach. Mostly we have been using the spin as a quantum number which we have utilized for making the implementable quantum computing. In ion traps also, it was the spin up the electron, whereas in terms of the NMR it was the proton on the nuclear spin which was looked at.

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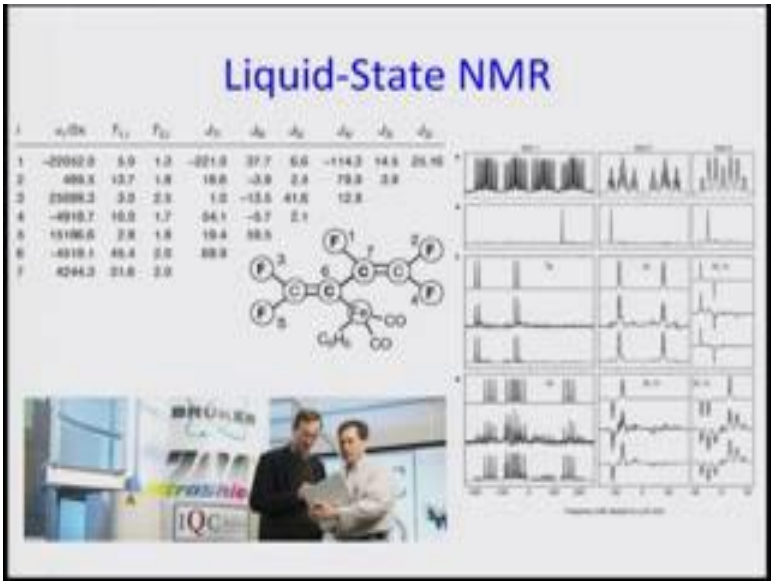

Here is the concept of the NMR quantum computing where the maximum number of qubits possible with that has been shown. It was the 7 qubits system where this particular molecule was specially synthesized to have the access to all this number of qubits. The fluorine and the carbon essentially set the stage for the qubits which could be coupled and entangled and utilized for doing Shor s algorithm.

This was one of the cases where it was used for doing quantum computing and this is by far the largest number of qubits which have been used in terms of liquid state NMR studies. It is now shifted to other areas of NMR, which is also been attempted with certain levels of success, our each of these cases of that difficulties. More details of this have been addressed in earlier lectures with this is just a revision in terms of looking back and showing that we have looked into all this different cases.

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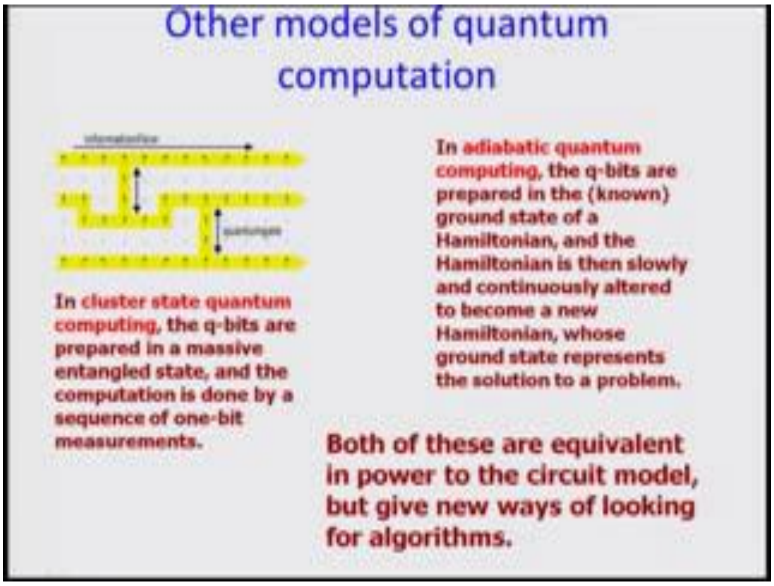

The other models of quantum computation that has been important, which has been the idea of cluster state quantum computing, where the qubits have prepared in a massive entangled state and the computation is done by a sequence of one bits measurements. Most of this required very low temperatures and that is one of the principle requirements for most of the process that we looked at. The another area which is being pursued is the adiabatic quantum computing where the qubits are prepared in the known ground state of a Hamiltonian and Hamiltonian is done slowly and continuously altered to become a new Hamiltonian, whose ground state represents the solution to a problem.

Both of these are equivalent in power to the circuit model, I mean the circuit model is the ones which are been discussed earlier, but and we have been discussing the circuit model in most of our cases of implementable quantum computing; however, these are alternate ways of looking at the quantum computing and they give a new ways of looking for algorithms. One of the ideas of the adiabatic quantum computing with light was shown in one of the implementation lectures, where the property of the light was chosen to interact with the system, quantum system.

In the particular case it was state of a molecule in a beam chamber and the state of the molecule was being addressed by the property of the light which was being provided and that was used in a adiabatic manner to try to show that new ways of looking at quantum process could be done and gates could be devised in that manner. In fact, I think CNOT gate was shown to be implementable by this way.

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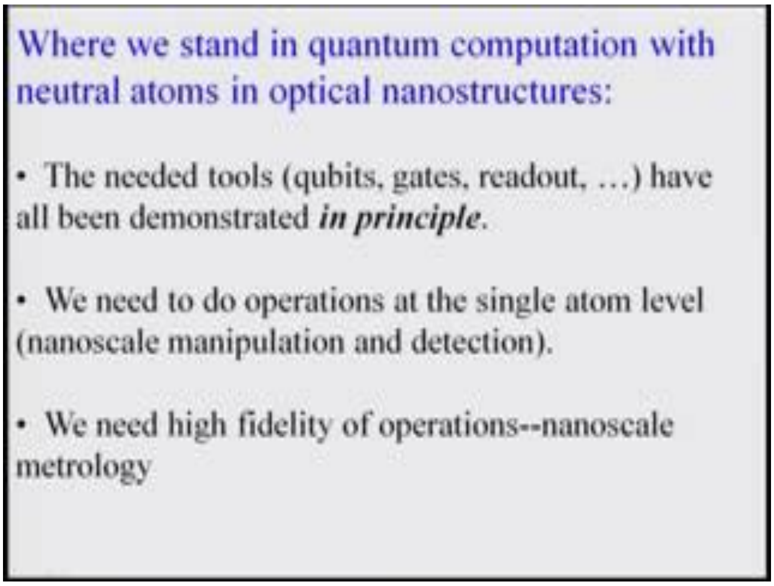

There are ways of doing equivalent it looks at quantum computing and this has been all discussed. In terms of looking at how we stand in the current picture, the needed tools have been in principle demonstrated in many cases and the operations at the single atom level in terms of nanoscale manipulation and detections require little more development so that it can do a better work in connection to the one of the most developed techniques, although not commercial yet, soon going to be commercial hopefully, is the ion trap as we discussed which also has the highest number of qubits, currently in real terms of how the circuit picture we discussed.

In other ways of looking at the there are commercial approaches of the D wave which has this own different approach of looking, that is not the same as this, but in this particular case of the ion trap for instance, high fidelity of the operations and can also help a lot and nanoscale metrology is developed, that can also go ahead in this direction.

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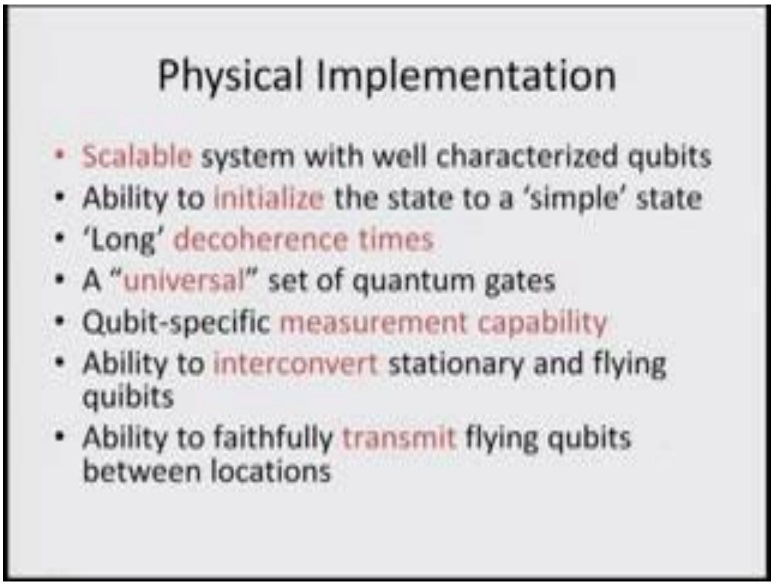

And we have been discussing on the physical implementation aspects and we have shown the scalable systems with well characterized qubits, are the basic way how the research is going towards. The ability to initialize the state to a simple state is one of the important criteria to start with. These are all practical ways of restating say the divisive criteria. Long decoherence times, a universal set of quantum gates, qubits specific measurement capability, ability to interconvert stationary and flying qubits.

And finally, ability to faithfully transmit flying qubits between locations are very important in terms of finally, getting quantum computing as well as quantum information processing to occurs. The idea of having flying qubits and transmission are critical to quantum information processing.

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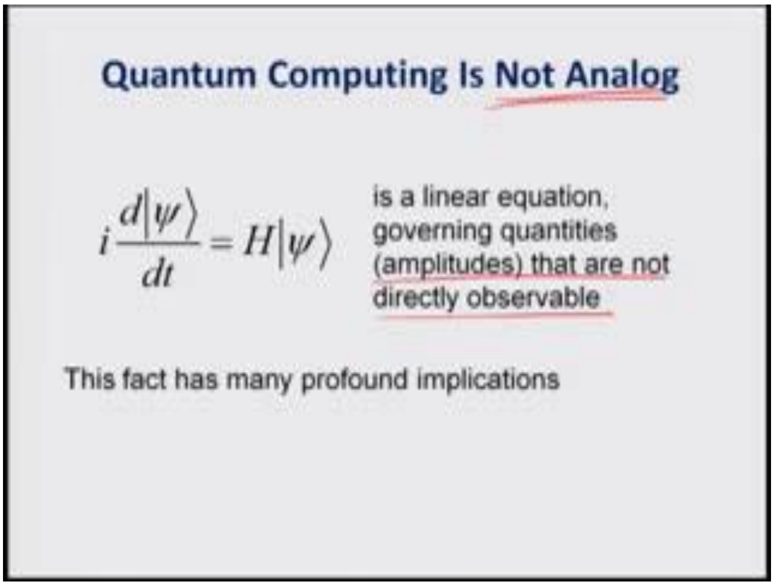

Now, one of the things which is to be cleared up because many times the advantage of the quantum computing in terms of its huge paralyses makes people feel that it is sort of like an analogue, continuous processing aspects because when we try to explain the idea that it is all the possible states between say 0 and 1, which are the 2 conditions of a classical bit is available when you do quantum computing. It is sort of gives a picture and may be some times it is colloquially even put as a way of doing analogue computing, which is not really the process. That is what I would like to clarify because this may be something which might be pictured by some of you.

We would like to point out that the basic idea of quantum computing is not analogue it is definitely a digital process because we are having discrete values and unless and until see the basic point out of the word quantum lies in discreteness. If we ever make our self confused with the idea of having analogue in synergy with quantum processing, it will not work. It is true that the way ultimate results are coming, these power and the way things happened, it might look that there are continues operation or continues states which are available, but still each of them are suppose to have very individualistic discrete values, that is the basic ideas and what it does in the process solves the Schrodinger equation which is a linear equation, governing quantities which are amplitudes that are not directly observable. That is power of the computing.

There is the process of looking and manipulating the amplitudes that are not directly observable which gives raise to the main power of the computer and this fact has put into the profound implications that we are been discussing all this time.

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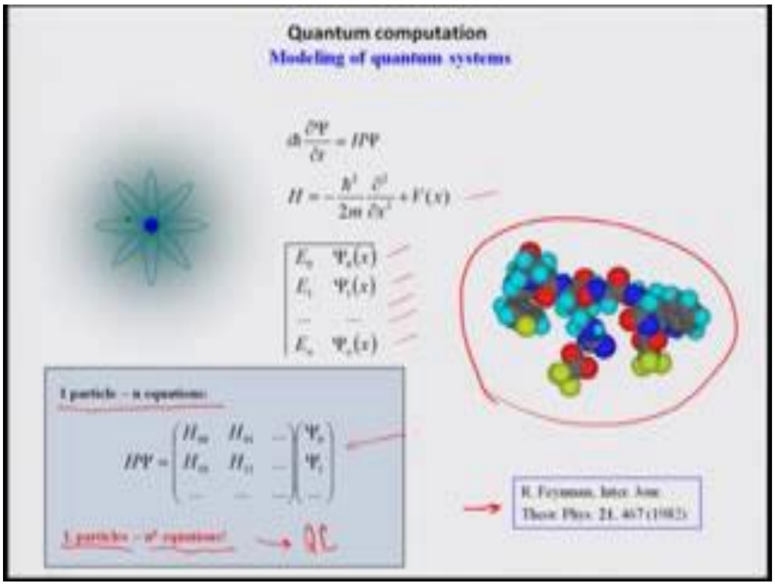

In some sense, one of the major aspects which led to the development of quantum computer, if you go back, all the way was in some sense popularised and recognised first by Feynman, where he pointed out the most important part of the problem that is the quantum computation is the way to go for modelling of quantum systems and that is to understand that no matter what we do, the quantum process that we are looking at is going to require in some sense the quantum computer to finally give the best results. In the simple is possible case when we are solving linear equations. We are looking at the condition where we are solving the energy of the problem is the bound condition and we have the Hamiltonian which is essentially nothing but a kinetic energy and potential energy part in this simplest possible one electron or one dimensional module.

This is the simple possible Hamiltonian that we have a right and this is partly the case which we first solved in terms of the particular in a box and those kinds of other basic is that we have discussed and each of the states that we talk about has discrete energy and that is the reason to believe and understand that is never going to be what we talk in terms of analogue and when we are looking at this process. We have essentially one particle giving raise to N equations that is one of the biggest issue to understand here that if one particle gives raise to

N equations, if we are going to look at L number of particles. We are in principle looking to solve N to the power L equations and that definitely cannot be done by an analogue computer. It requires quantum computer which can then go ahead and solve the problem.

This is what it is looking at that. In order to really solve the problem in terms of a large molecule, in terms of the way how Feynman proposed the problem is that, if one particular would require an equation and; obviously, to solve large quantum systems you would require a quantum computers because that only has the power to solve N to the power L equations. That is one of the basic points behind the idea of getting to quantum computers even from the basic principle of understanding the level of levels that would like to do.

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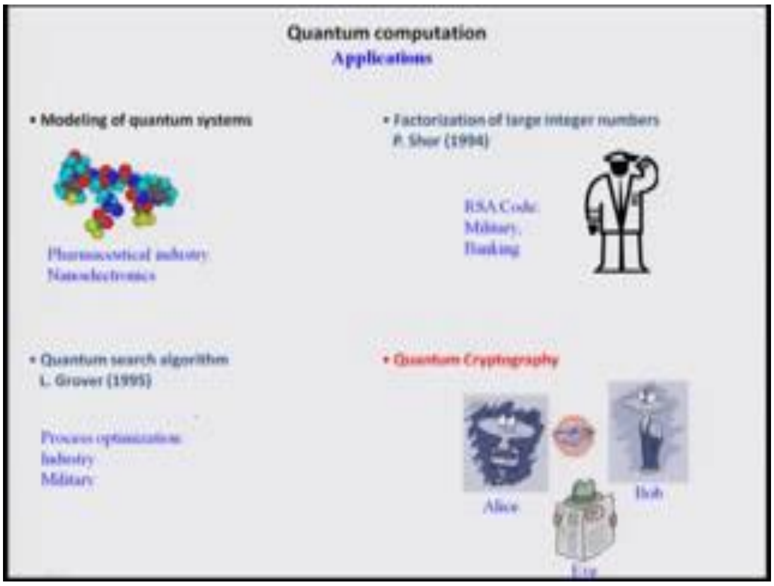

There have been several applications and the first part as we mentioned is the modelling of the quantum systems and in recent years from pharmaceutical industries and nano electronics have often wanted or demanded this level of computation necessary which are in terms of modelling quantum systems more and more accurately where Feynman prediction come into being and soon necessary to get into that kind of available.

One of the other very important applications has been factorization of large integer numbers which is proposed by Peter Shor in 1994, which has been very important point because this could lead to breaking of the security currently used in terms of using large integer for encoding data. However, that same principle can be utilized for achieving quantum cryptography which would then be making sure that the information is so secure that it can never be accessed by anybody else, in other words it is like if the information is excess, it is known that the information has been tampered we done.

Therefore, the information can be considered to be invalid in that case, giving 100 percent security and cryptographic information transfer. On the other important aspect development has been this research algorithm because that is also very important process where getting the answer from a set of possibility this is very important issue. In many a times, we have problems where we know that the solution excess is just to find out where the solution is and this can also have huge implementation in many industry military areas.

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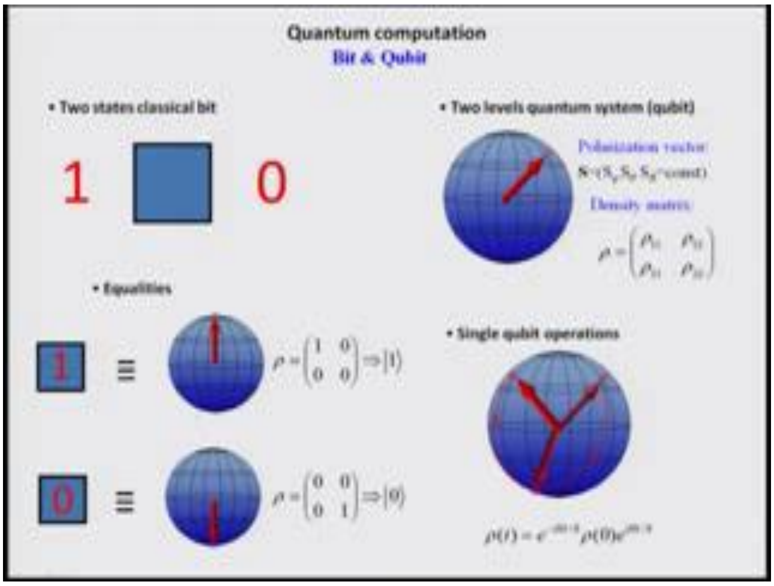

There is a lot of application that is going to be important for this kind of processing. What we will do now is to close on this summary kind of a lecture that we have been putting together in terms of the applications in connection to the quantum processing that we have been discussing.

And, in the next lecture deal little bit more into the concept of the quantum system, a little bit more in details so that it relates to all the developments that we have been discussing in terms of implementations which may become more clear as a result of that. And we will in go ahead further with that.

Thank you, see you next week.