Implementation Aspects of Quantum Computing

Prof. Debabrata Gowswami
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture – 29
Back to Basics – I

We have been looking at the commercial Implementation of Quantum Computing in the last week. It is a very important step because as we started in this area of quantum computing we were discussing how difficult the concept of getting to build a quantum computed today is. So, in that respect the very fact that we are now able to discus commercial implementation of quantum computing is a huge step forward.

In order to understand the implementation issues further on and to be able to connect ourselves to the principles and the ideas that are still a huge gap between the development of this problem as well as the implementation. This week we have decided to revisit the concept from where we all started this area of quantum computing. We are going to revisit the some of the principles and we will find out if we can make necessary connections to the places where implementation have been achieved and to areas were implementation can even have a better aspects in the future.

Also in many cases these implementations that we discussed about have a much larger impact than just the very principles of showing quantum computing. So, we will be dealing with these in this week a little bit more in order to understand how this has been developing.

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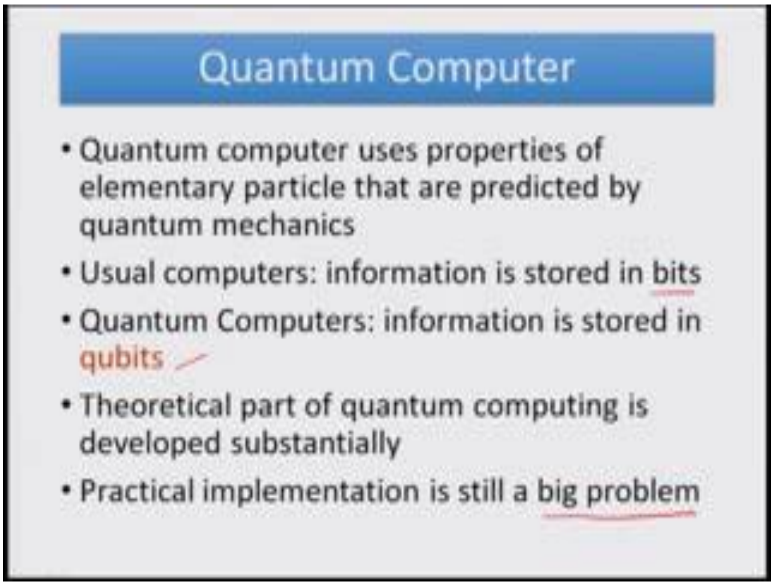

So, we started off the idea of quantum computer from the very idea that quantum computer uses properties of elementary particles that are predicted by quantum mechanics

In general we are use to the idea of computers were the information is stored in bits. In these quantum computers that we have discussed information is stored in terms of qubits. The theoretical part of quantum computing has been developed substantially based on the idea of these qubits, and the practical implementation as we have been discussing from the first point onwards is that it is still a big problem. However, at least our last week lectures must tell you that there have been large progress in the last several years which are making it possible for real quantum computing to become a reality. And there are many more companies who are coming in to this particularly area.

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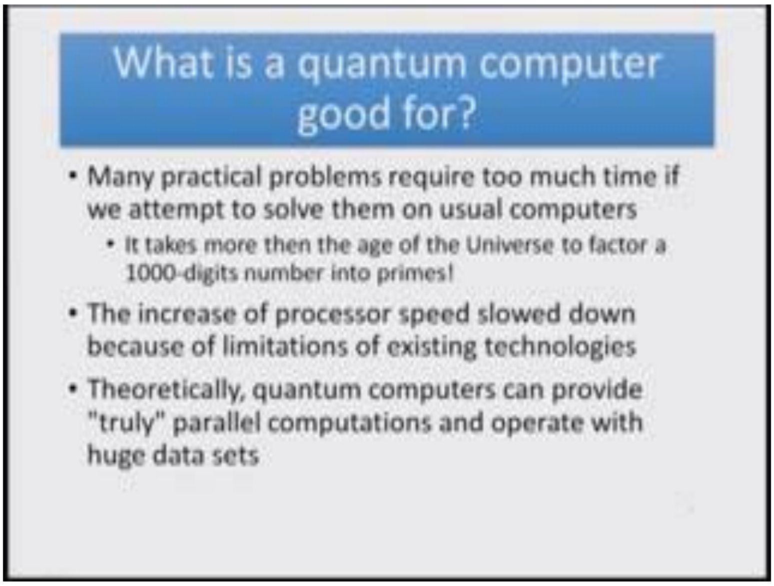

We all know the reason for this effort lies in the fact that quantum computers promise a lot of development as we have been discussing. So, many practical problems require too much time if we want to solve them in usual computers. There can be problems which can take the age of the universe, for example the factorization of 1000 digits numbers into primes.

So, certain problems definitely require this particular kind of radical computational ideas which will make them go or make such almost not possible problems into if solvable problem. With our conventional computers there are issues which are limited for example; the increase of processor speed has slowed down because of limitations of the existing technologies.

Beyond is a certain point these will again become bigger and so there has been a drive towards going to these principles. Theoretically quantum computers can provide truly parallel computations and operate with huge data sets. So, we these basics as we have been discussing form the word (Refer Time: 04:31) quantum computers have been an area which has been pursued for the feature of computing.

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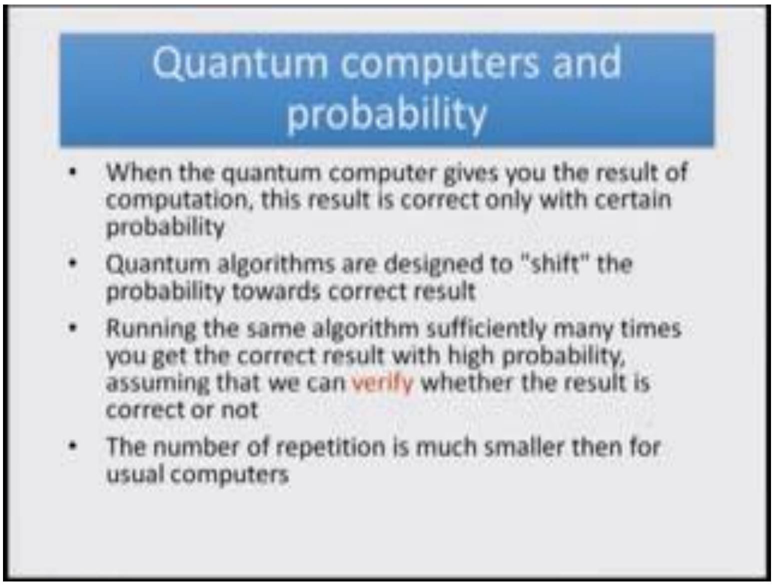

In many ways quantum computing is probabilistic and that has its advantages. When the quantum computer gives the result of computation this result is correct only with certain probability. Quantum algorithms are designed to shift the probability towards correct results.

So, running the same algorithm sufficiently many times the correct results can be gotten with very high probability assuming that we can verify whether the result is correct or not. The number of repetition is much smaller that are necessary as compare to the usual computers.

So, the probability angle of the computers in these cases is taken advantage of and many interactions which are otherwise required can be put to certain advantages when we are applying these kinds of principles.

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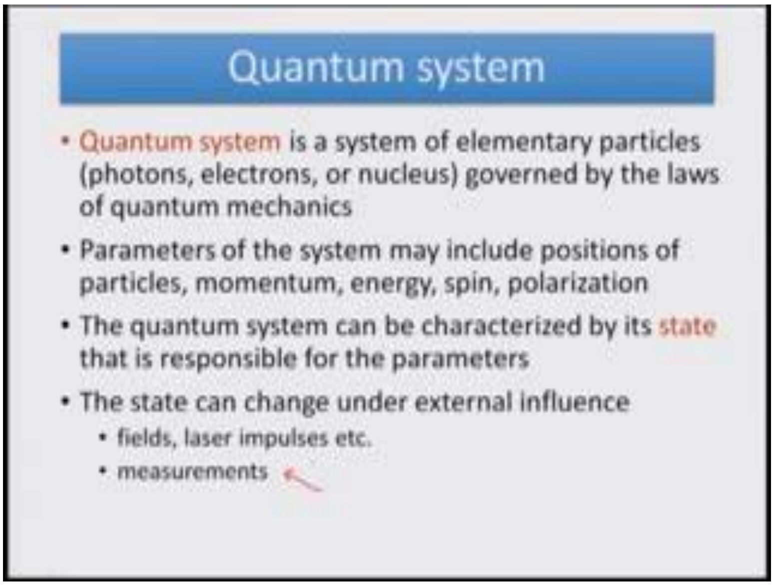

Now, Quantum systems that we have been using are the ones which are of elementary particles nature. So, for example, photons, electrons and nuclei that is governed by the laws of quantum mechanics.

Parameters of the system may include positions of particles, momentum, spin, polarization. These are all the things that we have utilize for implementing quantum computer. The quantum systems can be characterized by its state that is responsible for the parameters. The state can change under external influence and that is one of the ways how this particular principle of implementation of quantum computers had been taken care of. So, by using fields, laser impulses etcetera the concept of computing has been implemented

The measurements are the last and the most important part of this entire exercise. So, that these can be finally, used as computation.

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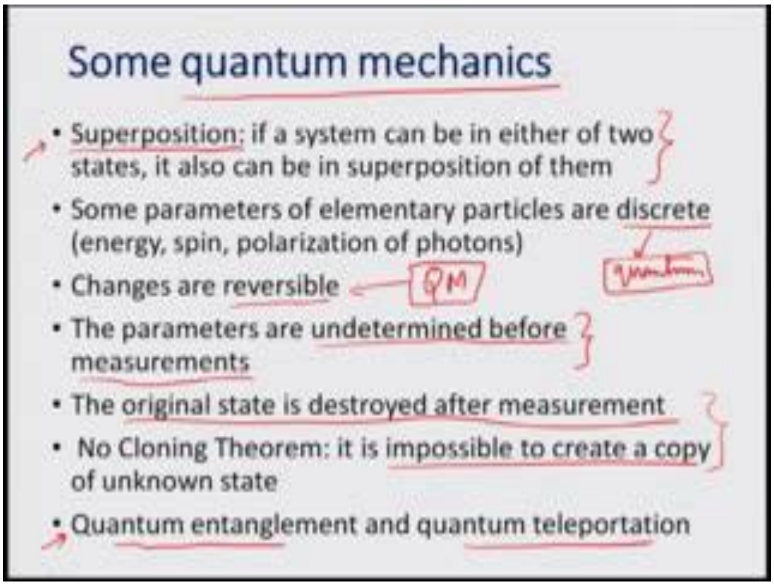

So, some of the most important Quantum mechanical aspects which have been used for quantum computing are the principles of Superposition which is one of the first principles that are necessary for the system to have any benefit over the classical system. If a system can be either in two states; it can also be in a Superposition of them. This is the principle which is use in terms of the superposition idea. Some parameters of the elementary particles are discrete for example, energy, spin, polarization the photons and those are the discrete parts which becomes the Quantum mechanical quantities for us.

Changes are Reversible and that is one of the biggest hallmarks of quantum computing that the Quantum mechanical aspects make sure that the process would be Reversible. The parameters are undetermined before the measurements and that is one of the most important parts of quantum computing that is different from the classical computer because these parameters if they are determined; they become classical.

The original state is destroyed after the measurement and that is another very important aspect of quantum computing which is distinct from the regular computers. It has to follow the No Cloning Theorem which means that it is impossible to create a copy of an unknown state and which means that certain aspects of quantum computer are going to be always extremely different from the principles of classical computing that are used to.

So, for instance since cloning is not allowed it would be difficult to think about processes where the same system is suppose to be reused the other big aspect of quantum

Mechanics lies in quantum entanglement and quantum teleportation. So, superposition, quantum entanglement these are often the key elements which are talked about in quantum computing.

However, the other very important aspects as we discussed or laid it out here are obvious one we have looked at the implementation aspects which are in the discreteness of the quantities that we are looking at which is the quantum nature, the reversibility of the entire process that we are looking at which is the quantum mechanical aspect of this entire computing process, the undetermined condition of the parameters before the measurements to ensure that the quantum nature of the system is maintained.

The No Cloning idea or the fact that the original state is destroyed after measurement are also some of the very important key features of quantum mechanical aspects of quantum computing that has to be maintained while the process of computing is done in approach.

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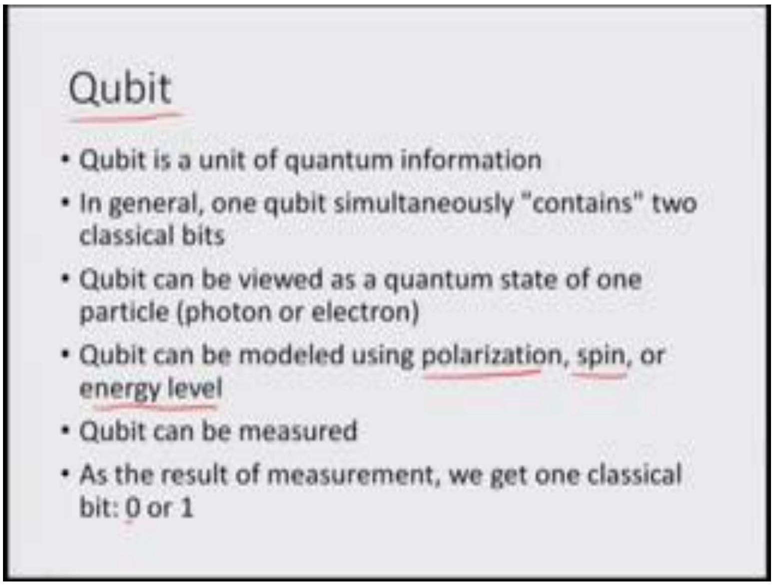

The qubit is the unit of quantum information for us in quantum computing and in general 1 qubit can simultaneously contain 2 classical bits.

The qubits can be viewed as quantum state of one particle say the photon or the electron and the qubit can be modelled using polarization, spin, energy level which ever are the quantize properties of the system. The qubit can be measured; however, once measured it is destroyed as a result of measurement we get one classical bit 0 or 1.

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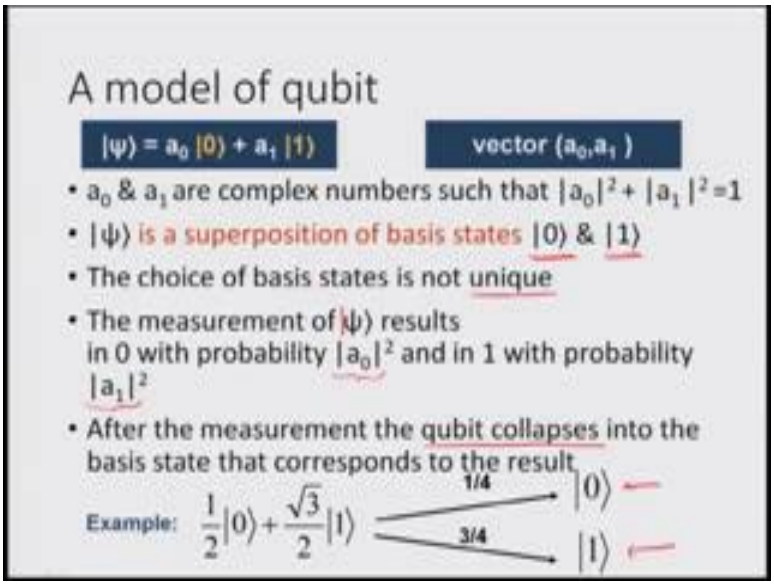

So, the module of a qubit has been popularly used in our entire approach here which is the 0 and one states to give rise to the wave functions psi. So, we have approach this problem in terms of vector algebra with the coefficients a 0 and a 1 are complex numbers such that the mod square of them add up to give rise to a total of 1. So, in essence these; a 0 and a 1; coefficients are containing the contribution of each of the states that are possible in the quantum state. So, the wave function is essentially a superposition of the basis states. So, the basis states are our zeros and the ones.

The choice of the basis state is not unique and this is one of the things we had also discuss where the basis set transformation is often necessary for understanding or applying the principle of quantum mechanics quite easily the measurement of the wave function results in 0 with probability of say its coefficients square and 1 with the probability of the coefficient of (Refer Time: 12:12) particular coefficients square. After the measurement the qubit collapses into the basis state that corresponds to the result.

So, this qubit collapse essentially means that we have lost the quantum bit. So, here is an example the coefficients are half and root 3 by 2 which means that we can have a one-fourth probability of measure 0 basis state and three-fourth probability of measure of 1 basis state.

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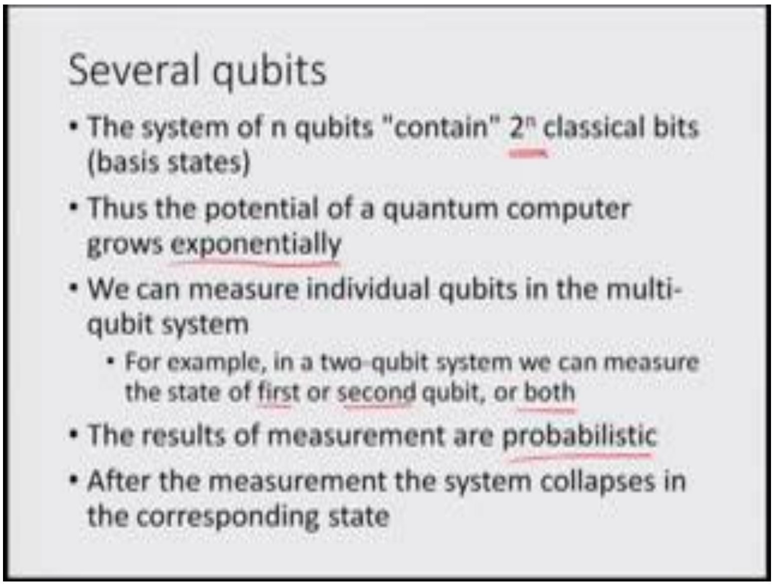

So, in general the subsystem of n qubits would contain 2 to the power n classical bits which are our basis states.

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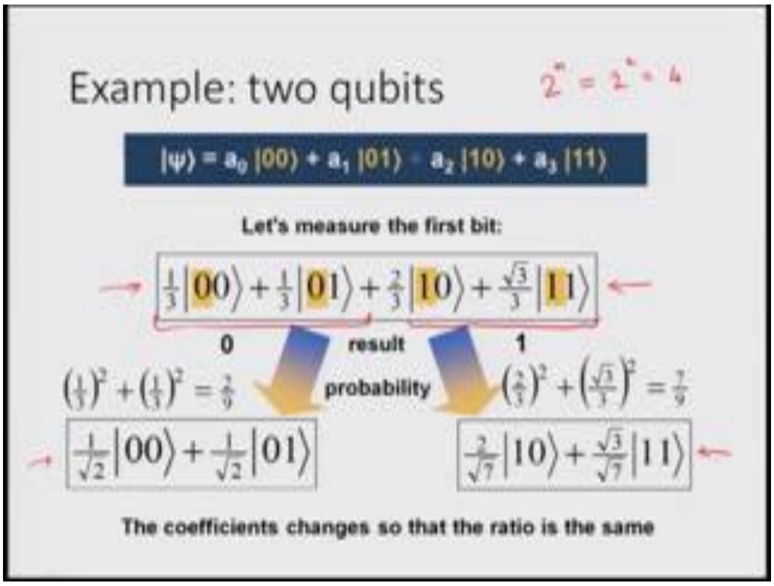

And which means that the potential of a quantum computer would grow exponentially. W e can measure the individual qubits in multi qubit system for example, in a 2 qubit system we can measure the state of the first or the second qubit or both the results of measurement are probabilistic.

After the measurement the system collapses in the corresponding state. Let us take the case of 2 qubits; 2 qubits can combine such that they will have all possible combinations of these basis sets. So, there will be 2 to the power n which in this case will be 2 to the power 2. So, there are 4 possibilities that we start with; with different weightage factors and if we take an specific example and we measure the first bit what will find is there are two cases where we are measuring the qubit 0 and in the second part we are measuring qubit 1. With each with probabilities which can be calculated for the part where we measure the first qubit as 0 the probability is 2 by 9 and the part where we measure the first qubit as 1, the probability is 7 over 9.

So, it can be written in terms of two different representations each with probability one; the first case were we measured the first qubit as 0 and the second case were we measured the first qubit as 1. So, the coefficients change so that the ratio is the same, but they essentially represent the same form. So, over 2 qubits are getting superimposed to give us the results that we are looking at it is a combination of the 2 qubits which can be separately looked at so that they come together to form the superposition states.

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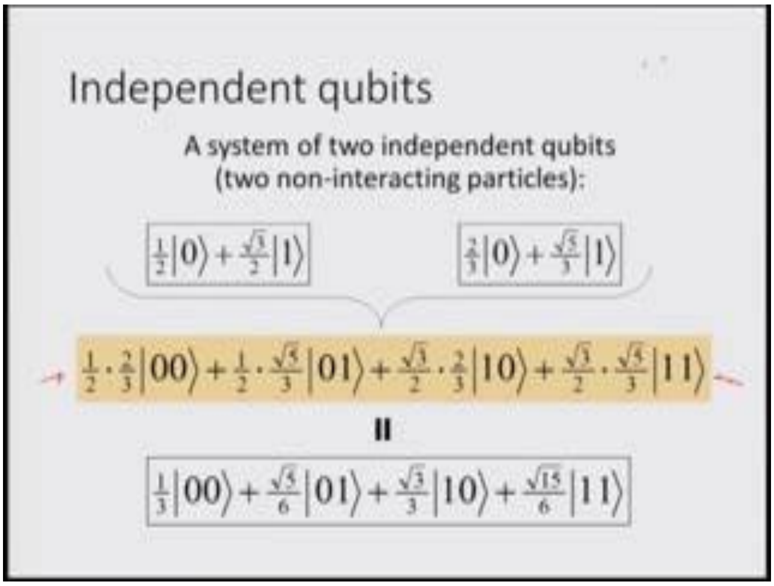

So, these are Independent qubits so that they could come together and we can have a system of 2 Independent qubits which are 2 Non Interacting particles for examples as we take here each having zeros and 1 qubits and when we put them together then we land up producing these total combine system which will be eventually looking at the kind of superposition states that we talked about and so we can have the basis which starts with individual zeros and one states. So, this is the principle of Superposition.

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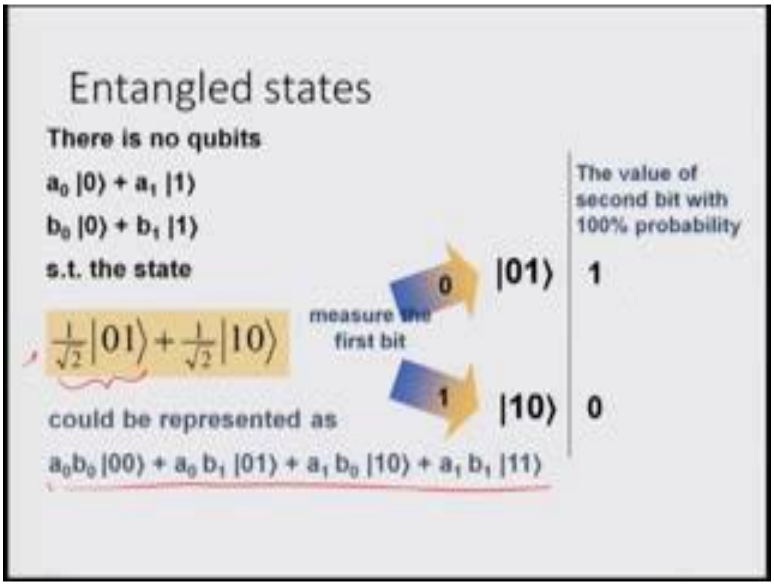

However there is also another set of states which are Entangled states; the principle there is that there would not be possible to have any initial sets of individual states which have the zeros and ones such that their combined state is possible to be represented in terms of the entire set so that they can be broken down in to the combination from where this start off in other words when a state which is entangled is measured in terms of the first bit. For example, we are going to measure the first bit as 0 then we have 100 percent probability of the first case only and there is no probability of finding the second case. So, the probability of finding 0 in the first case is going to be 1 the value of the second bit with 100 percent probability is going to be 1 in the first case and 0 in the second case.

In other words, the measurement of the first bit essentially ensures the measurement of the second bit and this is one of the principles here which makes it as if the measurement of the first qubit is ensuring the measurement of the second qubit. So, only a single measurement in this case would give rise to the measurement of the second qubit with 100 percent probability.

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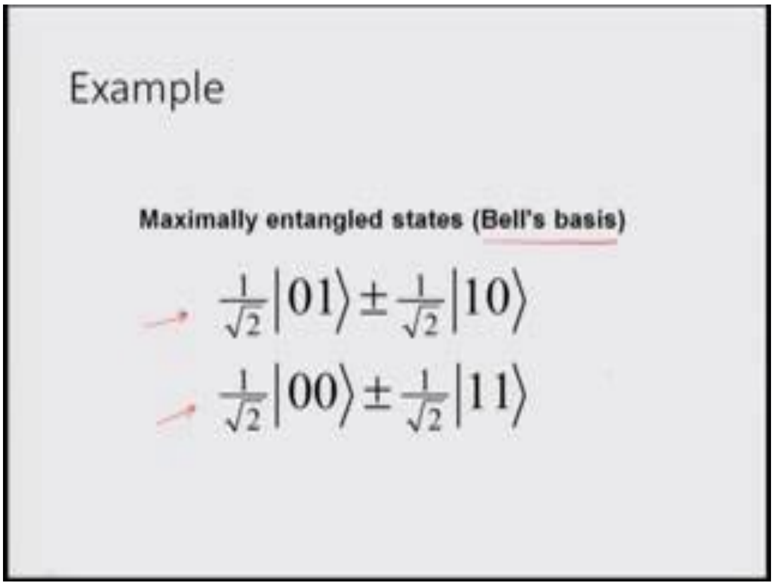

So, the entangled states are such where we only need to measure one of the states which ensure the measurement of the other state. So, maximally entangled states or the Bell's Basis are the once that we just looked at one of the examples which is of this kind and the other example could be of the other kind and both of them are ensuring that once we measure the first qubit the second qubit measurement is guaranteed because they are entangled. So, that is the point of entangled states they cannot be broken down in to the individual qubits which is possible for Superposition states and that is why these are unique and they have been utilize as we know in Teleportation a lot.

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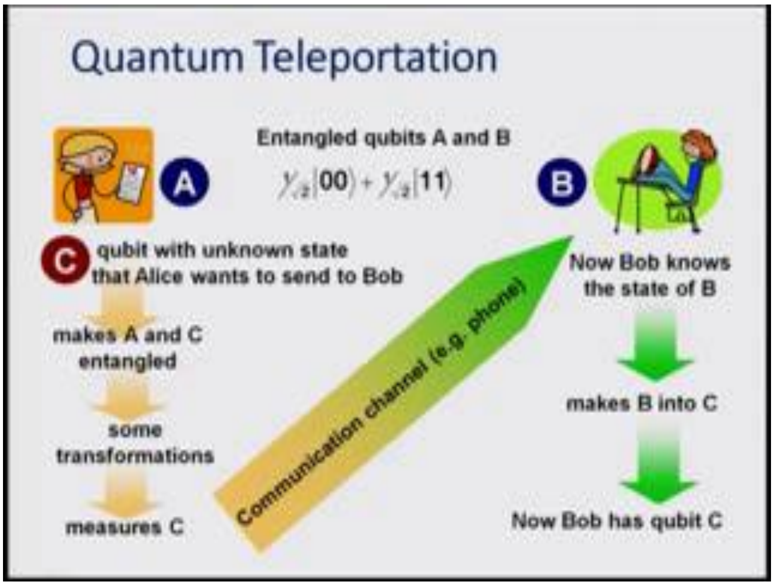

So, here is the idea behind the Teleportation scheme which we have discussed earlier and we utilize the principle of these Bell qubits being sent as a measurement of the information exchange in this particular case enables this advantage. The first step involves entangled qubits A and B and the communication channel which is going to be for example, a phone so that the qubits with unknown state that Alice wants to sent a Bob; A is Alice, B is Bob makes A and C entangled. Some transformations are necessary and Alice measured C whereas, Bob now knows the state of B makes B into C and Bob has the qubit C.

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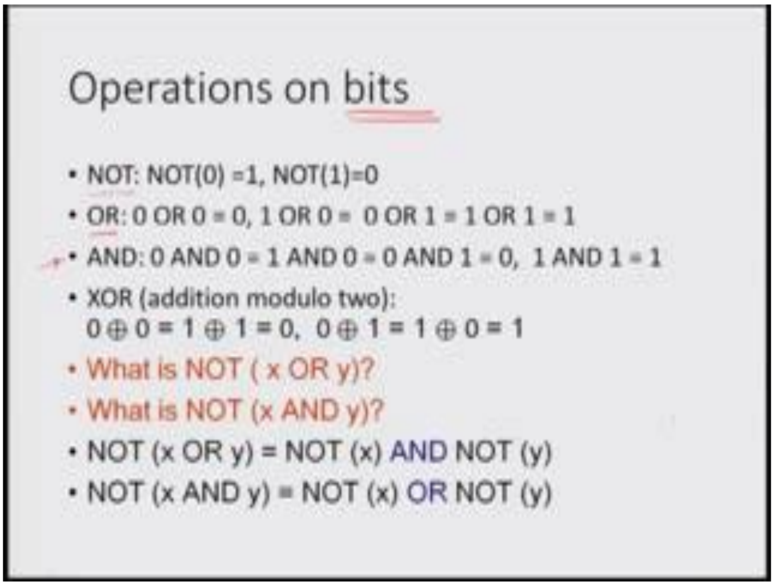

So, here are some simple operations on bits. So, these bits are the classical bits where we have use the principle of NOT which is one of the measure starting points for the computation in the classical sense or the OR gate these are all reversible; however, AND is a not reversible gate. Addition modulo two a XOR gate is also a reversible gate because it is a combination of the OR and the NOT gate. So, in terms of classical computing it is possible to have gates which are non reversible and that is why the AND gate is possible; however, the quantum mechanics as we have discuss all these gates will not be possible.

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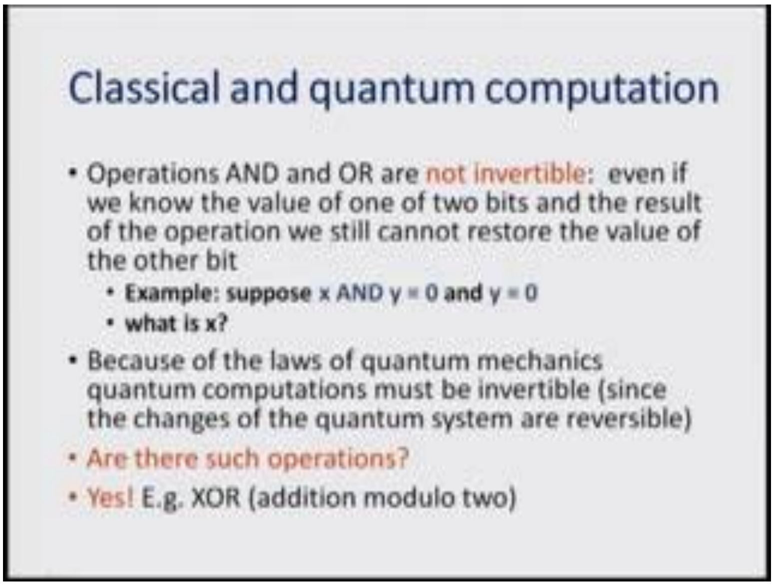

So, what we notice is the operation AND and OR are not invertible; even if we know the value of one of the two bits and the result of the operation we still cannot restore the value of other bit. So, for example, if we have x and y and y is equal to 0 what is x? So, that is the problem of the AND or the OR gates and. So, because of the laws of the quantum mechanics; Quantum Computations require to be invertible which means that the classical basis of the gates for computation has to be looked at in a way. So, that it has to be reversible.

Are there such operations and it is true that the XOR gate which is the addition modulo two gate is 100 percent reversible the other important aspect is the linearity.

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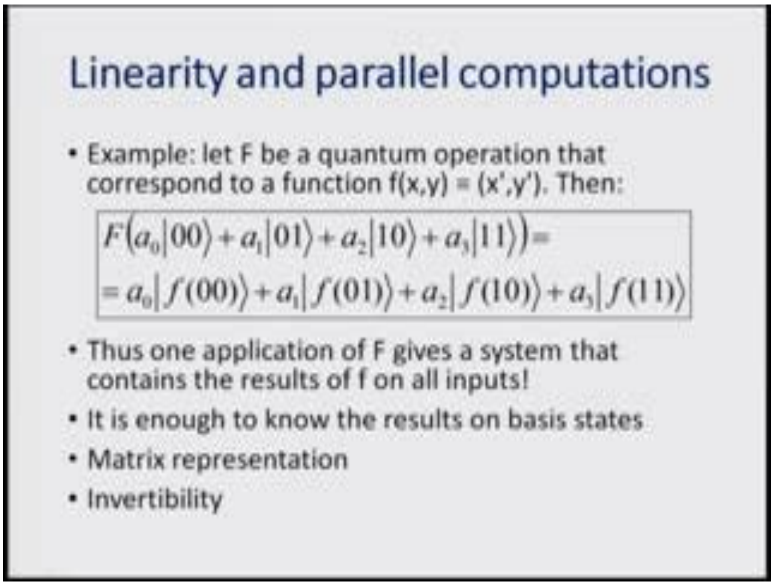

And the principle of parallel computations which is followed in quantum computing; so, if we have F as a quantum operation that correspond to a function f of x taking to x prime to y prime; then the quantum operation has to be such there it will be doing a linear processing of the entire system and one application of F gives rise to a system that contains the result of f in all the inputs.

So, it should be enough to know the results on the basis sets it has to be possible to do this entire processing through matrix representation and by invertibility.

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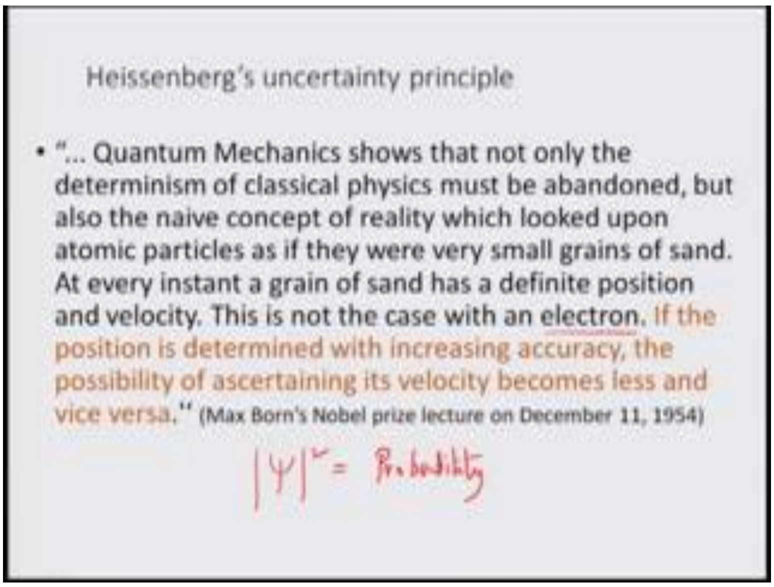

So, these are the basic requirements and one of the important aspects we have to always remember in terms of quantum mechanics is the fact that Heisenberg's uncertainty principle always has to be there which says that this is actually is a code taken from Max Born's Noble lecture which gave a very nice understanding of the quantum mechanics in terms of Heisenberg's picture. Born by the way is the person who basically gave the physical meaning of the psi. So, Max Born is the one who gave the idea that psi square represents the probability.

So, his interpretation is very important. Quantum mechanics shows that not only determinism of classical physics must be abandoned, but also the naive concept of reality which looked upon atomic particles as if they were very small grains of sand. At every instant a grain of sand has a definite position and velocity; this is not the case with an electron which is the quantum particle. If position is determined with increasing accuracy the possibility of ascertaining its velocity becomes less and less and vice versa.

So, this principle of quantum mechanics in any way built in. So, we have to be very careful when we are taking about determinism which is the determined final result of computation.

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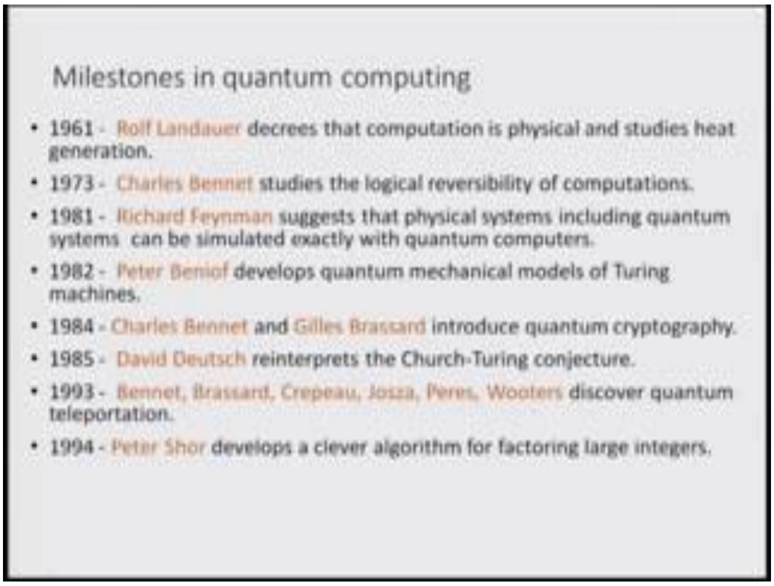

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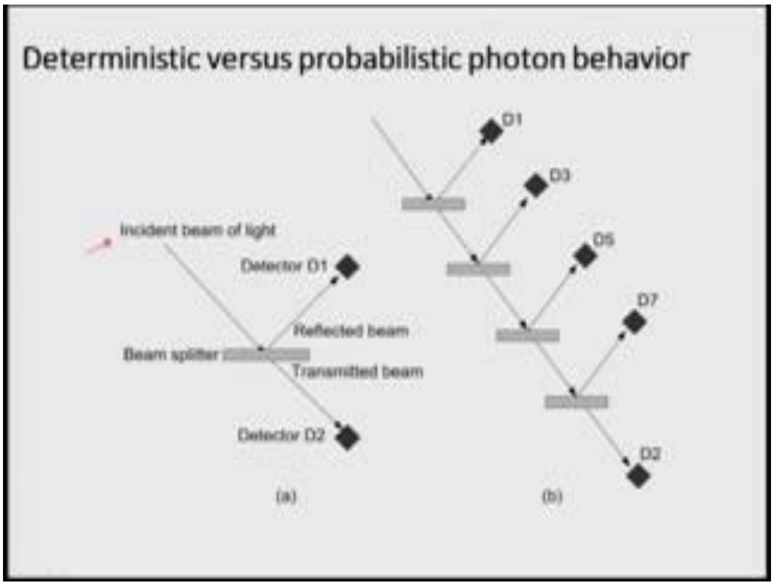

So, one of the first principles of implementation of quantum computing that we looked at involved optical methods, interferometers; where we use the principle of light or photons to understand the idea of quantum computing. So, in some sense brought in fourth the idea of Deterministic behaviour versus the Probabilistic nature on the Photon. Whenever an incident beam of light is going to fall on a beam splitter which splits the light into two parts, a detector on two ends can measure both the reflector beam as well as the transmitted beam and this can keep on going on in change and this can be a cascading process which can keep on going on as we show in this second part.

And everywhere we can keep on measuring how much light will go through an how much will be reflected as a result this is the principle which was use to show how the two could be related by using the principle of photon probabilities.

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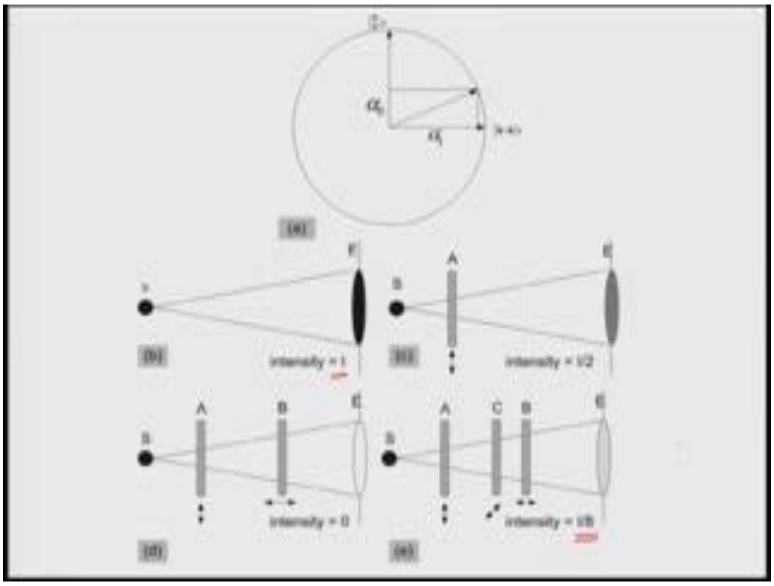

So, the source whenever it was directly measured it was of some value and then as it was put through these different changes we were able to see how these things are getting broken up. So, if the split at each place is half then we expect at every point of a beam splitter measure at the end an intensity which would be in the order of one-eighth of the original intensity which is measured because at every element only 50 percent of the light is going to come through.

So, this was one principle which was been used and we discussed that.

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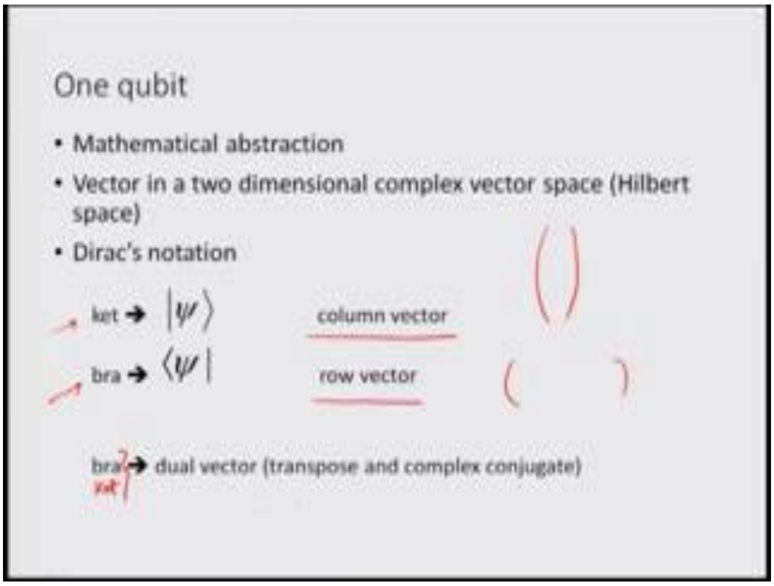

Now, we are going to look at basic ideas behind the 1 qubit operation where the principle of the mathematical abstraction vectors in two dimensional complex space which is our Hilbert space and the Dirac notation involves the ket bracket and bra bracket; the ket one is the column vector and bra one is the row vector and each of them can be transposed with respect to each other to get from one to the other the bracket together forms the dual vector which is transpose and complex conjugate.

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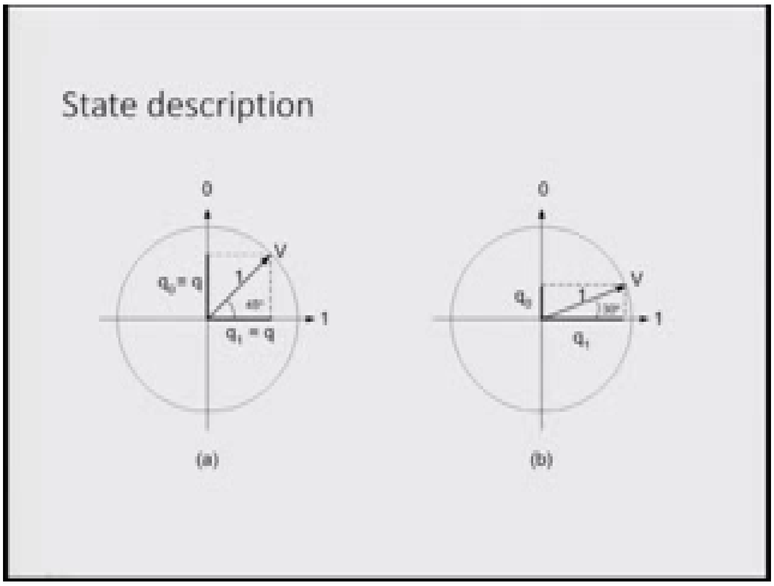

The state description therefore, can be looked at by using this representation in block sphere in the two dimensional case just with the respect to a circle where each has a certain representation with respect to the other one.

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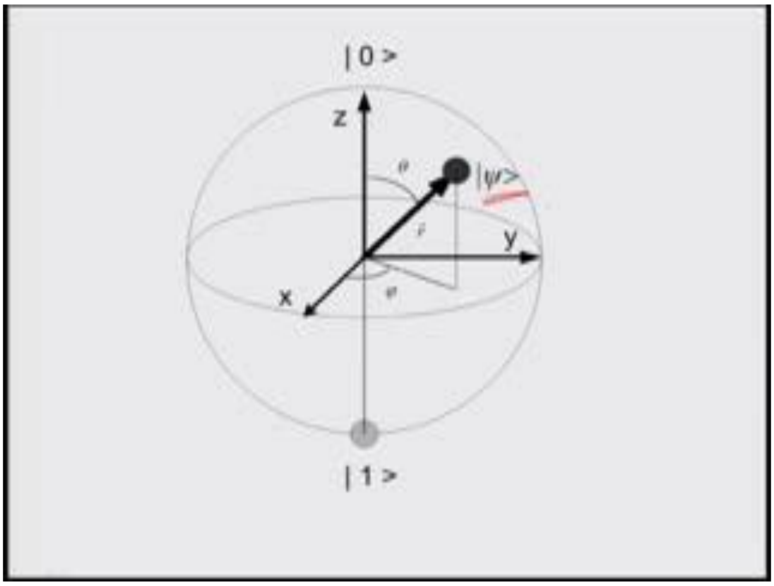

So, in terms of the three dimensional picture as we are saying is a sphere about which the maximal probability of one or the other are at the two ends of the axis and anywhere else it is a superposition which are represented by the rotation of this particular representation. So, the wave function is the one which can collapse on either of the two ends at any point of time, but before measurement all the possible combinations are existing and that is the power of this particular quantum way of evolving.

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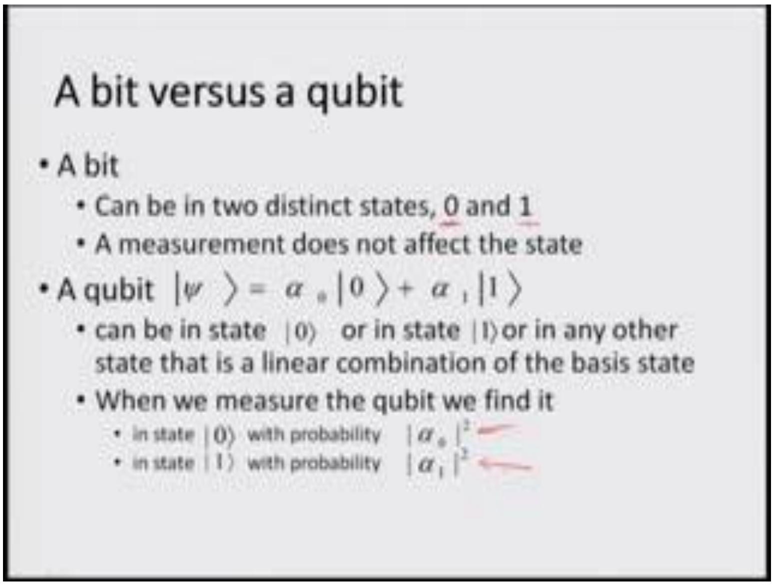

So, that is why a bit can be in two distinct states only 0 and 1 and the measurement of one does not affect the other; however, for a qubit it is going to be in the superposition of both of these conditions can be in state 0 or in 1 or any other state that is a linear combination of the basis states; when we measure we find it has a probability of finding it in state 0 with probability of the coefficient square of each of these states depending on which we measure.

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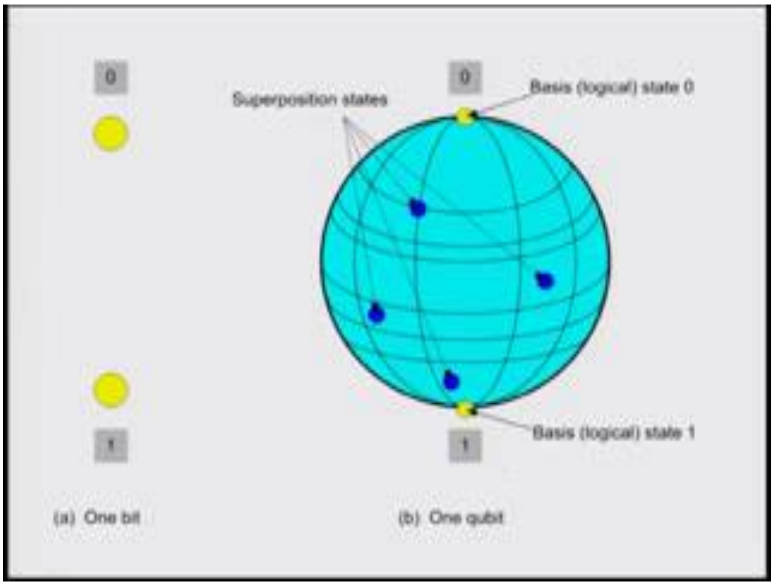

So, in some sense a single qubits will be possible; will have all the possible superposition states in addition to the basis logical states of 0 and 1 whereas, the bit can only have two possibilities 0 and 1.

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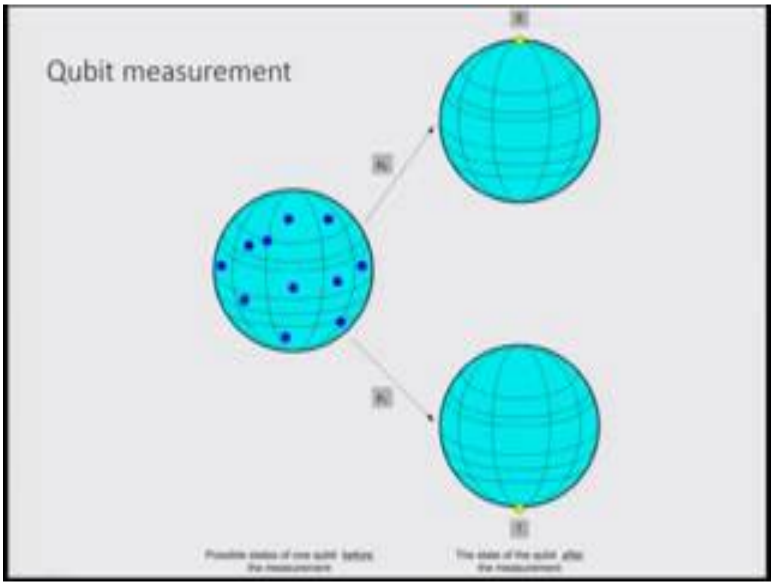

So, the qubit measurement; however, will give rise to the two probable conditions one with probability p 1 of finding it in 1 and probability of p 0 finding it in 0, but all possibilities before the measurement exists.

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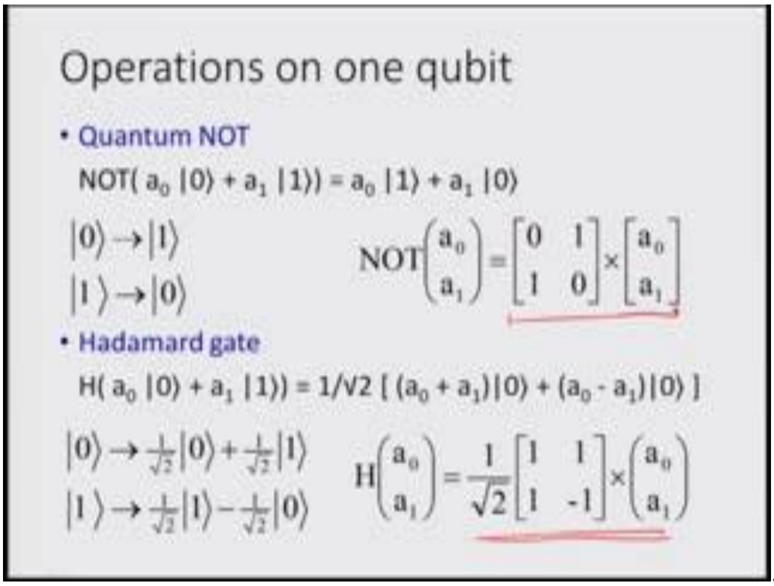

So, the typical operations that are valid for these states can be quantum not as we say that is a reversible one and it can be put in linear sense because that is what we have just discussed. So, a NOT would essentially mean that if we have state 0 it will go to 1 and if it is of 1 it will go to state 0. So, NOT operation; on any particulars state will be represented by this particular approach were we can go from one to the other state with this matrix multiplication.

Similarly Hadamard gate would make an equals superposition of both the states that we have and that can be return in terms of this particular operation where this square matrix represents the Hadamard gate operations.

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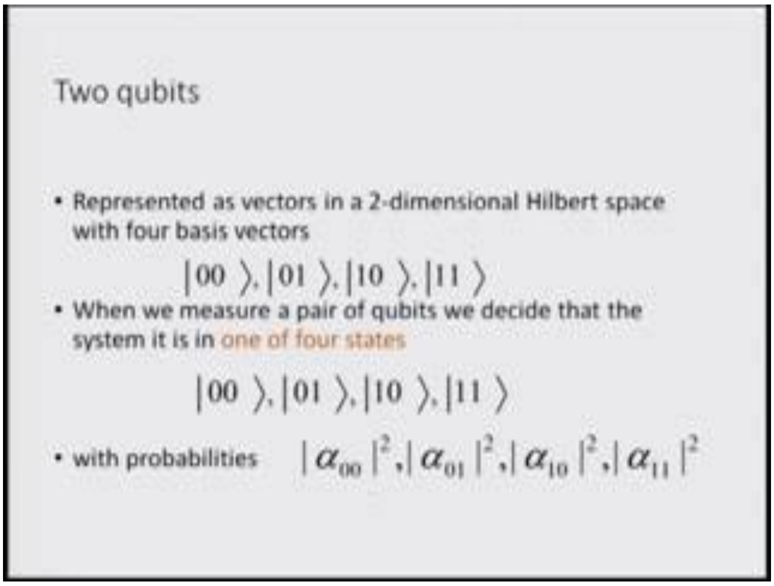

When we go to 2 qubits we can represent them as vectors in two dimensional Hilbert space with 4 basis sets as we discussed before. When we measure the pair of qubits we decide that the system is in one of the 4 states, and these are given with respect to the probabilities that we discussed here.

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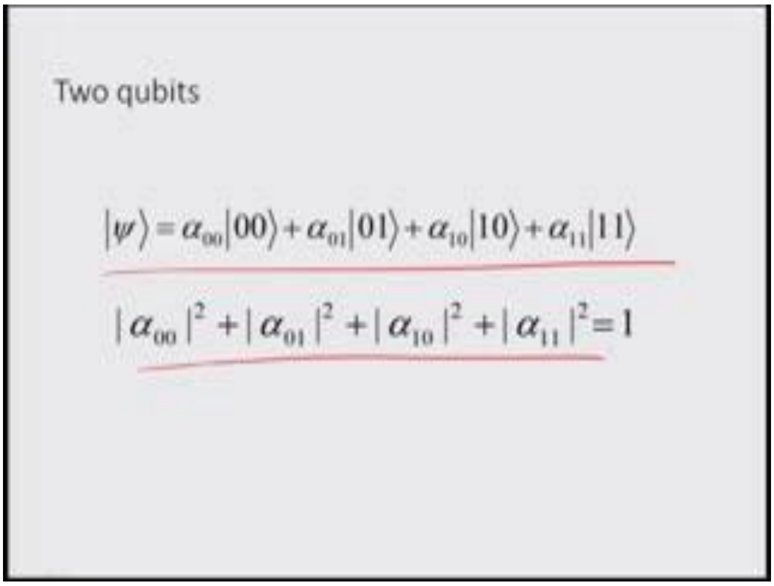

The two qubits will again have their different probabilities which can be represented in this form, where the sum total of that square of them will give rise to a total probability of 1.

We have been looking at several aspects of the initial basics of quantum computing which we had looked at earlier. We revise this area once more because we are going to relook at the implementation angles in such a way so that we can understand how these different processes that we are looking at can be improved on or can be looked at in to the other various different ways that we are doing this problem.

We will continue with this in our next lecture. And we hope to see you there.

Thank you.