Compliant Mechanisms Principles and Design
Prof. Debabrata Goswami
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture – 28
Spintronics Quantum Computing

So, we have been looking at implementation of quantum computing in terms of commercial devices. Now, will be looking at the other important aspect where spin place an important role and we mentioned about it earlier also scoreless Spintronic approach.

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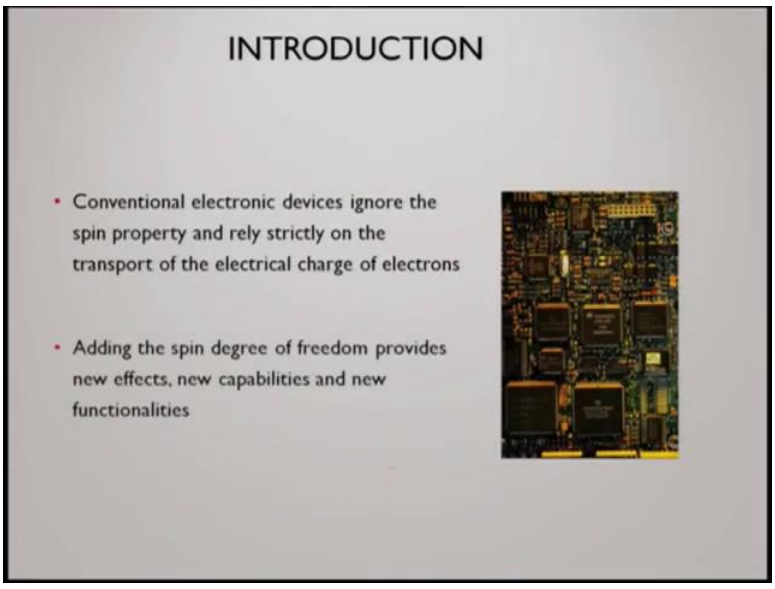

So, let us see what this idea was Spintronic come from, typical conventional electronic devices ignore the spin property and rely strictly on the transport of the electrical charge of electrons, adding the spin degree of freedom provides new effects new capabilities and new functionalities.

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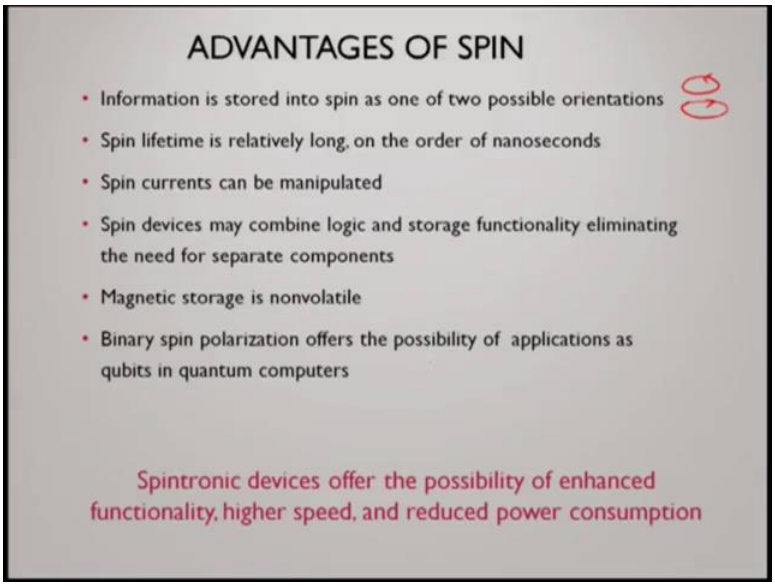

This advantage of spin essentially gives raise to these Spintronic devices that offer the possibility of enhanced functionality higher speed and reduced power consumption. So, what are the advantages of this spin? The information is stored into spin as 1 of 2 possible orientations circular going clockwise or going counter clockwise the spin lifetime is relatively long on the order of nanoseconds. Spin currents can be manipulated spin devices may combine logic and storage functionality eliminating the need for separate components the magnetic storage is non-volatile.

So, that is actually a very important issue because most of the time whenever we talk about spin what happens is that it induces magnetic behaviour 1 way or the other and that can be utilized in terms of storage which will be non-volatile, binary spin polarization offers the possibility of applications as qubits in quantum computers and part of that has already been seen when we even looked at the commercial procedure of quantum any link where the spin of these individual qubits were used and similarly in a mode processing the spin of the nucleus was used as 1 of the principles of quantum computing here 1 thing we should remember; however, at this spin we are talking about is mostly to do with a electrons spin or the spin of the system and not the nuclear spin.

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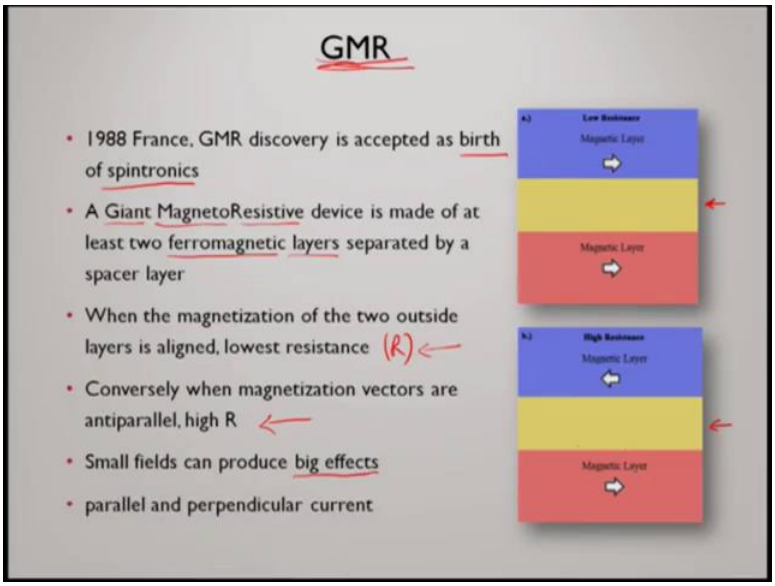

So, what is it that we are relying on when we talk about the magnetic field as well as the spin? So, the most important term in this area is the GMR or the giant magneto resistivity. So, gaint magneto resistivity was discovered in 1988 in France, and is often accepted as the birth of Spintronics, a gaint magneto resistive device is made of at least two ferromagnetic layers separated by a spacer layer.

So, when the magnetization of the 2 outside layers is aligned lowest resistance is seen. So, for example, you have 2 ferromagnetic layers the blue one and the pink one and these spacer is the yellow part which is in the middle spacer layer, when the magnetization of the 2 outside layers are aligned we get the lowest resistance r of the system. On the other hand when the magnetization vectors are anti parallel in the same device then the resistance is high. So, this is again the spacer and these are the 2 magnetic layers and when the magnetic layers are aligned then it is lowest resistance and when the magnetic layers are anti parallel then it is the highest resistance.

So, this gaint magneto resistance is one of the most important concepts, which gave rise to the birth of Spintronics. So, in some ways the small fields which are necessary for making this alignment go in parallel verses the opposite directions are the ones which can produce big effects and therefore, this particular approach has been one of the most critical in the development of Spintronics, and this can be achieved by simply a providing parallel and perpendicular current.

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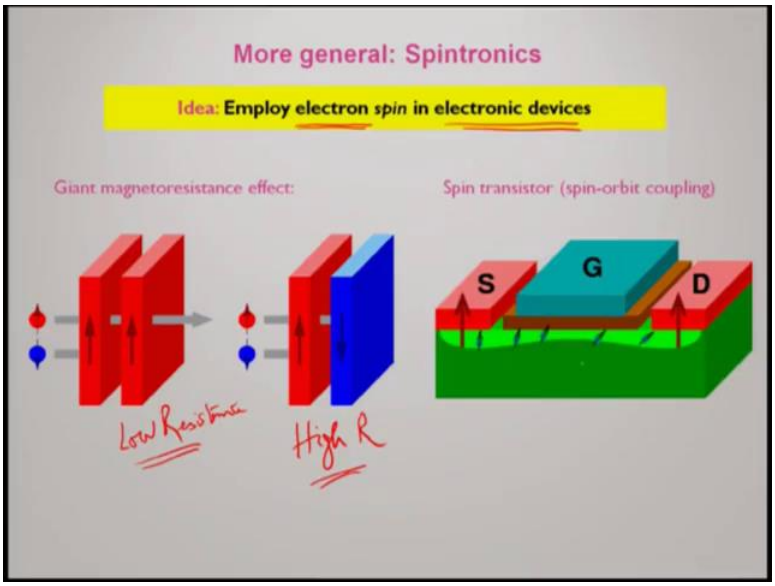

So, in more general the idea of Spintronics is to employ electronic spin in electronic devices and that is why I wanted to mention that this is distinct from the concept of NMR where it is the nuclear spin.

So, here the electrons spin is the one, which is been used for electronic devices. So, the gaint magneto resistance effect that I just mentioned is the one, which is important in making sure that we have low r in one case and high r in the other case. And this principle this resistance r is resistance, this resistance is the hallmark of giving raise to the effect and the idea of having the ferromagnetic layers being in parallel verses counter parallel can be achieved by simply providing low currents and that is why this amplification processes is very important. So, similarly this can be also be utilized in terms of spin transistor spin orbit coupling can also be utilized where, the parallel and perpendicular are responsible for making sure that the GMR can be utilized very effectively. So, in general the parallel and perpendicular current is sufficient to make sure that the magnetization of the 2 layers can be made either aligned or put in the anti parallel mode, small fields can produce big effects the parallel and perpendicular current is sufficient to make the magnetic layers be parallel or be aligned in the opposite way.

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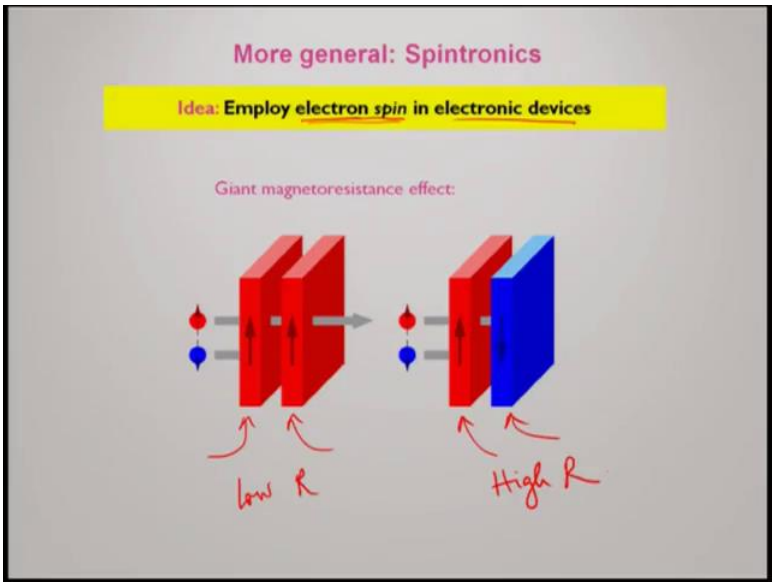

And therefore, gaint magneto resistance devices can be very effective in these kinds of applications; in more general cases of Spintronics the idea is to employ electronic spin in electronic devices. This as I mentioned earlier is important to note the distinction from the usage of nuclear spin which has been done in terms of NMR in this particular case it is the electron spin which is the important aspects which is being utilized for the electronic devices. The gaint magneto resistive effect is critical in these cases where the 2 ferromagnetic layer has been mentioned whether they are parallel or they are counter or anti parallel are going to effect as to having a low resistance verses high resistance and that is the principle behind this idea of using the Spintronics concept.

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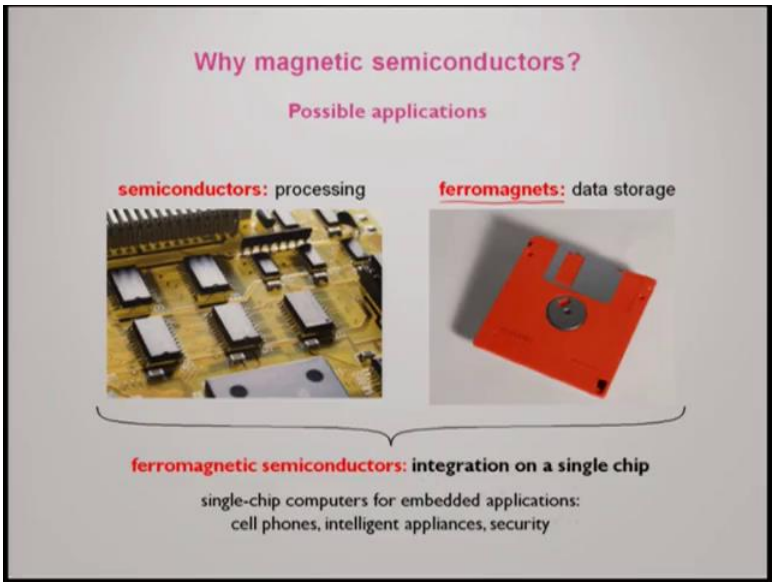

So, these magnetic semiconductors are very effective, because they can be utilized for processing or could be utilized in terms of ferromagnetic materials as we just mentioned in terms of data storage where the magnetic fields that are induced as the result of the applied changes in the relative orientation can lead to data storage. So, ferromagnetic semi conductors can be integrated on single chips and single chip computers can be utilized for embedded applications such as cell phones intelligent appliances security, which are all currently being utilized for these kinds of technology.

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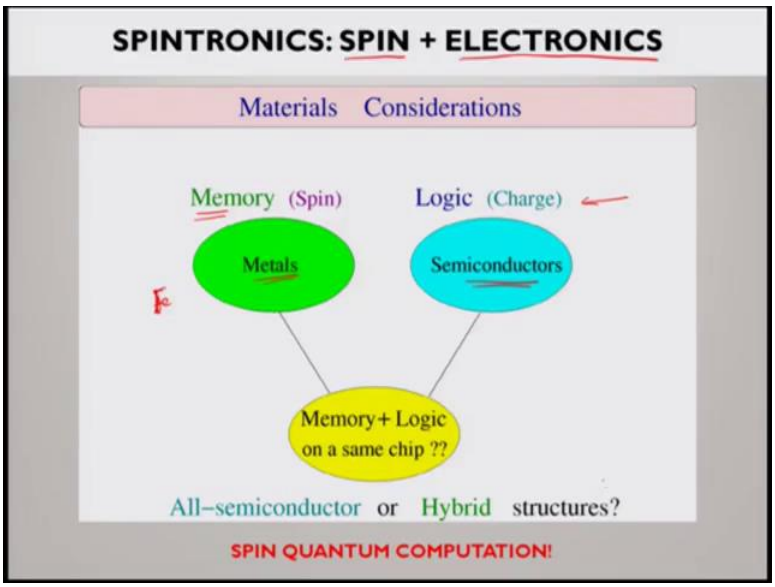

So, in effects Spintronics is basically a mixture of spin with electronics is the electron spin and electronics put together is the principle of Spintronics. So, the materials and the considerations which are effective are metals which can act in terms of this spin memory the other principle would be the logic which is going to be the charge.

So, in terms of the electronics it is the charge of the material which could be in terms of semiconductor, which give raise to the logic aspects where as the memory part of it could be in terms of the spin as we talked about ferromagnetic materials which need the metal alliance to do this job and therefore, we have the principle of the memory and the logic on a same chip as a result of this combination of the say the metal ion with respect to a semiconductor with the charge species given raise to the logic. So, all semiconductor or hybrid structure is the question, because we could also use semiconducting substance which could have spin property.

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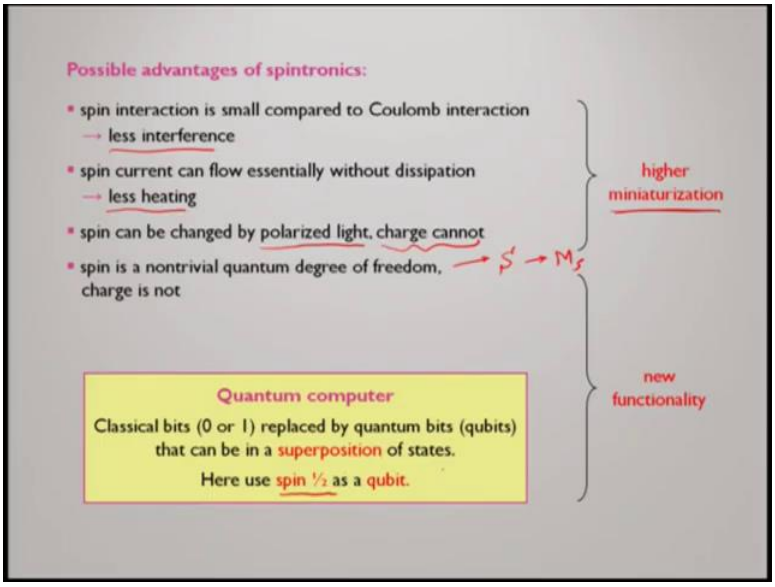

So, we could have both all semiconducting properties or materials or hybrid structures for Spintronics applications, spin quantum computation is the part which we were looking at right here where the advantages of Spintronics lie in many particular areas, the spin interactions are small as compared to coulomb interaction and there is lesser interference which is there as a result they can be miniaturize is here, the spin current can flow essentially without any dissipation which means that there is a less heat to worry about. Which is one of the major advantages with respect to a miniaturization issues a

spin can be changed by polarized light, which cannot be by using the charge and. So, spin has its advantage of interaction with light to do or produce interaction which are effective in terms of spin logic spin is a nontrivial quantum degree of freedom.

Because we know that there is a spin quantum member, which is can be utilized for our quantum states, where as charge is not a quantum degree of freedom that sense. So, a quantum computer would therefore, be utilizing the superposition of spins and you can use the spin half as a qubit which is our new functionary that we have been discussing.

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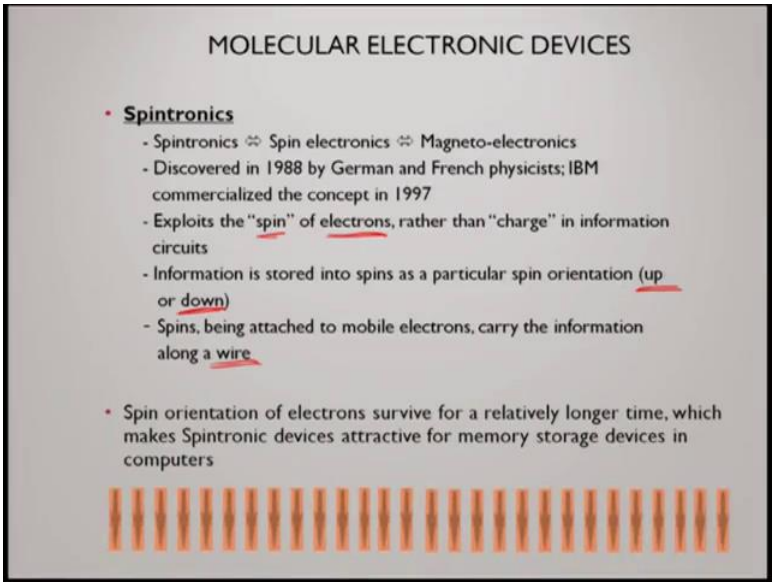

So, in terms of these molecular electronic devices the Spintronics place a major role where the spin electronics of the magneto electronics, which can be utilized by this is one of the area where this can be taking to the next level, it was discovered in 1988, by German and French physicists and IBM commercialise the concept in 1997, in terms of the Spintronics idea. It exploits the spin of electrons rather than charge information of the circuits the information is stored into spins in particular spin orientation whether it is up or down and a spins being attached to mobile electrons carrying information along a wire, this is one other very important aspects of the spin which can be utilized in this process, the spin orientation of electrons survive for a relatively long time which makes Spintronics devices attractive for memory storage devices in computers and because of the long range of time scales which the spin orientation can provide.

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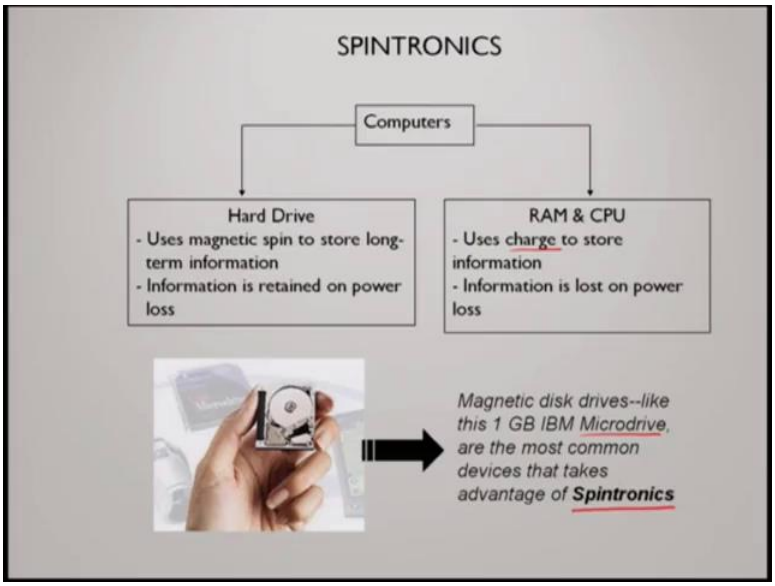

There have been applications of Spintronics in computers in terms of the hard drive which uses the magnetic spin to store long term information and the information is retained on power loss. So, that is a permanent memory which is am storage, which is which is been utilized already in terms of computers the ram in the CPU on the other hand does not use these Spintronics principle and essentially uses the charge and as a result information is lost on power loss. So, here is the example of how the magnetic disk drives which have been utilized on the basis of the micro drive for instance utilize the spin of the system and takes the advantage of Spintronics to store information on a permanent basis.

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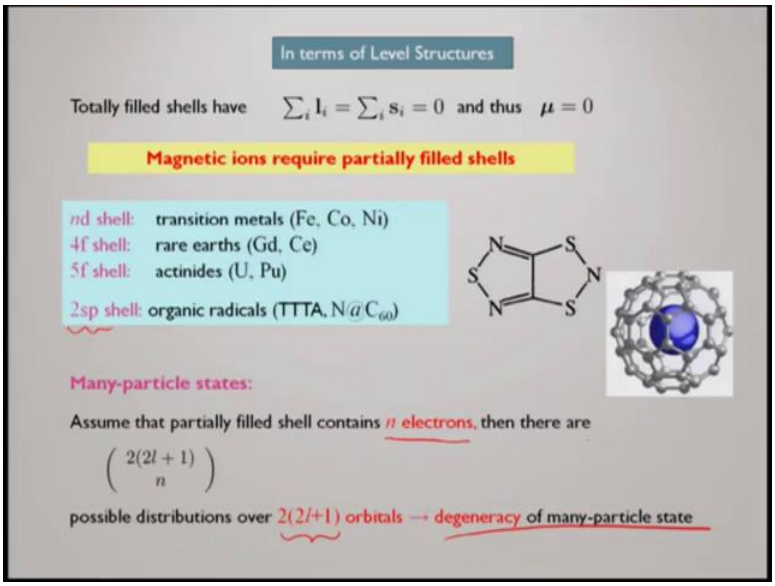

So, let us now explore a little bit on the aspects of Spintronics that we have been talking in terms of molecular or the termic states. So, that we understand what we are actual discussing. So, in terms of the level structures totally filled shells will have an angular momentum or the spin as 0 and. So, the angular momentum associated with the spin will be 0. So, the magnetic ions required partially filled shells.

So, that the total angular momentum or the total spin is non 0 and that is why the choice of the system depends on this property, which means that the as long as their transition metals for example, iron cobalt nickel which have these nd shells where you can get them partially filled or 4 f shells rare earths like gadolinium or the 5 f actinides, which can also be utilized for these kinds of Spintronics devices, it could also utilize the molecular states for example, 2 sp shell which are found in organic radicals and others for example, nitrogen inside c 60 as long as hybridisation it can always be utilized, many particle states require that we assume that partially filled shell contains n electrons then there are say 2 times 2 l plus 1 states corresponding to the n-th shell and the possible distribution are over 2 times 2 over 2 l plus 1 orbital's and these are the degeneracy of many particle states, and this is because for every particular electrons there are 2 possible orientation that are possible.

So, with every orbital representation of an electron there are 2 spin states, which are possible and that why these numbers are becoming in these kinds of terms.

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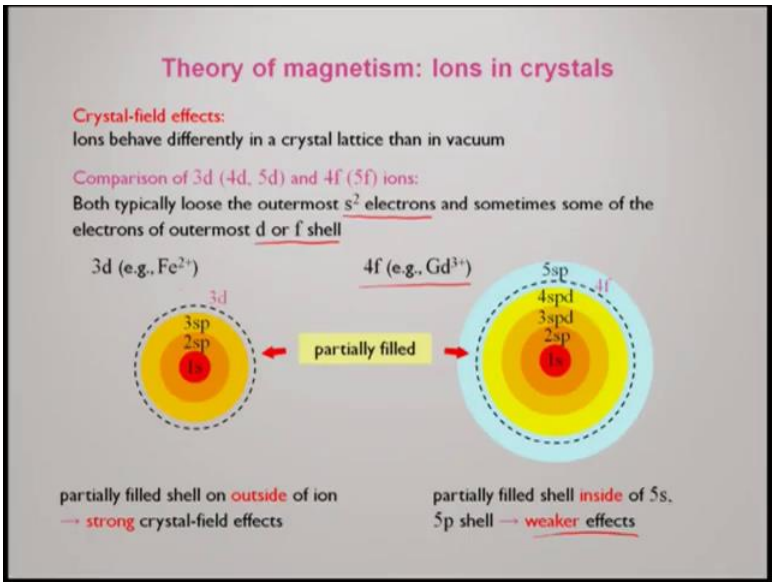

So, the irons in the crystals are therefore, going to interact with a magnetic field in terms of the crystal field effects they behave differently in a crystal lattice than in vacuum for instance the 3 d 4 d 5 d and 4 f 5 f ions, typically lose their outer most s 2 shell electrons and sometimes some of the electrons of outermost d or f shells for example, the 3 d and in terms of ion 2 plus is partially filled and the partially filled shell on the outside of the ion gives rise to strong crystal filled effects, which can then interact strongly with a magnetic field and the partially filled shell inside of 5 sp shells have weaker effect and therefore, what we are essentially seeing are the effect of how they are interacting.

So, for example, the gadolinium 3 plus ion a partially filled shells inside of 5 s and 5 p shells which have weaker effect whereas, on the other hand in ion 2 which is the partially filled shells outside of the iron have strong crystal filled effects and therefore, ion has very strong magnetic effect as we all know as a result of this kind of interactions.

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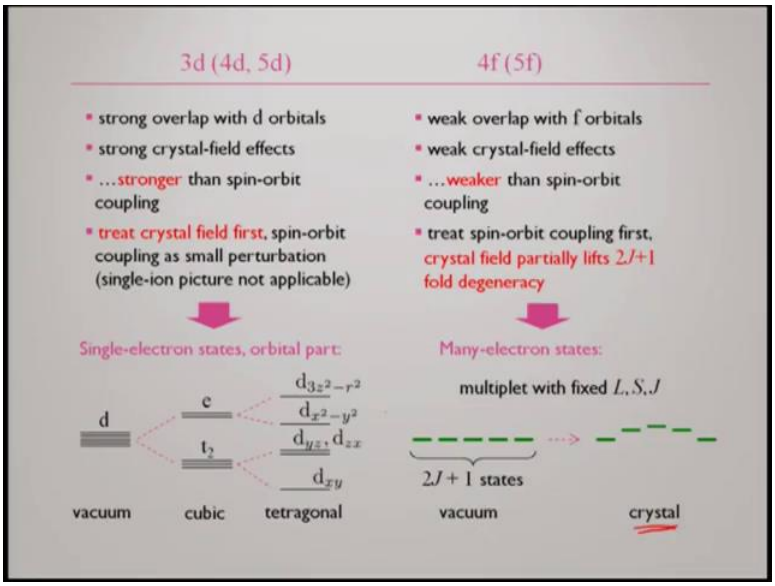

So, depending on which states we are looking at will be have a different interaction to look at. So, the 3 d 4 d or 5 d states which are on the d shell verses the f shell which is 4 f and 5 f, we have 2 different conditions. These are the ones which are transition and the other ones are in transition elements which we are looking at. So, the transition elements have strong overlap with d orbital strong crystal filled effect stronger than spin orbit coupling and these treats the crystal field 1st spin orbit coupling as small perturbation in a single ion picture is not applicable.

So, in these cases the single electronic states orbital part sort of splits to look into a tetragonal job of condition and the effect of the field, where as in these case the weak field effect due to the 4 f leads to weak overlap with f orbital weak crystal field effects weaker than the spin orbit coupling and these needs to be treat as spin orbits coupling 1st, crystal field partially lifts the 2 j plus fold degeneracy and leads to many electrons states, which has multiplex with fixed L, S and J geometry and. So, when they have the 2 J plus 1 in the vacuum state in the crystal lattices they have these states which are getting separated out.

So, the 2 effects whether they are in terms of the transitional elements or the or the others where we are using the f orbital they have slightly different effects, but due to crystal field effect verses their original conditions where they are considered and one of them is stronger than the other and they can be utilized in different ways.

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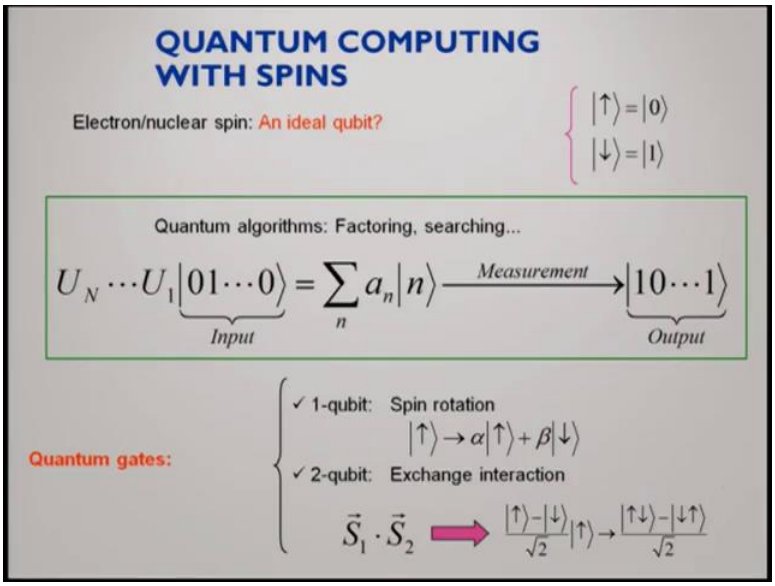

So, generally speaking what we have discussing is with spins we have the rotation the almost an ideal cubit, because these are essentially looking at the rotational status as we have been talking about it is almost an ideal condition, because it is separated and can be addressed very easily.

So, we can consider its up actual, but typically this spin up is consider as the 0-th state, for instance and spin down as the defer state and quantum algorithm factoring searching sincerely would require an input of this array of state, which output into some superposition state, which have been addressed with unitary operations and they all work simultaneously to produce the net result and at the end of it when the final state is achieved the measurement gives raise to the state that is being measured. Simple quantum gets in terms of spin would be just in terms of 1 qubit spin rotations for instance a 2 qubit exchange interactions, which can go between the spin interaction between them and the exchange interaction give raise to say adamant operations whereas, the spin rotation can simply produce super positions.

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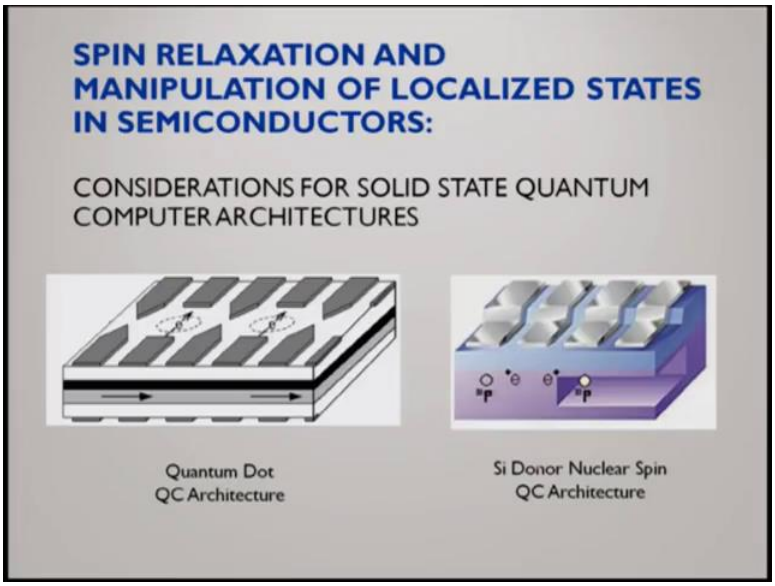

So, the spin relaxation and manipulation of localised states in semiconductors can actually be utilized as we have discussed earlier also, in terms of quantum computing architecture or the quantum dot architecture for example, is placed in between the different condition of their states and then they have been put together. So, for example, here is a silicon donor nuclear spin in the quantum computing architecture where the phosphorus with 31 is going to have with the additional advantage of electron and that is why this electron donor from the silicon is going to act like the device where it can be utilized for doing this work.

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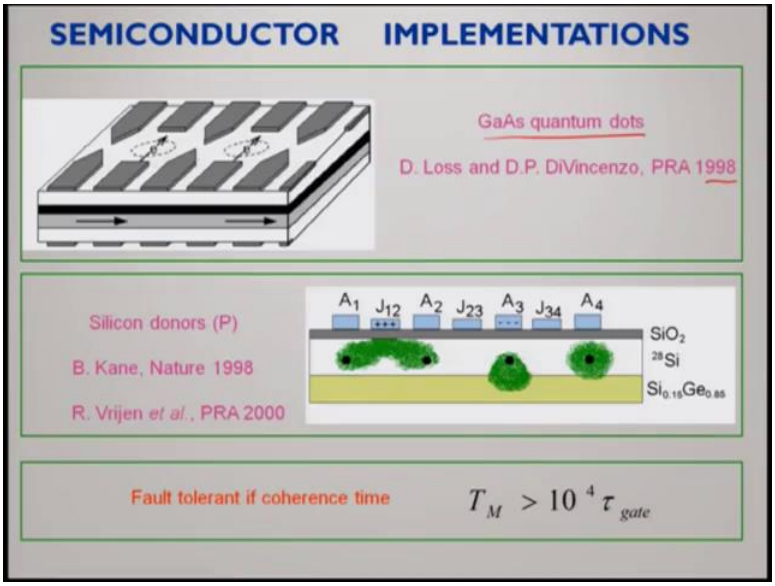

This is how the solid state device have been done here, is some of the implementation aspects which had been taken care of the gallium arsenide quantum dots for the instance where 1st shown in the work by Divincenzo in 1998, where they had proposed this simple idea of the electrons being provided by the silicon.

So, consideration of the solid state quantum computer architecture both quantum dot structure as well as silicon donor nuclear spin quantum computer architecture has been utilized in quantum dot architecture the electron transition have been manipulated while the other structure involves the silicon donor nuclear structure architecture from this particular case where the phosphorus is utilized along with the silicon donor. So, here are the more details of these ideas that have been utilized.

So, the gallium arsenide quantum dots structure was 1st shown by Divincenzo and others in 1998, where they placed the quantum dots acting like a single electron system in between the device where they could apply the field to make them interact, where as in the other case it was the silicon and phosphorous called the silicon and germanium which were put together for doing these kinds of similar aspects where these junctions were been addressed at different levels.

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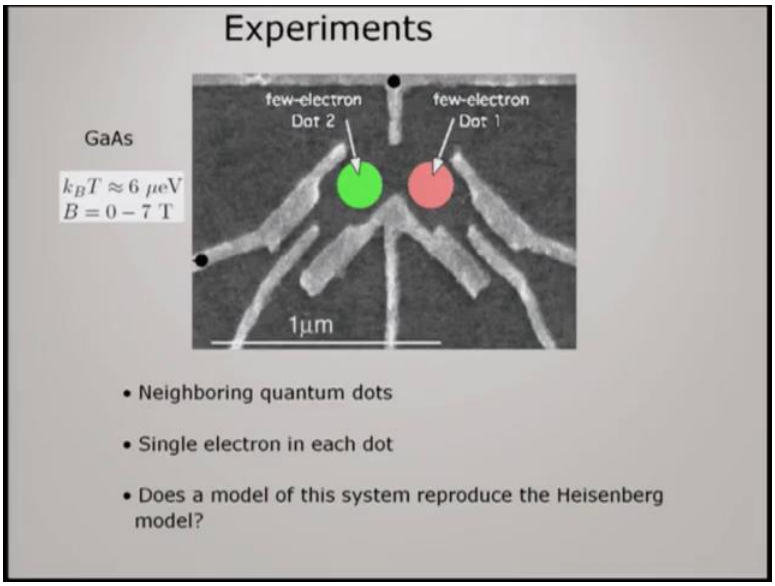

So, the typical experiments for these cases for instances required the few electron dots to interact at close enough distance, in this case for example, the gallium arsenide case the neighbouring quantum dots were being interacted the single electron in each dot was

been utilized and the question is they were able to address were whether this model was able to reproduce the Heisenberg model, where the electron jumped and the electron transition could be reached by utilizing the same quantum mechanical concepts that have been addressed earlier.

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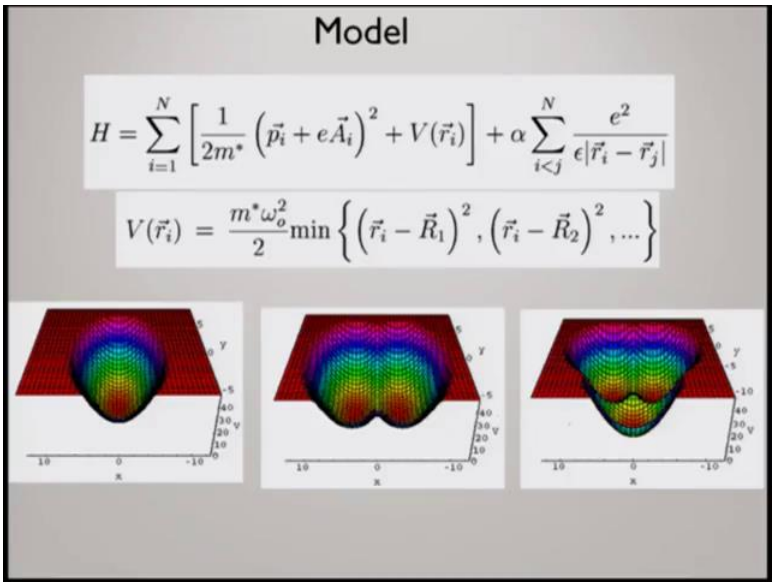

So, the magnetic field that was been utilized to make the interaction occur because of this spin of the electron was based on principle that the Hamiltonian involved the momentum part and the interaction was due to the spin conditions of these electrons and when these 2 states were being put together they were going to interact and give raise to multiple conditions instead of having just a single minimum point.

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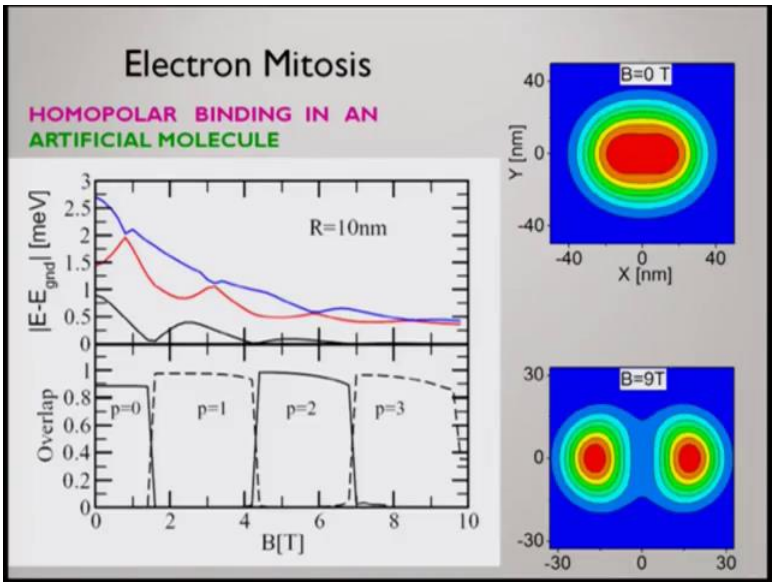

And it almost look like that they were able to separate out and form into different conditions and it was almost like they were forming homo polar binding in an artificial molecule based on their interaction with applied magnetic field; however, the applied field was quite high in these cases and the apply magnetic field in these cases were about 9 tesla where the 2 hole could be completely separated out.

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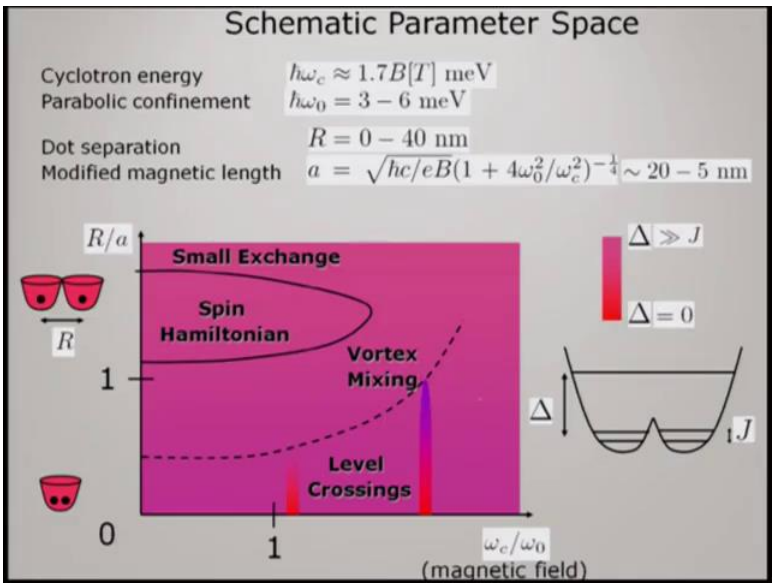

On the other hand, so, these kinds of experiments required a devices and energy which were not possible under normal conditions. So, for instance this particular work have

require cyclotron radiation where the energy was in terms of very high and magnetic field which were possible from cyclotron energies provided, and the confinement was then able to be achieved because of the interaction at those high intensities, with a application of modified magnetic length the separation could be worked on and could be utilized in this principle.

So, this was the idea of the how this was being applied. So, depending on the amount on magnetic field applied the principle spin Hamiltonian interaction, whether they had small exchange or they had vortex mixing or they were level crossing is a result of that which were mean being looked at, and depending on whether they were able to be in individual states or they were having some coupling or they were separated out was been looked at by these utilizing these principle. So, depending on the energy provided for instance this particular case the level crossing was achieved when the energy was greater than the spin coupling. So, by utilizing magnetic field in consumption with these energy levels that we talked about this particular system was been applied.

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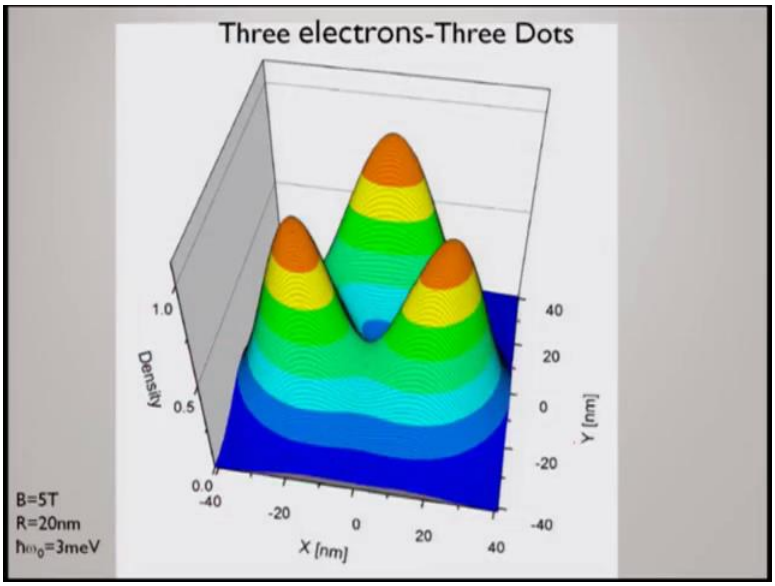

And with higher and higher energies other levels of mixing was possible which gave raise to this particular principle. So, these concepts were very easily forwarded into cases where 3 electrons for example, were available when there were 3 dots and their interactions could be looked at in terms of how their energies were being looked at.

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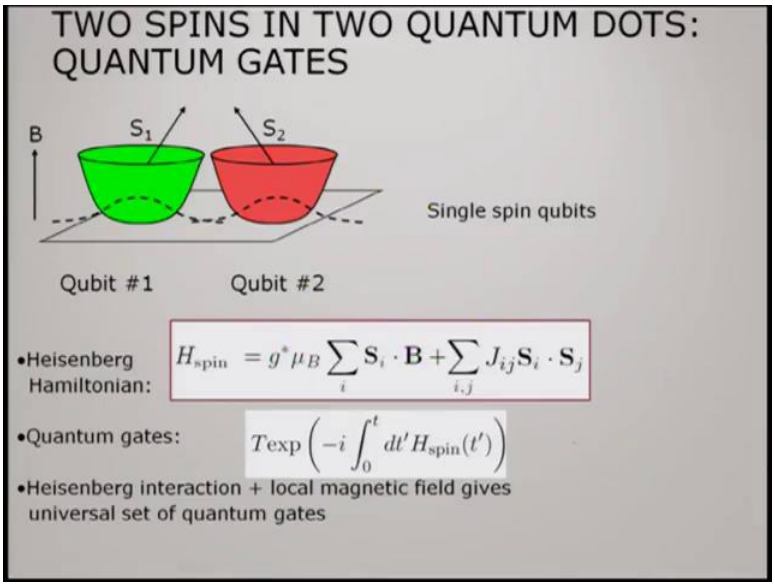

So, the 2 spins and 2 quantum dots for example, b 2 the quantum the quantum gates put together in this, these considered them as single spin qubits where the Heisenberg Hamiltonian essentially had this spin coupling parts, which have been looked at the quantum gets were based on the rotations available from the spin Hamiltonian and the interaction of the local magnetic field gives raise to universal set of quantum gates.

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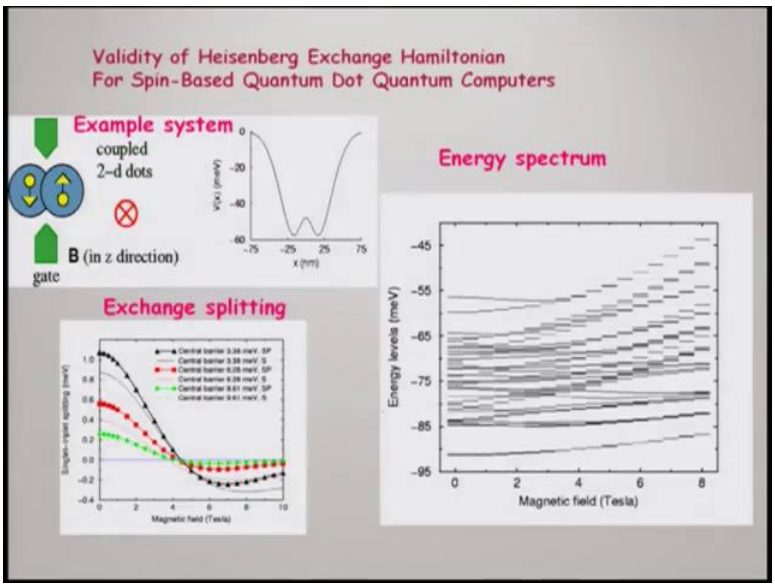

And this is how the 2 qubits were being connected and been looked at the Heisenberg exchange Hamiltonian was validated for the spin based quantum dot quantum computers

in the example system of couple 2, 2 d quantum dots the applied field direction in the z direction was able to produce the gate energy that was necessary and it was possible to create these levels of interactions by using these splitting and the amount of magnetic field necessary to do these kinds of activities.

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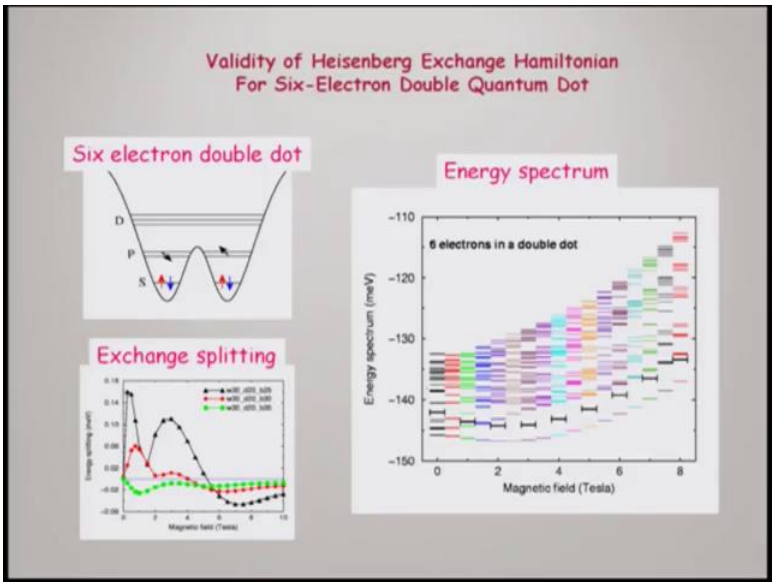

The validity of the exchange Hamiltonian for 6 electron dot was also shown in these kinds of experiments, where 6 electron double dot was been utilized and they were able to show that interactions were able to be controlled by using the magnetic field of the applied system. In most of these cases these experiments were able to address the idea that the Heisenberg exchange Hamiltonian worked for these kinds of systems and they could be put to the applications as has been discussed.

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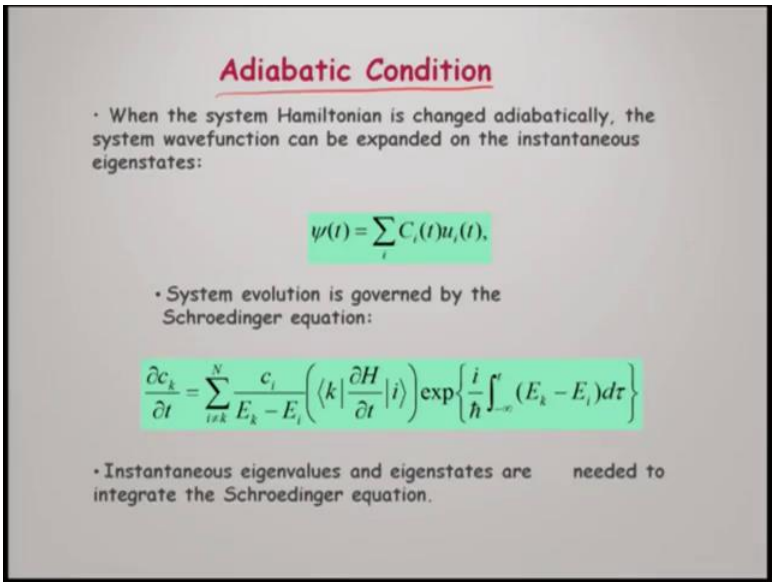

When the system Hamiltonian was changed adiabatically the system wave function was possible to be expanded in instantaneous wave functions and the process were better explained in that condition and the system evolution was then governed by the Schrodinger equations where the instantaneous eigenvalues and eigenstates are needed to integrate the Schrodinger equations.

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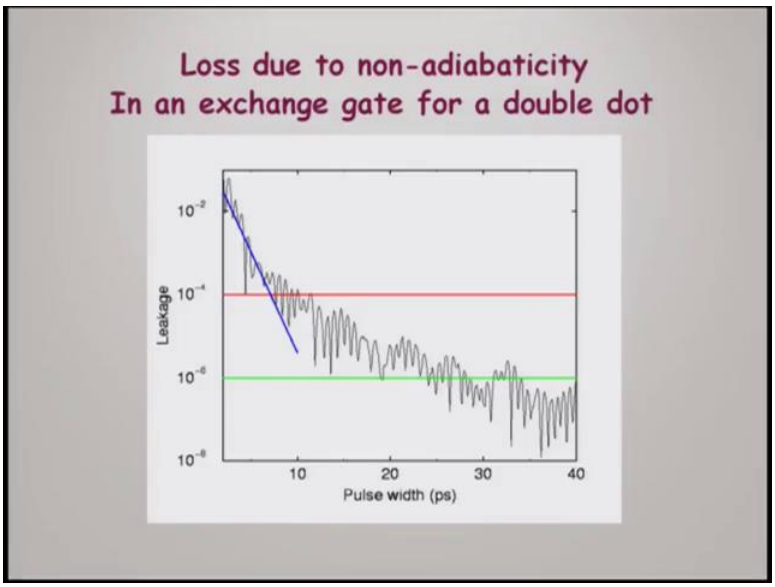

So, by application of adiabatic condition it was possible to make sure that the system wave function was interacted in a way and under that condition it was possible to provide

all the quantum correlation; however, due to the non adiabatic interactions in the exchange gate of double dots, there were cases where the interaction was lost and as long as the adiabaticity was maintained it was possible to get the interactions work in the Heisenberg in the quantum mechanical principle and computing could be achieved.

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So, in this particular case the principle of adiabaticity was important when the quantum dots who had been made to interact in multiple ways, the extreme sensitivity of the exchange coupling to the relative positioning of the substitution donor pair in the silicon is entirely due to the 6 fold degeneracy of the silicon condition band is minimum and that led to the idea that the dipolar spin coupling and dipolar gates could perhaps be the reason for this extreme sensitivity.

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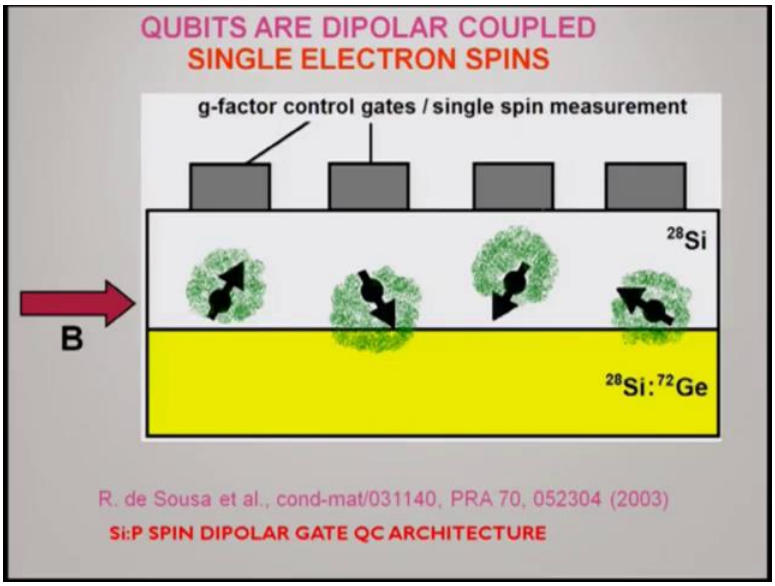

In order to ensure that that adiabaticity is maintained it was important to make sure the coupling and dipolar nature was maintained in very careful manner, for the qubits that are dipolar coupled single electron spins could be utilized and this work had also been done in terms of the silicon phosphorus, spin dipolar gate quantum architecture where the silicon and germanium mixed semi conductor was having these states being addressed by the control gates in single spin mechanism and the applied magnetic field was the way how these orientation of these spins were being addressed. The control gates where controlled by the single spin measurement properties and the in perfections in the presence of the exchange was possible to be addressed by using the principle that the long range dipolar interaction is much smaller than the short range exchange for large inter donor separations, how large should be the separation.

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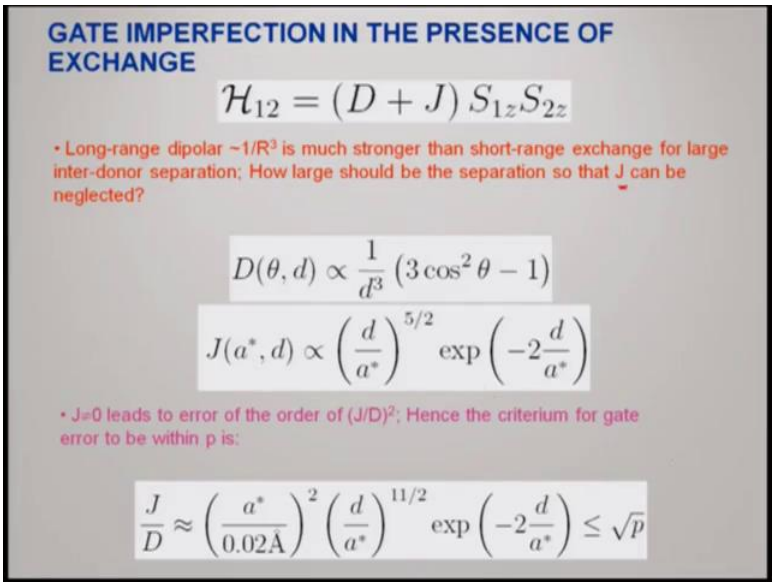

So, that the interaction or the rotation parameter can be neglected is one of the problems which were lead to these interactions and studies in that area were done. And it was found that the criterium for the gate error to be within the given study that was done was a particular parameter which was defined in this particular form.

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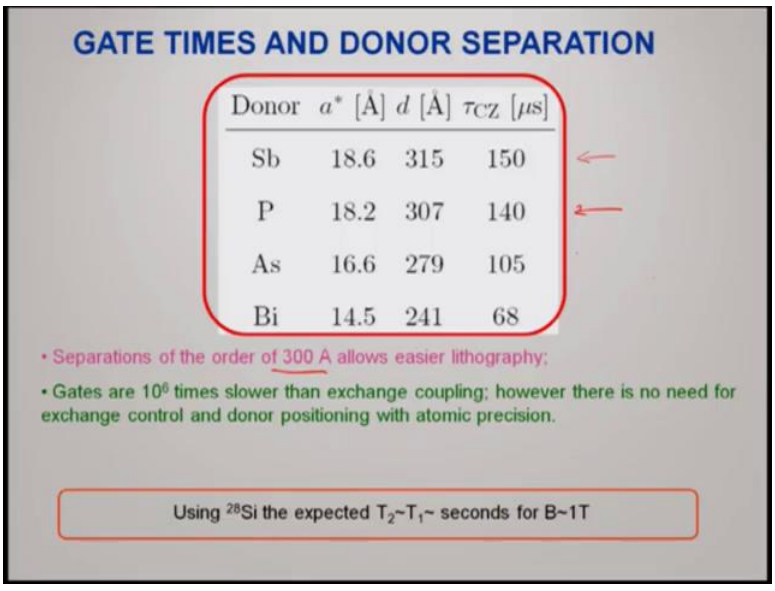

And based on that the gate times on the donor separation was found to be on the order of 300 angstrom, which allows easier lithography which was experimentally necessary, the gates are 10 to the power 6 times slower than the exchange coupling; however, there is

no need for exchange control and donor positioning with atomic precisions in these cases therefore, using silicon 28 the expected time constants were found to be about the order of the applied magnetic field about a 1 tesla and that was one of the issues that was been used using different donors for example, antimony phosphorus arsenic and dismac, the values which were found to be the most effective was the one which was phosphorus and because that is the one which has the separation of about 300 angstrom and the antimony also was reasonable in its applications.

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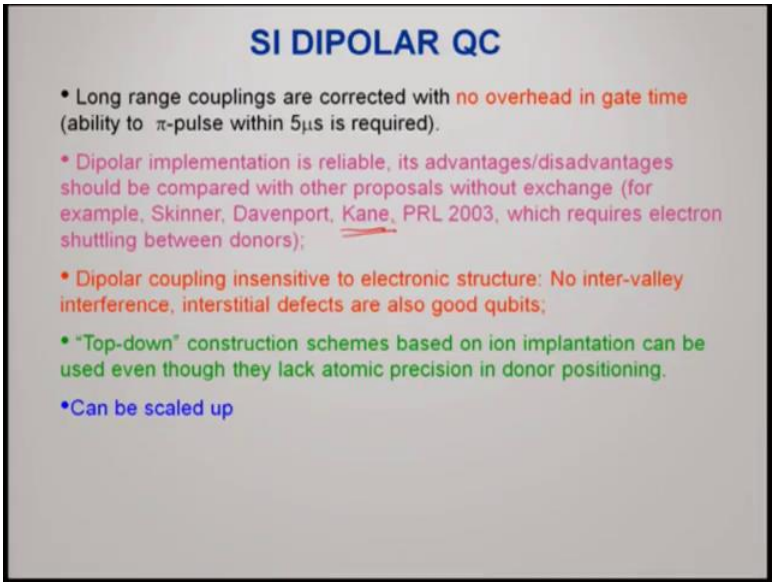

So, these are the ones which were the better ones for utilization of these techniques. For the silicon dipolar quantum computer long range couplings are corrected with no overhead in gate times in order to provide the ability to pi pulses within 3 5 microseconds, that is required the dipolar implementation is reliable its advantages and disadvantages should be compared with other proposals without exchange.

So, for example, the earlier work in these directions where in reported in these cases which require electron shuttling between donors, the dipolar coupling insensitive to electronic structure was also useful and no inter valley interference interstitial defects were also good qubits the top down construction schemes based on ion implementation could be used though they lack atomic precision in donor positioning and they can be scaled up all these work were done by the Kane group in the early 2000 and a lot of efforts have been put in this area.

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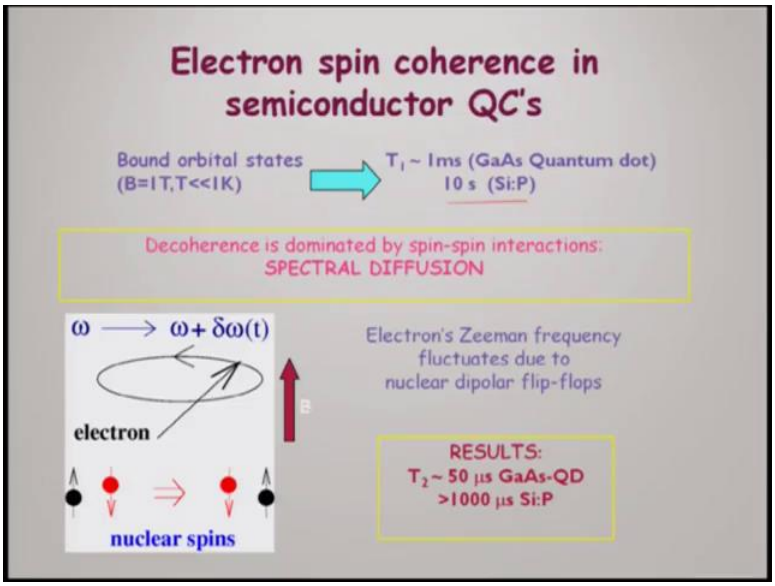

The electron spin coherence in semiconductor quantum computing required the usage of the bound orbital states such that, they had about the millisecond of their electronic decay times which is the gallium arsenide in quantum dots whereas, it was about ten seconds in terms of silicon phosphide. So, the Decoherence is dominated by the spin interactions and that was understood from the spectral diffusion the in the electrons spins, were the ones which got coupled into the nuclear spins and therefore, they have to be careful the electrons Zeeman frequency fluctuates due to nuclear dipolar flip flops and as a result de coherence times scale 52 about 50 microseconds were seen for gallium arsenide quantum dot whereas, it was greater than 10000 microseconds for the silicon phosphide. So, depending on the applied conditions they used to have different results.

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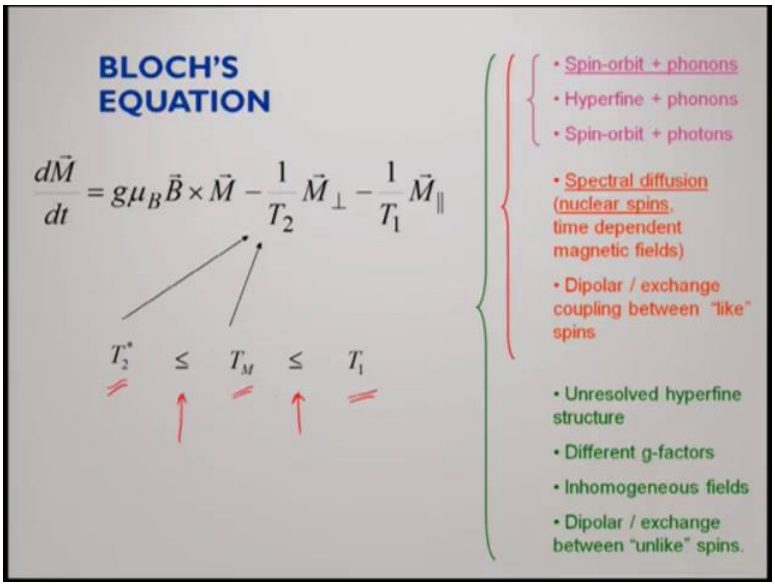

So, these were all based on blocks equation where the important times scales were due to the magnetic interactions could be understood in terms of the T 2 stars, these are the different time scales of the T M magnetization terms or the T 1 which is the lifetime parts. So, the spin orbit on the photon combination was 1 of the aspects and there are hyperfine with phonons and spin orbit photons were the other parts.

So, the spin orbit phonon hyperfine phonons spin orbit and photons are the ones which are responsible for these time scales the spectral diffusion parts with are interacting due to nuclear spins and the time dependent magnetic fields. The dipolar or the exchange coupling between like spins are also contributing to some of these time scales the unresolved hyperfine structure are the ones which give raise to other decays, and different g factors and inhomogeneous fields and dipolar exchange between unlike spins are the ones which are often used in terms of the different time scales which have been looked at when these are looked at and therefore, they are ordering in terms of which goes in effect towards the advantageous at the ones which have to be addressed when these processes are being looked at.

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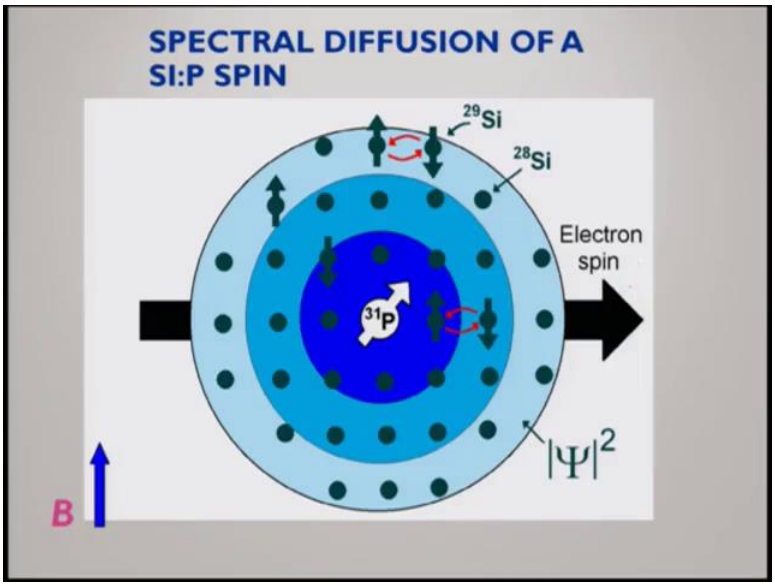

The spectral diffusion of a silicon phosphorus spin had mainly based on the idea that the applied magnetic field, the phosphorus spin can interact with the neighbouring silicon 29 and the silicon 28 particles and the electron spin of the system would can be resulting as a result of this process.

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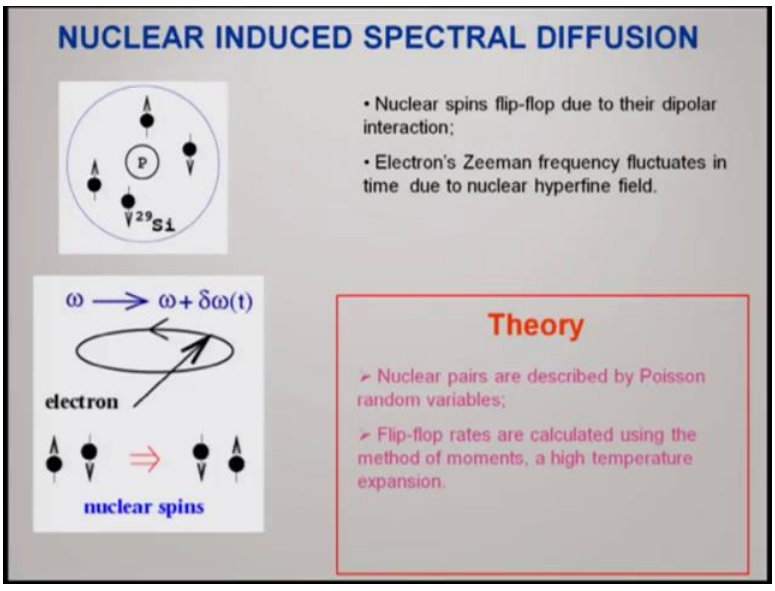

And the nuclear induced spectrum diffusion arises because of the fact that the spins can interact, the nuclear spins flip flop due to their dipolar interactions the electrons Zeeman frequency fluctuates in time due to nuclear hyperfine field and as a result this particular

approach is been measured, the theory behind this is based on the nuclear pairs that are described by the Poisson random variables whereas, the flip flop rates are calculated using the methods of moments at high temperature and that is possible due to high temperature expansion.

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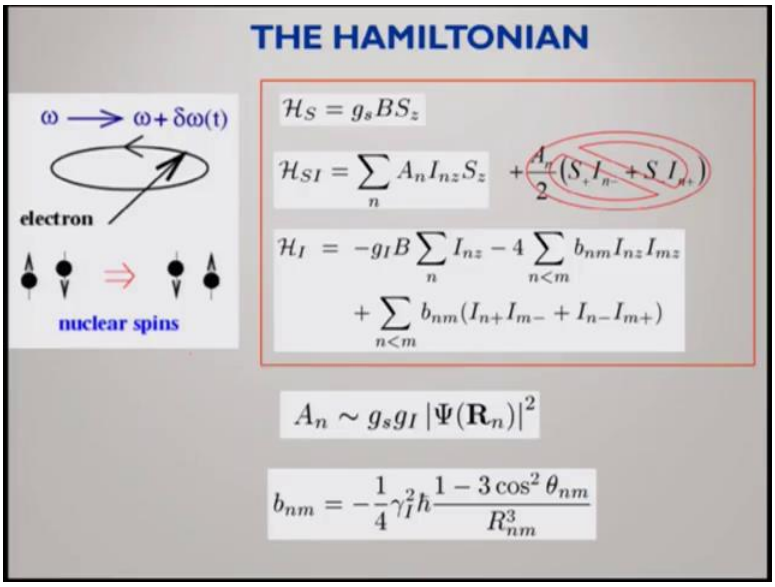

The Hamiltonian for these kinds of interactions can be looked at in terms of the spin coordinates of the coupling and the system together whereas, the other parts are due to the other coordinates which arise as the result of the coupling between the nuclear spins and the electron, and these are the areas where a lot of theoretical work has gone in to make sure that these can be understood in a way. So, there it becomes better and better in terms of this Spintronic application of the electrons which can then be preserved and applied in a proper manner.

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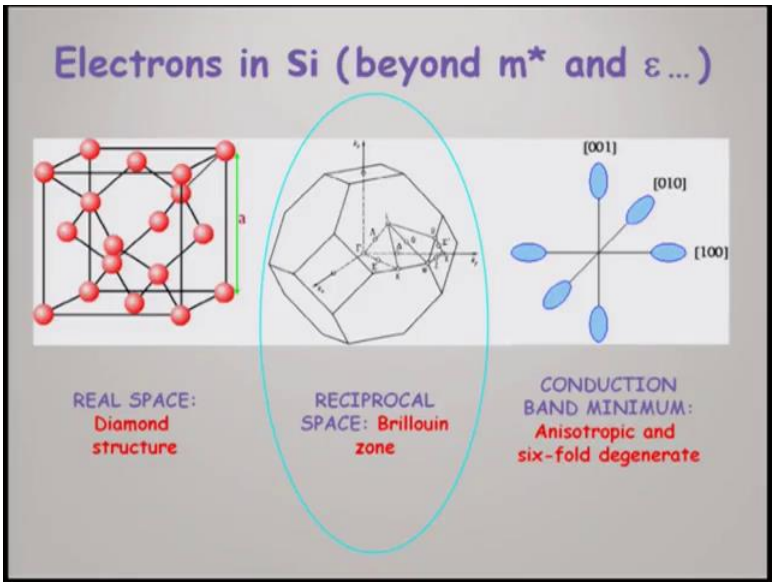

The electrons in silicon beyond the magnetic field and the applied electric field can basically be utilised also in terms of the real space where the advantage of these can be utilised. So, for instance the diamond structure of the silicon can look like in the reciprocal space in terms of giving raise to the brillouin zone, which can then be looked at in the conduction band minimum which will give rise to anisotropic and 6 fold degeneracy so, this anisotropic and 6 fold degeneracy as a result of the real space structure being subjected to the magnetic field would give raise to the structures of the anisotropic, which are of the appropriate degeneracy which can be utilized for further applications. So, the theoretical understanding of all these processes is being utilized for the study or the applications into the Spintronic concept.

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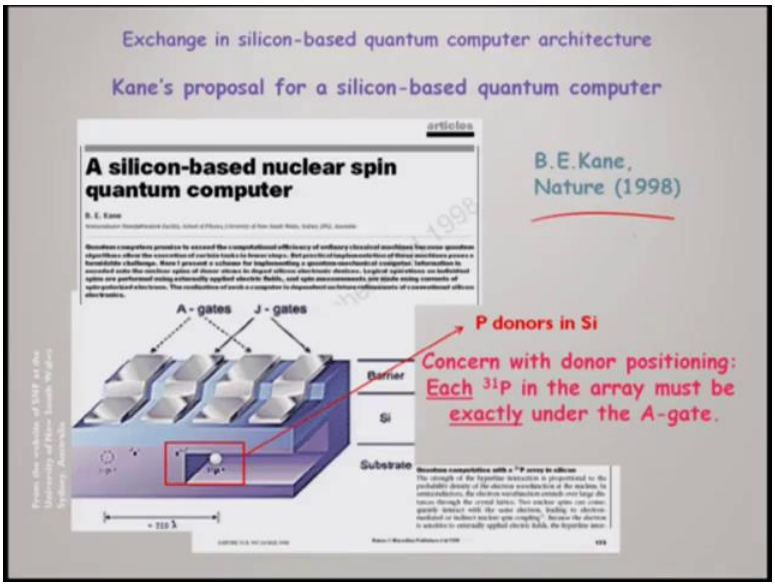

And here is the review article which was mostly based on these developments and was presented a lot more work after these were also been done, which is mostly to do with the phosphorus stone as in silicon which concerned with the donors positioning where each of the phosphorus stone as in silicon, which concerned with the donor positioning where each of the phosphorus in the array must be exactly under the gate that have been looked at. This particular proposal the initial ones you know based on the work done by Kane from Australia where they proposed that the quantum computers which promise to exceed the computational efficiency of ordinary classical machines can be practically implemented by using quantum mechanical processing, where the information is encoded into the nuclear spins of the donor atoms in dope silicon electronic devices.

The logical approaches are individual spins are performed using externally applied electric spins and spin measurements are made using currents of spin polarised electrons the realization of such a, computer is dependent on the future refinement on conventional of conventional silicon electronics and this particular work from the university of new south Wales Sidney was one of the important development, which as we know has been later on utilised as I mentioned earlier in many of the efforts coming from commercial areas also the computation in this particular case was possible due to the phosphorus 31 array in inside the silicon the strength of the hyperfine interaction of this interaction of the phosphorus 31.

Is propositional to the probability density of the electron wave function at the nucleus in semi conductors the electron wave functions extends over the distances through the crystal lattices to nuclear spins can consequently interact with a same electron leading to electron mediated or indirect nuclear spin coupling, because the electron is sensitive to externally applied electric field the hyperfine interactions are the ones which give raise to these principle. And the idea of this nuclear spin mediated electron being interacted is over which was done by these people and that is the part of one of the areas of Spintronics which has been aspected very heavily.

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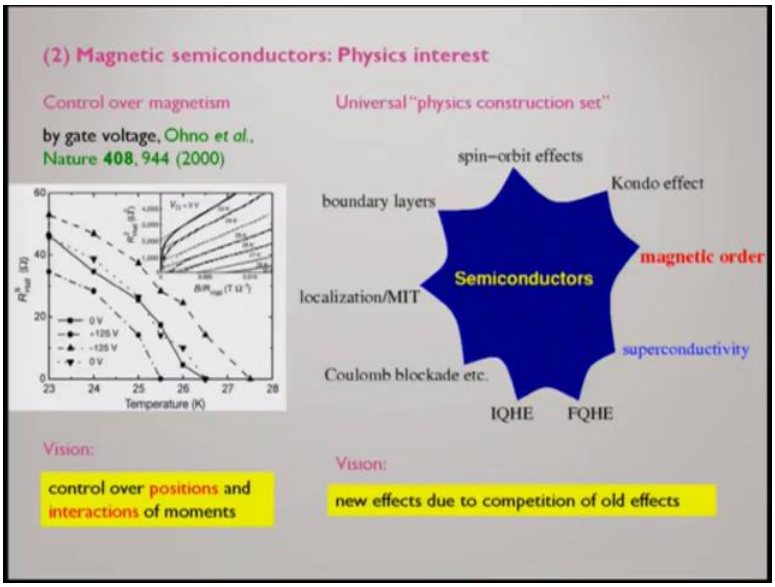

So, with this I would like to end today's lecture which was mostly focused on principle of how spin of electrons can be looked at or interacted or made to interact be a other methods of interactions either with a nuclear principle or magnetic principles. So, that they can be utilized simultaneously with other applications and can be put together with quantum inform.

Thank you.