DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

Ecole Nationale Polytechnique

Electronic Department

Laboratory of Communication and Photovoltaic Conversion

Master's thesis in Electronic

The quantum computer: a brief description

CHAIB Djamel

Supervised by :

PhD. Mourad ADNANE

Presented in public on : 15 th October 2017

Jury members:

President	Mr.R.SADOUN	PhD	ENP
Examiner	Mr. A. BELOUCHRANI	Professor	ENP
Supervisors	Mr. M. ADNANE	PhD	ENP

ENP 2017

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Dedication :

This work is for everyone that supported me, beginning with my mother and my father: who took care of me since my childhood till this day.

And finally, I would like to thank all my friends whom I met at every stage of my education, and every stage of my life.

Acknowledgment:

I would like to thank Dr Mourad ADNANE for his availability, for his valuable help, his availability throughout this thesis, his precious advices during the thesis, we learned a great a deal from him, not to forget his good humor and kindness.

D.Chaib

2016/2017

ملخص :

الحوسبة الكمومية : تستخدم الظواهر الميكانيكية الكم، مثل تراكب وتشابك، لإجراء عمليات على البيانات. وتختلف الحواسيب الكمومية عن الحواسيب الإلكترونية الرقمية الثنائية القائمة على الترانزستورات.

الكلمات الرئيسية: ميكانيكا الكم، التشابك، كوبيت، تراكب.

Resume :

L'informatique quantique étudie des systèmes de calcul qui utilisent directement des phénomènes mécaniques quantiques, tels que la superposition et l'intrication, pour effectuer des opérations sur des données. Les ordinateurs quantiques sont différents des ordinateurs électroniques numériques binaires à base de transistors.

Mots clés: mécanique quantique, intrication, qubit, superposition.

Abstract:

Quantum computing studies computation systems that make direct use of quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data. Quantum computers are different from binary digital electronic computers based on transistors.

Key words : quantum-mechanics, entanglement, qubit, superposition.

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Chapter 0: Introduction:

The ability to contemplate the meaning of world around us brings a constant desire to deeper our knowledge and broaden our horizons, this curiosity is fundamental to the development of our species and civilization, from the advent of the wheel to the innovation of engines, from the cultivation of herpes to the development of modern medicine, from the abacus to computers. Human history is a record of progress , our drive to explore has opened the door to new possibilities to improve the quality of our life , and allow our species to thrive .

Throughout the centuries of scientific development, human been driven by the conviction to uncover the mysteries of the universe, but with each new discovery, we were confronted with new questions and challenges, today we live in an age in which the possibility of crossing a new threshold of scientific knowledge is within arm's reach, this is the dream of quantum computerization.

This being said, it would appear that the next giant leap for humanity lies in understanding quantum computing and the harnessing of its potential. The computational power of quantum computing processing may hold the key to our future understanding of the universe and how it works.

We find that we live on an insignificant planet

... Of a humdrum star ... lost in a galaxy

... Tucked away in some... forgotten corner of the universe

... In which there are far more galaxies than people.

We make our world significant

... By the courage of our questions

... And by the depth of our answers.

Carl Segan

Chapter 1:
quantum computing overview:

1.1 Introduction:

In 1980 Russian mathematician yuri manin (**figure** 1) was the first to propose the idea of quantum computing [1], a year later eminent physicist Richard Feynman (f**igure2**) presented a logical quantum computer model at the conference on physics and computerization [2], the premise behind feynman's model rested in the conviction that it would be impossible to conduct the simulation of a Quantum system with the use of a classic computer. He finally understood that the traditional engineering approach to the problem of computer development would never lead to a revolution, he based his reasoning on the laws of nature. Feynman’s lectures from the last years of his scientific activities are considered by many to be a key moment in the development of quantum computer theory.

Figure 1 : YURI MANIN

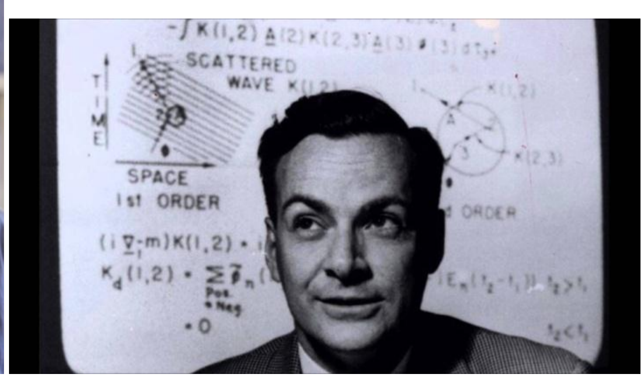

Figure 2 : Richard FEYNMAN

classic computers are devices that with the use of transistors (figure 3) process information in the form of sequences of various combinations of zeros and ones known as computer binary language, in simple terms a transistor is a type of switch, it can be turned on which corresponds to binary one, or it can be turned off which corresponds to a binary 0. The grouping of transistors into special circuits which are called logic gates allows the computer to perform calculations and make decisions in accordance with a man-made computer program, the computer's processing power depends on the number of transistors used.

Figure 3 bipolar junction transistor.

1.2 Why quantum computing:

According to Moore's Law (figure 4) [3], today this power is doubling every two years as of 2014 the commercially available processor processing the highest number of transistors is the 15 core Zion ivybridge x with over 4.3 billion transistors, in the case of graphic processors the world's record belongs to Nvidia, which offers computer accelerators in which the number of transistors exceeds 7 billion, although this type of device is admirable and undoubtedly contributed to the development of Science and Technology, it does not change the fact that there are still some problems of higher rank, which could not be resolved in optimal time even by the most advanced classic computers.

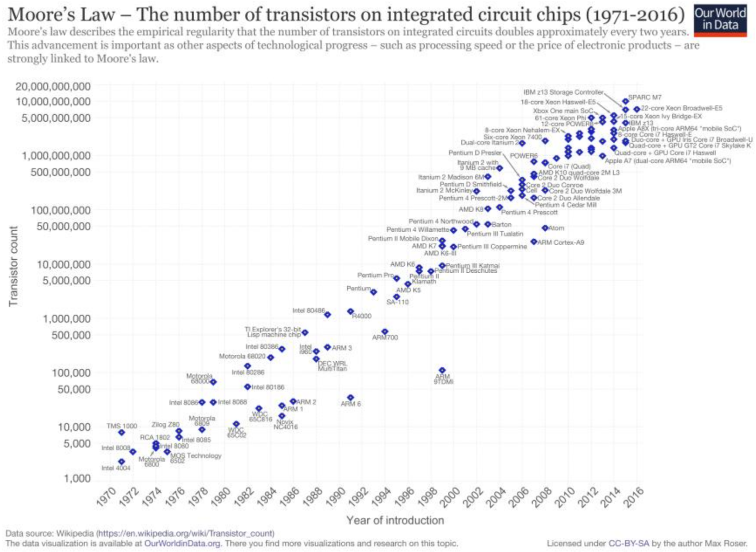

Figure 4 : the Moore's law evolving from 1970 - 2016

1.3 Qubit principle:

No conventional Solutions or improvements can compare with the endless possibilities offered by the laws of quantum mechanics, the quantum mechanical states of Elementary particles like transistor voltages can be described in zeros and ones depending on the method used, we can apply various kinds of particles to the calculations here (**figure 5**), the state described by the zeros and the ones is the internal angular momentum of the particle, known as its spin, although it's not possible to describe this particular feature through the use of classical mechanics [4], it can be likened to a magnetic bar capable of deviations when the bar is pointed up the state can be described by a value of 1 however when it is pointing down it can be described by the value of 0, in other words spin up corresponds to the turned on switch, and spin-down corresponds to the turned off switch, using this analogy, we can describe the defined quantum states with the use of binary system much like the classic computer, however Beyond this point all similarity ends.

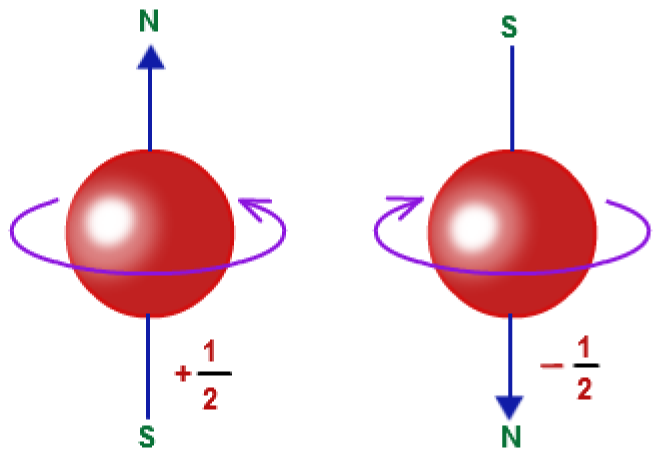

Figure 5 electron spin (up and down).

the advantage of quantum Computing mainly rest in the quantum mechanical feature thanks to which an elementary particle can be in multiple States [5], simultaneously this type of phenomenon called superposition occurs before the measurement that defines the particles permanent State, before the measurement when there's no surrounding noise the elementary particle experiences superposition manifesting quantum ability to occupy multiple particle States at the same time (figure 6) , in accordance with the principles of quantum physics a spin of exemplary particle may in a parallel manner indicates all directions at the same time forcing us to describe it with 0 and 1 simultaneously, thus unlike the classic computer, with a basic unit of information is one bit expressed by just one number in binary notation, in the case of quantum computing information is expressed through a quantum bit so-called qubit which is described by both of 0 and 1 binary units simultaneously, working with qubits provides us with Incredible new possibilities for the effect of processing of databases beyond what we could have ever before imagined.

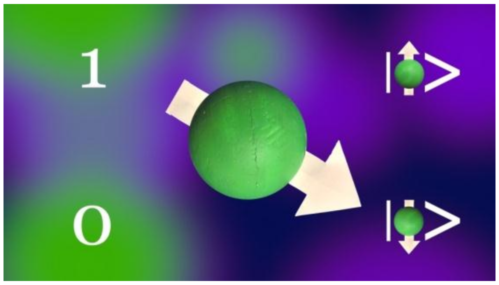

Figure 7 : Superposition of spin within an electron

To better illustrate the advantage of working with qubits, let's consider the example of all possible combinations of the two bit data system, we have four possible States 00 10 01 11, a two bits classic computer cannot simultaneously perform one of these four possible functions, in order to check all of them the computer would have to repeat each operation separately, a 2 qubits quantum computer, due to the phenomenon of the superposition, is able to analyze all of these possibilities at the same time in one operation this is due to the fact that 2 qubits contain information about four states, while two bits only contain information about one state, thus a machine with N qubits can be in superposition of the N States at the same time, a 4 qubits computer could analyze 16 parallel States in a single operation in comparison with 4 bit classic computer, which can only analyze one state to achieve the same solution as the quantum computer but classic computer would have to repeat this operation 16 times.

The advantages of quantum Computing will continue to increase in data, it is not impossible that a 500 qubits computer could one day analyze more data than there are atoms in the observable universe.

1.4 First attempts at manufacturing a quantum computer:

Early prototypes of quantum computers were comprised of test tubes, scientist Neil Gershenfeld Isaac long and Mark Cuban made use of the phenomenon of nuclear magnetic resonance (**figure 8)** to create the first quantum computer model [6], the model was comprised of a test tube which contain chloroform particles, the apparatus was placed in a constant magnetic field that help the scientists to focus on the interactions between spins of hydrogen and carbon, which acted as a logic gate the programming was conducted with the use of radio impulses of particular frequencies which resulted in the variation of spins, the test tube computer model successfully found the element in the 4 element data set although these early experiments were successful, researchers from University of New Mexico claim that these early computer models were nothing more than classic simulations of quantum computing.

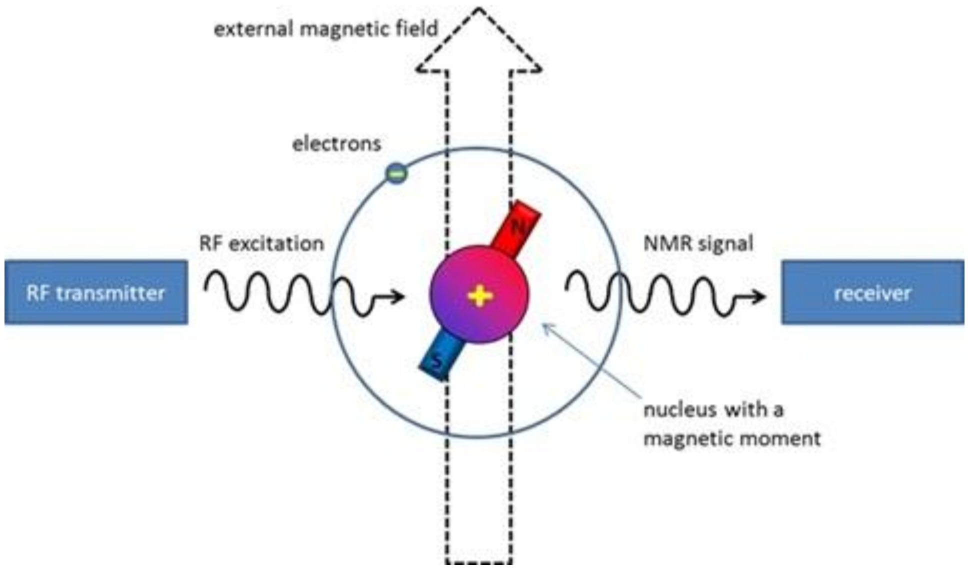

Figure 8 : Magnetic resonance of particle magnetic momentum

1.5 The challenges of quantum computer:

The possibility of actually developing such a system for practical applications is not readily conceivable, to develop a fully efficient quantum computer certain requirements must be fulfilled, one of the most important is to create appropriate conditions, under which it would be possible to manipulate qubits, while allowing them to maintain their unique properties(yes it is a very difficult task that requires great precision and special equipment) but doing so would give away to a plenitude of possibilities offered by the fundamental laws of nature.

however in a macro world such as ours there are many obstacles to the development of quantum systems one of the biggest problems faced by scientists working to develop quantum computers is the issue of decoherence [7], each elementary particle is subject to wave particle duality meaning that, sometimes, it behaves like a particle and other times it behaves like a wave, the particle behaving like a wave is subject to a phenomenon known as unitary evolution which is described by Schrodinger's equation, it's a state in which noise from the surroundings(i.e decoherence related among others), thermal energy is not sufficiently large enough to trigger the leakage of very susceptible information, such evolution of entanglement and mutual decoherence may be analyzed through time, which allows for the processing of information in a completely new way.

Additionally, it is essential that the qubits remain in the state of quantum entanglement only with each other i.e system in which the exchange of quantum information may occur between them, unfortunately our surroundings are comprised of elementary particles, which only serve to disrupt the precision of quantum processing, such uncontrolled entanglement of qubits with the surroundings outside the system could lead to a leakage of important information.

consequently it's essential to isolate and cool (**figure 9**) the quantum computer processor where the calculations take place is at extremely low temperatures near absolute zero, it helps to calm the qubits by propelling them into a state of extremely low energy levels and as a result makes them easier to control, cooling is also important due to the fact that some of the superconducting materials used in the construction of quantum processors and their unique properties can only be used at very low temperature, aside from nuclear magnetic resonance, other solutions and phenomena may be used to create a quantum computer, such as (**figure 10**) polarization of light Bose-Einstein condensate Quantum dots ion traps.

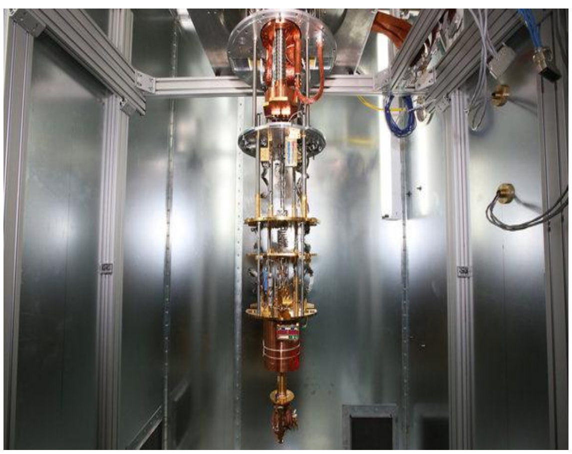

Figure 9 : cooling of a quantum computer

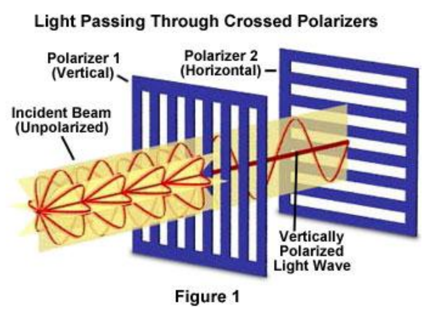

Figure 10 : phenomenon of polarization of light.

Regardless of the method used the goal is to achieve the capability to control that it would be possible to program the computer to perform the calculations and find the desired results.

1.6 Single atom computer:

In 2012, scientists from the University of New South Wales created the first single atom transistor (**figure 11**) made of silicon in light of the many positive and interesting results of the research on the control of quantum states [8], the team of Australian researchers led by Michelle Simmons has garnered worldwide recognition.

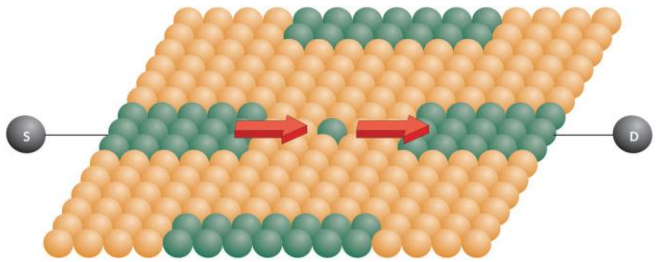

Figure 21 : single atom transistor

Information starts with the introduction of atoms into the lowest energy state through cooling of the device, phosphorus atoms have electrons, which also have a spin let's imagine the electron as a pendulum, when it is in its lowest position, it has the lowest amount of energy, but when we start to push it lightly, it gains energy, such pushes can be performed with the use of microwave radiation, which propels the electron into an increasingly higher energy state. When the pendulum reaches its culminating point the electron may detach itself from the atom.

The single electron transistor is a very sensitive measure of the flow of electric charge, thanks to which we can examine the flow of a single electron. This type of electron detachment from the atom is equivalent to a particular direction of spin corresponding to the number 1 in binary notation. In other words our capacity to measure the flow of a charge enables us to learn which spin had a single electron.

If he Australian team is successful in increasing the number of qubits, such that all of them are appropriately isolated from the environment, while in a state of quantum entanglement, then it will open up a new door in quantum computing.

1.7 The adiabatic computer:

In addition to the universal model based on logic gates which the Australian scientists have worked on there are many others [9], one such model is the adiabatic quantum computer the adiabatic computer (**figure 12**) was built by the company d-wave which was the first in the world to put such an Advanced Equipment on the commercial Market this company founded by Vern Brownell and Jordy rows began in the physics and astronomy Department of the

University of British Columbia in Canada, but it later became an independent entity the idea of building a quantum computer system was born out of the scientists experiments on superconducting materials.

the basic elements of D-Waves computer processors are called squids superconducting Quantum interference devices (**figure 13**) which are some of the most sensitive devices used to measure the intensity of magnetic field, in simple words squid is a certain kind of superconducting ring divided by what is known as the Josephine conductive materials that make up these devices have certain unique properties thanks to which at very low temperatures nearing absolute zero Quantum uniqueness takes precedence over the classic principles of physics that we are accustomed to, for example in the cooled superconductor or squid the phenomenon of electrical resistance does not occur at all and due to a phenomenon known as the meissner effect some object can even levitate unlike the single atom transistor here the form of qubit is the direction of movement of many united electrons which as a result of the low temperature and superconducting properties may be considered equivalent to what in the previous model was the direction of the spin.

in other words here zeros and ones describe the direction of flow of electrical current through the superconducting Rings the clockwise flowing current corresponds to 0 while the counterclockwise flowing current corresponds to one the entire computerization process in this type of model is based on the probabilistic method of what's known as quantum annealing(**figure 14**).

Quantum annealing consists of finding the optimal value among all possible solutions, the name of the Method is derived from annealing in Metallurgy which is a technique of controlling the temperature of the cold metal alloy, slow cooling allows for the formation of ordering crystalline structures, in quantum annealing the magnetic field is the equivalent of temperature, for instance to find the lowest valley during a hike in mountainous terrain we would have to track across all the terrain to finally arrive at the right place quantum mechanics reduces this search, Quantum tunneling is unique phenomenon which allows the particles of Micro World to cross the Wall contrary to the law of conservation of energy, thanks to Quantum tunneling the electron searching for the lowest point in the given terrain would not have to cross it up and down because it would have the ability to penetrate through those intuitive mountains allowing for much more efficient searches if the controlled variations in the magnetic field during this walk of electrons are sufficiently slow then once the magnetic field is turned off, we should be able to arrive at the correct solution, which in this analogy would be the lowest point of the area.

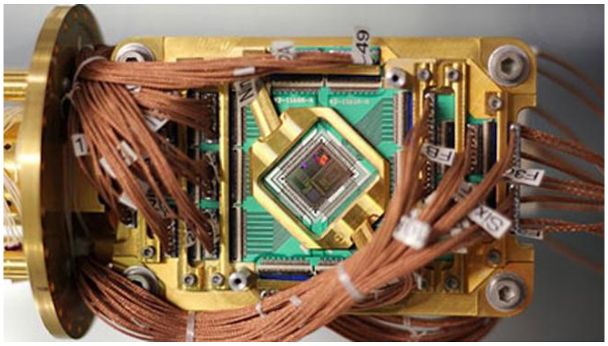

Figure 12 : the adiabatic processor .

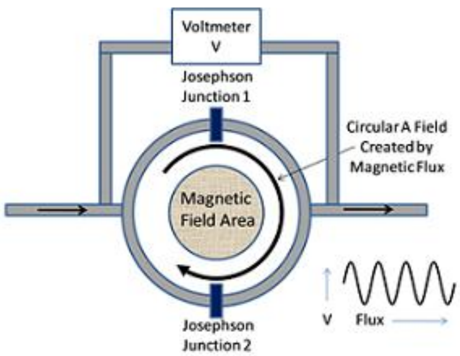

Figure 13 : the basic circuit (squid) of the adiabatic computer.

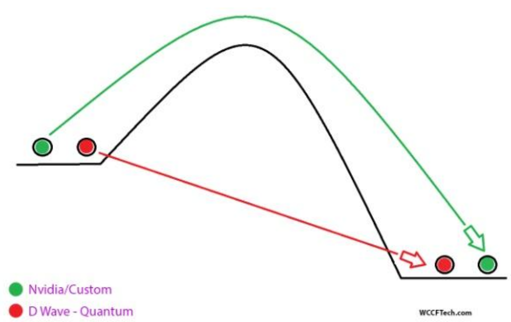

Figure 14 : the phenomenon of quantum annealing

Chapter 2:
The quantum computing theory:

2.1 Introduction:

Quantum mechanics (QM; also known as quantum physics or quantum theory), including quantum field theory [10], is a branch of physics which is the fundamental theory of nature at the smallest scales of energy levels of atoms and subatomic particles.

Quantum programmers are able to manipulate the superposition of qubits in order to solve problems that classical computing cannot do effectively, such as searching unsorted databases or integer factorization. IBM claims that the advent of quantum computing may progress the fields of medicine, logistics, financial services, artificial intelligence and cloud security.

2.2 The qubit:

It is basically, a quantum particle, that evolves according to the schrodinger equation, its basic notation, for a two states evolution, is as follows (when ignoring the time phase):

$$\Psi = \alpha|0> + \beta|1> \tag{1}$$

Where |0> and |1> are Eigen-vectors (we named them 0,1 for convenience) that represent the energy levels of the particle, this the α, β are the Eigen-values respectively to each vector.

In practical term, this configuration can be done through the adjustment of the particle energy states, the E energy state of a particle:

$$E = \hbar w \qquad (2)$$

Where h-bar is planck constant and w is the angular frequency

2.3 Electron’s spin:

The spin of an electron is the rotation of the electron around its axe, for simplicity we consider it to be a spin up, or spin down for a given axe.

The spin up is the rotation as shown in (left- figure 5), it generates a magnetic field S-N as shown in the figure.

The spin down is the rotation as shown in (right- figure 5), it generates a magnetic field N-S as shown in the figure.

The angular frequency for the electron spin is:

$$w = \frac{\hbar . B}{2}$$

The magnetic field B controls the w frequency that describes also the energy-state, so we can act on the electron’ spin through the means of the magnetic field, when we add the time phase, we can see that the spin depends upon two variables which are the magnitude and the frequency of the magnetic field.

2.4 The technique of computaion:

In order to illustrate the results of the first chapter, let us take the example of two particles with two superposed states:

$$\Psi = |\Psi_1 > ||\Psi_2 >$$

When written like this, it means that the two particles are independent, this feature is very important since it allows us to estimate the state of the first particle without altering the probability of estimating the second one.

This are called **separable states**.

Ex :

$$\Psi_1 = a|0> \; +b|1>$$

$$\Psi_2 = c|0> \; +d|1>$$

When combined into a quantum system, their configuration is as follow:

$$\Psi = \mathrm{ac}|00> \; + ad|01> \; + bc|10> \; + bd|11>$$

When we measure the state of the first particle above we get:

$P = (ac)^2 \; + (ad)^2$ if we find 0 or $P = (ac)^2 \; + (ad)^2$ if 1

So we can measure the state of the two particles and it gives us the coefficients of ac , ad, bc , bd and so we can estimate the state of the system.

Input/output are a superposition of the values we measure in a quantum system. In reality we choose our constant to be $a = b = c = \frac{1}{\sqrt{2}}$ and $= \; -\frac{1}{\sqrt{2}}$, it is called the Hadamard transformation [11].

There is a down side to this because in real systems there are always cross-terms due to interferences- effect , so the results we get are probabilistic , for some cases we can orchestrate this interferences to get the real value, or we can add a classical processeur to check the results when they easily checkable.

2.5 How to compute:

To implement a computation, we need to have the equivalent of gates in quantum system, this is done by using the matrixes of transformation , these matrixes are the result of applying a certain magnetic field to our system, there are many limitation to the computation that can be done with a quantum computer, such as cloning a state (replacing a value of a state by a copied one), researches in information theory are trying to further the limits of these models. One of most known algorithm is the deutsch jozsa algorithm that is the working horse of the quantum computation field.

Conclusion:

D-waves first client was an American Armament company, called Lockheed Martin, which at the end of 2010 decided to purchase a 128 qubit d-wave one computer for 10 million dollars.

in 2013 with the cooperation of Google NASA and Ursa d-wave created a 512 qubit d-wave to computer for an artificial intelligence laboratory, researchers in this laboratory are using the d-wave two computer to facilitate them in their work in areas such as the Improvement of voice activation, device technology development of new drugs, climate change modeling optimization of traffic, control development of Robotics and machine navigation and shape.

There is a continuous and Lively debate over the question of whether the computers manufactured by this Canadian company can actually be considered as fully Quantum.

one of the basic allegations posed by the critics is the possible absence of quantum entanglement occurring between the qubits comprising the d-wave processors, however according to most recent published scientific studies the computer definition used by d-wave is correct only time will tell whether this information is definitive.

in order to take advantage of all that is offered by the fundamental laws of nature we need software and algorithms, which are just as necessary as basic construction elements creating the algorithms, however it is a very difficult task as it requires that we take into account the counterintuitive laws of quantum mechanics, nevertheless there are many people, who have risen to the challenge Peter Shore and love Grover are the creators of some of the most well-known Quantum algorithms most notably, since its creation shor's algorithm has generated a great deal of discussion among the scientific Community, as it could be used to break the modern encryption Keys such as RSA, if there were a quantum computer capable of efficiently using shor's algorithm, the use of encryption to secure bank accounts and other operations and the other company difficulty of mass numerical division would cease to exist.

classic computers don't handle these type of difficulties very well, so we can sleep peacefully, without worrying that our bank account will be cleaned out by a Quantum hacker, another significant algorithm is Grover's algorithm, which was devised to sort through information in unordered databases imagine searching through a phone book with a random assortment of names, in order to find a given telephone number, you would have to search through each and every listing, which would undoubtedly be cumbersome and time-consuming however by applying Grover's algorithm to a quantum computer, you could retrieve the desired name in only a few seconds, it should be noted however that a single outcome obtained from such calculations is only a probable solution, the more times the computer performs the calculations, the more likely it is to find the proper solution to the problem.

Quantum computers are devices mainly designed to solve complex problems, which require us to deal with very large amounts of data, these types of machines will soon find their practical application in Research Laboratories instead of computer games.

The role of a quantum computer is to provide assistance in capturing what is beyond the boundary imposed by time and energy, perhaps the ladder such as the creation of new Breakthroughs in research on climate change, and the development of new technological devices.

It is the hope that these new discoveries will provide us with a deeper on under of the reality that surround all of this, thanks to the laws of nature and the desire to explore, which defines Humanity.

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