Feasibility Study For Producing a Quantum Computer:

A Completion Report

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Abstract

“Feasibility study for Producing a Quantum Computer”

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Current semiconductor based computers will not be able to increase in computing speed beyond certain limitations. A semiconductor-based computer will not be able to provide us with the demands of the future. Therefore, one viable alternative is a quantum computer. Although highly capable in theory, a quantum computer has many problems at this point in development. A quantum computer must be cooled to operate properly. A quantum computer must also have insulated and isolated logic gates to perform adequately. These two major problems have lead to our research. This report describes our research into cooling and insulating quantum computers. This report also details our promising findings and includes recommendations that we believe will lead to an effective working quantum computer. Our research provided us with a way to both cool and insulate s with a way to both cool and insulate a quantum computer therefore making it possible and feasible.

Executive Summary

In January of 2001, we began researching quantum computing. In our research we discovered that the greatest downfall of quantum computers was the inability to successfully isolate a logic gate. Without the ability to isolate a logic gate, a quantum computer interacts with its surroundings and cannot perform as it is supposed to perform. If a logic gate can successfully be isolated from its surroundings, a quantum computer may be feasible for consumers in the near future.

However, there are two aspects associated with isolating logic gates. A logic gate must remain at a constant, controlled temperature. This is much more difficult than it may sound. By stating that it must remain at a constant, controlled temperature, research tells us that this temperature must be very low and have little or no fluctuations at all. In order to achieve this state of control, we need a small, powerful unit with precise instrumentation and exact temperature control. Any changes in temperature would cause the quantum computer to operate abnormally.

The second problem associated with isolating logic gates involves isolating each gate from every other logic gates within the quantum computer. This problem is the main reason why a quantum computer is not feasible at this point. In order to isolate a logic gate, we must develop a substance that is on the sub-atomic scale. The isolating material must be able to isolate photons, which are on the sub-atomic scale. This material must be able to isolate certain photon interactions.

We began our research based upon these two problems. Soon after beginning our research, we discovered that it is currently possible to cool a quantum computer to a level at which these two problems will no longer exist. We used available material to research these products. Most of our knowledge came from Internet web sites. Mainly, this information came from the Massachusetts Institute of Technology web page. However, we received additional information from the Center for Quantum Computing web page. Currently, physicists from many universities are further reviewing and researching this technique for cooling and insulating a quantum computer. However, it is already

well proven and with further research, it will be in use in the near future.

We recommend that you invest your time and money into research in this area of quantum computing. We believe that it will be of great use to you and your money will be a great investment. However, this will be a time consuming task and will also be a high cost endeavor. If researched properly, this cooling and insulating technique will be the final step or link to producing a quantum computer that is both operational and cost effective in the near future.

Introduction

On February 18, 2001, we received approval to research the feasibility of isolating and cooling a quantum computer in order to provide us with a successful quantum computer.

This report presents the findings of our research in detail. We studied all available products that could be possible of meeting our needs and discovered that our research was successful. We discovered a product that is capable of meeting our demands and could provide us with the cooling and insulation demands of a quantum computer.

Our research began as a result of the demands that are currently being placed on the semiconductors based computers. We quickly discovered that these semiconductor-based computers would not be capable of meeting the needs of people in the future. We decided that a quantum computer would be capable of meeting these high demands of corporation and consumers.

The current semiconductor based computers provide us with the power needed to handle most tasks efficiently. However, they are limited in several ways. They cannot be made into a more portable, lightweight system due to their limited thickness of wiring and costly products needed to downsize them. The modern computer is also limited in processor speed. The solution to this problem is a quantum-based computer. They will be small and lightweight and will offer an outstanding increase in speed and efficiency.

A modern computer has many limiting factors. Wire thickness must be at least the size of one electron. At this size, the flow of electrical current is decreased. However, most wires are significantly wider than one electron. These wires add both weight and size to a modern computer. A microprocessor in a modern computer can only be a certain size. Although this size is relatively small, it is not on a small enough scale to allow the production of extremely small computers. Likewise, the speed of a microprocessor is extremely limited. Even significant advancements in technology would not allow a microprocessor to have the computational abilities of a quantum computer.

A quantum computer offers several advantages over a microprocessor-based computer. A quantum computer is only limited in size by the size of the refrigeration product that must be used to keep a quantum computer at a constant, controlled temperature and by the size of the material that is need to isolate each individual logic gate. With our successful research into these two products, a quantum computer could be less than one fourth the size of a modern computer. A quantum computer also offers speed that cannot be surpassed by any other type of computer. Although the actual speeds may vary, a quantum computer could be capable of speeds in excess of 100 million times as fast as a microprocessor based computer.

Quantum computers face two essential problems that must be resolved in order to produce these powerful units. They must be kept at a constant, controlled temperature throughout their operation. This demands the need for a cooling system that is far superior to the cooling systems that are in use today. Not only would this system have to be extremely accurate, it would also have to be small and lightweight in order to keep the size and weight of a quantum computer to a bare minimum. We propose to research possible systems that would be able to achieve these capabilities. Our research would determine possible systems that would allow a quantum computer to work as theory states it can. A quantum computer is based on logic gates. These gates carry out the operations of the computer. In theory this works. But in practice, these gates interact with other surrounding gates as well as with the environment. We propose that a certain isolating material can be used to isolate and control these gates. If these gates are isolated, then a quantum computer will exist.

Based on these preliminary findings, we decided that further research would be necessary. We began to research quantum computers hoping to find an answer to our problems.

Research Methods

We performed the following research to determine the best methods and products for cooling and insulating a quantum computer in order to achieve an operable, real life quantum computer.

To begin our research, we all acquired an extensive background on quantum computers. We began by studying quantum physics and then studied quantum applications within computers. Much of this research was completed on the Internet web sites. We received most of our information from the Massachusetts Institute of technology web pages and from the center for Quantum Computing web sites.

After achieving an extensive background in quantum computers we began to study the specific problems that are commonly associated with quantum computers. We found most of these problems listed within reports written by physicists that are currently attempting to produce a working quantum computer. We researched many papers and report written about the problems that are often associated with quantum computer.

After discovering two distinct problems that are often associated with quantum computers, we began further research into these problems. We went to several web sites that appeared to offer products that would eliminate these two problems. However, we soon discovered that by solving one problem the other problem would no longer exist. Our research proved that by cooling a quantum computer down to a certain specified degree we would no longer need to insulate the logic gates within a quantum computer we then decided to focus only on cooling a quantum computer. Further research proved that this would eliminate completely, the need to insulate logic gates.

We analyzed the information that we achieved through our research. Then we drew conclusions based on out research. Finally we discussed our recommendations and finalized our feasibility report presented here.

The constraints for computers come from the circuits that form them. The most important component of a computer is its "brain", commonly referred to as the central processing unit. Computer chip manufacturers, such as Intel, spend billions of dollars to build plants and do research that will allow these chips to shrink in size. However, the costs of research and plants are increasing at a substantial rate. Once the components of these chips come close to the size of atoms, the costs to build plants may be in the trillions of dollars. What's worse is nothing can become smaller than an atom, so advances in computer speed will not be possible. Scientists estimate the end will come around the year 2010, and scientists are working on developing a quantum computer. A quantum computer uses subatomic particles to solve problems. According to quantum mechanics, electrons can be in many different places and many different states all at the same instance in time. The possibility that an electron can be anywhere or be in different states is supposed to make quantum computers extremely fast. This along with other laws of quantum mechanics present the most challenges for building quantum computers.

The only similarity a quantum computer should have to an ordinary computer is usefulness. A quantum computer will not be a machine in a box; instead it may look like some big magnets surrounded by other stuff. A quantum computer may differ from a modern computer in other ways also. For example, a quantum computer may not have the permanent data storage a modern computer has with a hard drive. However, a quantum computer will certainly need a device similar to a monitor in order to be of any use to an average person. The composition of a quantum computer helps give it many advantages. Scientists are trying to develop a quantum computer due to its potential. A quantum computer is supposed to be able to solve a problem all at once instead of in steps. A modern computer takes a problem and quickly solves a single step then moves on to the next one. If there are trillions of things to search through, like every word on the Internet, this can be extremely slow. However, a quantum computer would be exponentially faster than a modern computer at a similar task by searching through a million words at once. A quantum computer shows no resemblance to a modern computer Perhaps an even more useful task for the quantum computer involves factoring numbers.

Research Results

Modern computers have been used a lot for factoring large numbers. The largest number ever known to have been factorized had 129 digits, it took a network of supercomputers working in parallel eight months to find the answer! To factorize a 1,000-digit number would take our most powerful conventional supercomputers more than the estimated 100 billion years the universe has left to run. Factoring large numbers is known as cryptography. It is used to secure things over the Internet such as financial transactions and email. However, a quantum computer would break the most sophisticated code in no time flat. This basically means someone could intercept someone else's email messages. A quantum computer's potential goes beyond cryptography. A quantum computer may prove useful in the math and physics. A quantum computer would be fast enough for physicists to do computer simulations of nuclear explosions and other physical processes. A quantum computer could enable mathematicians to solve seemingly impossible problems. While these two things might not sound great for people outside the scientific community, a quantum computer will probably be more useful for things that seem impossible now. One thing that scientists have deemed possible is teleportation. However, teleportation has many problems and challenges in front of it just like the quantum computer. Because teleportation uses quantum physics, the development of the quantum computer may help scientists learn more to solve problems related to teleportation. Fortunately, researchers have made some progress developing a quantum computer. Two physicists, Neil Gershenfield and Isaac Chuang, have built a very basic quantum computer. They were able to solve two simple problems. They used liquid alanine to solve the problem one plus one. They were able to solve another problem in liquid chloroform. This problem was to select a correct telephone number given four different numbers. The physicists hope to be able to make a more complex quantum computer that is able to factor 15 into 5 and 3. While all of these tasks are simple for a modern computer, the process to solve the problem was done differently than it would have been done on a modern computer. All possible answers were checked at the same time, compared to checking each answer until the correct one was found.

In our research we found that a quantum computers requirements are quite well fulfilled in a linear Paul trap. A certain number of ions are stored in a chain configuration. These ions are the carriers of the quantum bits. These 'qbits' can be prepared from the outside world by shining laser light on them. They are strongly coupled to each other because of their common oscillatory motion in the longitudinal direction of the trap. The process of computation, which involves the individual manipulation of the qbits can be done with laser pulses. Finally, the state of the system can be read out after the computation by again using lasers and by detecting the fluorescence on sensitive cameras.

Some ions are trapped in a linear Paul trap. The geometry of this trap is such that there is one direction (the longitudinal direction) in which the trapping potential is rather weak and that in the two other directions (the transversal directions) the trapping potential is rather strong. This forces the ions to be positioned along the longitudinal direction, and they keep a certain distance from each other due to the Coulomb repulsion.

If now these ions are laser cooled it is appropriate to consider the quantum mechanical behavior of this chain of ions. A second cooling stage is necessary to cool the ions even further so that they finally occupy only the lowest state of a harmonic oscillator ladder. This is then a truly pure state and it is starting point for the quantum computation.

The actual process of quantum computation consist of a coherent evolution of the system where the internal electronic degrees of freedom of the ions are the qbits which interact with a) laserlight from outside and b) interact with each other via their common oscillatory motion. According to quantum mechanics, we thus end up with two ions of the chain whose internal degrees of freedom are correlated ('entangled'), while the oscillatory motion of the chain is left in the ground state. Together with on-resonance laser pulses on single ions these blue and red detuned pulses are all you need for implementing some quantum computational algorithm. Finally, the state of the quantum bits can be read out with the help of an additional strong transition. This is the usual way of how the state of a two level system is measured on a single trapped ion.

Conclusions and Recommendations

During our research, we discovered that a product is capable of both cooling a quantum computer and isolating the logic gates within a quantum computer. From this discovery, we conclude that a quantum computer could indeed be produced for both corporation and consumers in the near future. We believe that with further research, a quantum computer will exist in real life and not only in theory as it does now. We believe this because our research seems very promising. We realize that a quantum computer currently only exists in theory. This is due to the fact that they have yet to have been able to cool a quantum computer and isolate the logic gates within a quantum computer. Our findings prove that this is possible with further research and development.

Although this type of research is costly, the long-term benefits are nearly endless. A quantum computer will have the power to meet the needs that will be demanded of computer in the near future. A quantum computer will be able to offer the high-speed processing and exceptional reliability that semi conductor based computer attempt but fail to achieve. The money invested today in research will show results soon.

We recommend that an appropriate scientific foundation or school carries out our research to a higher level. With proper funding, and the necessary equipment, we feel that their research will be highly successful. We believe that three conditions must be met in order to produce a quantum computer. First, long research at high costs must be financed by a capable institution or corporation. Second, talented and highly skilled professional must be devoted to their work and able to carry out this research in a highly organized manner. Finally, a capable electronics company must be willing to produce this specialized product.

We feel that these three steps will lead to a future with working quantum computers. At this point quantum computers merely exist in theory, but our research and further research will provide us with a working and highly functional quantum computer.

Glossary

Logarithm: the exponent that indicates the power to which a number is raised to produce a given number <the logarithm of 100 to the base 10 is 2>.

Particle Physics: a branch of physics dealing with the constitution, properties, and interactions of elementary particles especially as revealed in experiments using particle accelerators -- called also high-energy physics.

Proton: an elementary particle that is identical with the nucleus of the hydrogen atom, that along with neutrons is a constituent of all other atomic nuclei, that carries a positive charge numerically equal to the charge of an electron, and that has a mass of 1.673×10^{-24} gram.

Quantum: any of the very small increments or parcels into which many forms of energy are subdivided.

Quantum Computer: one that computes; specifically : a programmable electronic device that can store, retrieve, and process data using any of the very small increments or parcels into which many form of energy are subdivided.

Quantum Mechanics: a theory of matter that is based on the concept of the possession of wave properties by elementary particles, that affords a mathematical interpretation of the structure and interactions of matter on the basis of these properties, and that incorporates within it quantum theory and the uncertainty principle -- called also wave mechanics.

Quantum Physics: a branch of physics dealing with any of the very small increments into which many forms of energy are subdivided.

Quantum Theory: a theory in physics based on the concept of the subdivision of radiant energy into finite quanta and applied to numerous processes involving transference or transformation of energy in an atomic or molecular scale.

REFERENCES

Barenco, A. 1996 Nov. Introductions: Quantum Computing. Center for Quantum Computing. <http://www.qubit.org/intros/comp/comp.html>. Accessed 2001 February 2.

Braunstein, Samuel L. 1995 Aug. Quantum Computing. Tutorials. <http://sees.bangor.ac.uk/~schmuel/comp/comp.html >. Accessed 2001 February 3.

Braunstein, Samuel L. 1995 Aug. Model Quantum Computer and Quantum Code. Tutorials. <http://www.sees.bangor.ac.uk/~schmuel/comp/node8.html >. Accessed 2001 February 3.

Gershenfeld, N, Chuang I. 1998 June. Quantum Computing with Molecules. Scientific American. <http://www.sciam.com/1998/0698issue/0698gershenfeld.html>. Accessed 2001 February 2.

Glover, Lov K. Quantum Computing. The Sciences. 1999 Aug pp.24-30

Platt, Charles. 1995 Mar. A Million MHz CPU. Wired Magazine <http://www.wired.com/wired/archive/3.03/limits.html>. Accessed 2001 February 2.

Chuang, Isaac L. 1995 Mar. A Simple Quantum Computer [personal notes]. ERTO Quantum Project <http://www.chuang-qcomp/qcomp.001.html> Accessed 2001 February 4.

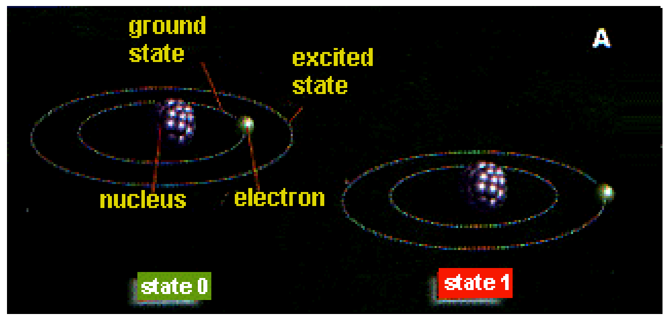
W. Heisenberg, Der Teil und das Ganze (Munich: Piper, 1969). English: Physics and Beyond: Encounters and Conversations. A.J. Pomerans, trans. (New York: Harper & Row, 1971), chapter 5.

Abraham Pais, Niels Bohr's Times: In Physics, Philosophy, and Polity (New York: Oxford Univ. Press, 1991).
John Hendry, The Creation of Quantum Mechanics and the Bohr-Pauli Dialogue (Hingham, Mass.: D. Reidel, 1984).

Max Jammer The Conceptual Development of Quantum Mechanics (New York: McGraw-Hill, 1966), chapters 4-5.
Mehra and Rechenberg, Quantum Theory, volumes 2-4

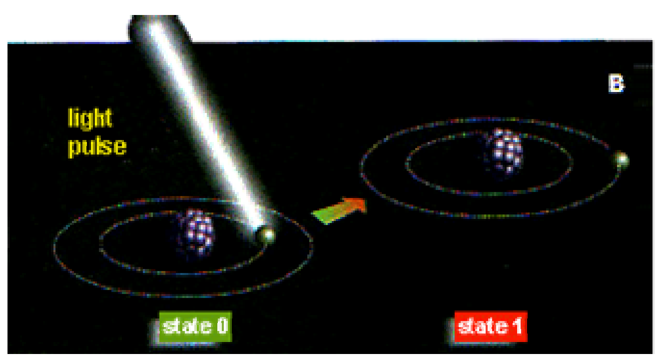
Appendix A: Simple Quantum Gates

Any quantum system with at least two discrete and sufficiently separated energy levels is an appropriate candidate for a qubit. So far the most popular qubits among the experimentalists have been atoms of rubidium or beryllium. In an atom, the energy levels of the various electrons are discrete. Two of them can be selected and labeled as logical 0 and 1. These levels correspond to specific excitation states of the electrons in the atom.
To see how it is possible to control the two logical values, let us simplify the situation and consider an idealized atom with a single electron and two energy levels, a ground state (identified with the value 0) and an excited state (value 1), (See Figure A)

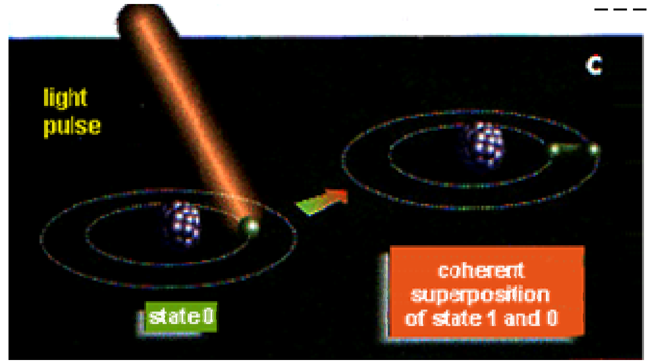


Let us imagine that the atom is initially in state 0 and that we want to effect the NOT operation. The NOT operation just negates the logical value so that 0 becomes 1 and 1 becomes 0. This is easily performed with atoms. By shining a pulse of light of appropriate intensity, duration and wavelength (the wavelength should match the energy difference between the two energy levels), it is possible to force the electron to change energy level. In our case, the electron initially in the ground state will absorb some energy from the light pulse and transfer itself to the state 1 (See Figure B) If the electron were initially in the state 1, the light pulse would cause transfer of the electron to state 0.

Logical NOT, described above, can be understood in completely classical terms; however, we can also perform purely quantum logical operations without any classical analogs. For instance, by using a light pulse of half the duration as the one needed to perform the NOT operation, we effect a half--flip between



the two logical states. What does this mean? In substance, it means that operation 0 --->1 is only half performed and that the state of the atom after the half pulse is neither 0 or 1 but a coherent quantum superposition of both states (See Figure C). Just like the photon that travels through both A and B routes, the electron of the atom ``is'' in both 0 and 1 state. Acting on an atom in that state with another half pulse of light will complete the NOT operation, and set it in the 1 state. Because operation NOT is obtained as the result of two consecutive quantum "half--flips'' this purely quantum operation is often called the square root of NOT. Using this kind of "half--pulses'', it is possible to create superpositions of states in the memory of a quantum computers (a memory would, of course, consist of many atoms), opening thus new ways to perform computations. Subsequent logical operations usually involve more complicated physical operations on more than one qubit.



Appendix B: Factoring on Quantum Computers

A naive way to factor an integer number N is based on checking the remainder of the division of N by some number p smaller than square root of N. If the remainder is 0, we conclude that p is a factor. This method is in fact very inefficient: with a computer that can test for 1010 different p's per second (this is faster than any computer ever built), the average time to find the factor of a 60-digit long number would exceed the age of the universe!

Rather than this naive division method, quantum computers rely on a slightly different technique to perform efficient factorization. Indeed it is possible to show that factoring a number can be related to the problem of evaluating the period of a function. To explain how this method works, let us take a simple example and let us imagine we want to find the prime factors of N = 15. To do so we pick a random number a smaller than N, for instance a = 7, and define a function f(x) = 7x mod 15. This function raises 7 to the power of some integer x and takes the remainder of the division by 15. For instance, if x = 3, f(x) = 13 because 73 = 343 = 15 times 22 +13. Mathematics shows that f(x) is periodic and that its period r can be related to the factors of 15. In our example, we can check easily that f(x) evaluates to 1, 7, 4, 13, 1, 7, 4... for the values of x = 0, 1, 2, 3, 4, 5, 6.... and conclude that the period is r = 4. With this information, computing the factors of N only requires to evaluate the greatest common divisor of N and ar/2 +/- 1. In our example computing the greatest common divisor of 15 and 50 =7 4/2 + 1 (or 48=7 4/2 - 1) returns indeed the values 5 (or 3), the factors of 15.

Obviously classical computers cannot make much of this new method: finding the period of f(x) requires to evaluate the function f(x) many times. In fact mathematicians tell us that the average number of evaluation required to find the period is of the same order of the number of divisions needed with the naive method we outlined first. With a quantum computer, the situation is completely different: by setting a quantum register in a superposition of states representing 0, 1, 2, 3, 4... it is possible to compute in a single go the values f(0), f(1), f(2) ... . These values are encoded in superposed states of a quantum register, retrieving the period from them requires another step (known as a quantum fourier transform), that can also be performed very efficiently on a quantum computer.

Appendix C: Laser Ion Trap

As an optical counterpart to the one-atom maser we are setting up an experiment to realize an ion trap laser using an optical high finesse resonator (see reprint section). While the one-atom maser and previous experiments in optical cavity QED employed atomic beams, the laser medium in the new experiment is a single ion in an electrodynamic trap, which interacts with the cavity field for an unlimited time. Therefore we can measure cavity-QED effects without the need to average the interaction over an atomic trajectory and without lifetime broadening. The optical field generated by the ion-trap laser has been calculated and shows a number of nonclassical properties like sub-Poissonian photon statistics, antibunching and in addition lasing without inversion.