Introduction of Quantum Computing

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Abstract— Quantum Computers are being developed with the challenge to take advantage of physics which predicts end of Moore’s law for the classical computers and quantum tunneling. In a classical computer, there are 4 billion transistors in a single chip available now a day. It is observed by Moore’s law that number of transistors doubles in every 18 months. So in nearby future, to control the flow of electron with the number of transistor in a single chip, will leads to physical limitation because of quantum physics. Thin transistors have no ability to stop electron flow rather particle wave duality of an electron gives it ability to pass through barrier wall or in other words, electrons appears at either side of a barrier wall. This property of a single electron sometimes called quantum property of the electron. A quantum computer gives exponential speed when adding one more qubit to a system. This makes quantum computers thousand times speedier than combined speed of the super computers in today’s world for the specific problems solving. However quantum computers are not an alternate to classical computers but it can be used for a specific purpose like drug discovery, security of a data or air traffic controlling.

Keywords: Quantum Computing, Qubit, Superposition, Entanglement, Spin

I. INTRODUCTION

Quantum physics is not a new branch of physics but it’s almost 100 years old, even it made confusion in a mind of an Einstein. The Einstein got confused about quantum physics which violates the rules of some classic physics. Quantum behavior of an electron violates rules of theory of relativity when it comes to entangled property of electron or photon. Entangled electrons instantly get changes at the same point of time when any entangled another one electron or photon changes even at the distance of an edge of the universe. Superposition is another one property of a quantum world of electron and photons. Duality as a particle and wave of an electron has a probability of appearing either side of a barrier wall.

Classical computer doubles its capability of processing every 18 months as described by Moore. Current classical computer has 4 billion transistors in a silicon chip with the size of a postage stamp. It means by the 2025, there will be no possibility to work on nano scale transistor due to quantum tunneling. Quantum tunneling gives ability to electron to pass through barrier wall of a transistor. Quantum tunneling is the reason that transistor may not be able to control flow of an electron. What it gives us challenge to either make a computer more powerful with the same current classical technology of computers by doing something in transistor or thinking something else, something to use quantum properties of an electron in a computer. Spin property of an electron gives superposition of an electron to be in a both state of 0 and 1 at a time until observed. Super position of an electron gives exponential power of speed when adding each new qubit to the quantum computer.

Some complex problems like optimization, machine learning, material simulation, air traffic controlling, banking data security, encryption and security can be easily solved by quantum computers. Moreover qubits cannot be copied or intercept by anyone without interfering it and when someone interferes with qubits and so it gives unbreakable security.
Quantum computers are not alternate to the classical computers because it is not used to solve general problems which are solved by classical computers. Qubits cannot be controlled using classical computer technology. A quantum property of an atom which makes possible to develop quantum computer is described as below.

II. QUANTUM PROPERTIES OF AN ELECTRON

A. Spin and Superposition

Bloch sphere representation of a qubit. [1]

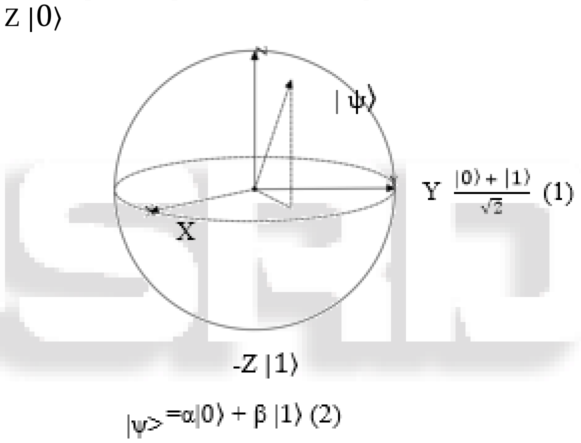


Fig. 1: Superposition of an electron in a quantum spins

Quantum computing technology is not an improvement in a classical computing technology but it is totally based on different principals. One of those principals is quantum spin of an electron; it gives superposition state to the electron until observed. Classical computer processes bit 0 or 1 state of an electron. Quantum computer uses spin of an electron which gives exponential speed to the quantum computer. Exponential speed is possible because electron in a super position remains in the state of |0⟩ and |1⟩ both the position at the same time until measured.
|↑⟩is called spin up and | ↓⟩ is called spin down. In other words 0 and 1 but, electron can remain in any state between 0 and 1. Spin up is considered as a | ↑↓⟩ and spin down is considered as a |↓↑⟩. 0 state is considered as a |10⟩ and 1 state considered as an |01⟩ however When observed an electron it has a certain probability to be in either| 0⟩state or in |1⟩ state, either in a |↑⟩ spin up state or in a | ↓⟩ spin down state. So we can consider it as a probabilistic. When we use the spin property of an electron in a computing, that bit is called qubit.

Superposition state of an electron gives exponential speed to solve some specific problems in an quantum computer, it means by adding each one qubit to the quantum computer it gives 2^n power speed to the quantum computer .when we add each one qubit , the probable states of the system increases exponential. Let us see this; If there is a one qubit, there is two possible state of a qubit $|0\rangle$ $|1\rangle$simultaneously until observed.

1) Qubit Bases States of Superposition

$$|0\rangle=\binom{1}{0} \quad (3) \quad \text{and} \quad |1\rangle=\binom{0}{1}\ .\ (4)$$

$|0\rangle$ has a two possible states $|1\rangle$ and $|0\rangle$. $|1\rangle$ qubit has also two possible states $|0\rangle$ and $|1\rangle$.here each qubit has a two possible states, when we add an extra one qubit to the system it gives 2^n power possible states. For example if we add one more qubit then possible states will be

2) Qubit Bases States of Superposition

$$|00\rangle=|0\rangle\otimes|0\rangle=\binom{1}{0}\binom{1}{0}=\begin{pmatrix}1\\0\\0\\0\end{pmatrix} \quad (5)$$

$$|01\rangle=|0\rangle\otimes|1>=\binom{1}{0}\binom{0}{1}=\begin{pmatrix}0\\1\\0\\0\end{pmatrix} \quad (6)$$

$$|10\rangle=|1\rangle\otimes|0\rangle=\binom{0}{1}\binom{1}{0}=\begin{pmatrix}0\\0\\1\\0\end{pmatrix} \quad (7)$$

$$|11\rangle=|1\rangle\otimes|1\rangle=\binom{0}{1}\binom{0}{1}=\begin{pmatrix}0\\0\\0\\1\end{pmatrix} \quad (8)$$

The vectors are respectively shorten in $|00\rangle$ $|01\rangle$ $|10\rangle|11\rangle$

So for the n qubit state, $|\alpha_0, \alpha_1, \ldots\ldots\ldots\ \alpha_n|=|\ \alpha_0>\otimes|\ \alpha_1>\otimes |\alpha_2>\ldots\ldots|\ \alpha_3>$ are the possible states.

B. Entanglement

This feature implies the existence of global states of composite system which cannot be written as a product of the states of individual subsystems.[2] This phenomenon, known as - "entanglement". There are some different methods of creating entangled form of electron or photon pairs, but the well-known method is to create two electron or photon at the same instance of a time with the same source.

Entangled electrons cannot be viewed as single individual electrons, but a pair of electron. if one electron gets some change at the same point of time another one gets its effect. This is also called spooky action at a distance. Einstein didn't believe this type of behavior of entangled electrons and said that god does not play dice with the real world, but David Feynman thought to calculate it and then believe it. Later on entanglement proved to be true in quantum theory.

Measurement of the entangled electrons is correlated. For example, measuring the first qubit in the state $\frac{1}{\sqrt{2}}(|00\rangle+|11\rangle)$ (9) with respect to the standard basis yields 0 with probability $\frac{1}{2}$ and 1 with probability $\frac{1}{2}$. In the former case, the state of the 2-qubit system is $|00\rangle$, thus measuring the second qubit yields 0 with probability 1. In the latter, the state of the system is$|11\rangle$, and measuring the second quantum bit yields 1 with probability 1.[3] The exploitation of a number of entangled qubits can lead to a considerable computational speed-up in a quantum computer over its classical counterpart.[4]

Secure communication by quantum entangled electrons or photons is now a days in experimental phase in different countries. If it becomes successful then it will be a great milestone in this field of quantum physics and quantum computing.

III. Basic Quantum Gates

A quantum circuit (also called quantum network or quantum gate array) generalizes the idea of classical circuit families, replacing the AND, OR, and NOT gates by elementary quantum gates.[5] Some of gates are explained below

A. Hadamard gate for Single Qubit – H Gate

Hadamard gate is a single qubit gate H which performs the unitary operation known as the Hadamard transform whose action is the following:

1) Matrix representation of the Hadamard Gate

$$H=\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix} \quad (10)$$

2) Operation by Hadamard Gate

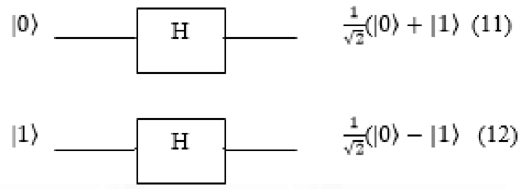


Fig. 2: Hadamard Gate Operation which makes qubit in a super position

3) Work of Hadamard Gate

While applying operation on qubit through Hadamard Gate we get equal probability to get 0 and 1 but this Gate rotates qubit from x to z axis means rotation around x+z axis.

Hadamard gate places qubit in a super position because until measuring the qubit, this qubit remains neither in 0 states nor in 1 state but in a super position

B. PAULI – X Gate – NOT Gate

It is a single Qubit Gate and performs unary operation of inverting state of qubit.

1) Matrix representation of a PAULI –X GATE

$$H=\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix} \quad (13)$$

2) Operations by PAULI –X Gate

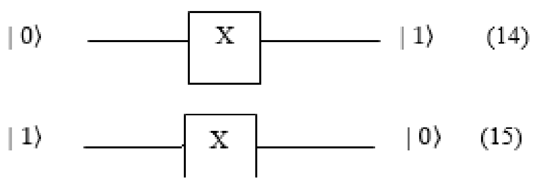


Fig. 3: PAULI – X Gate

3) Work of PAULI-X Gate

PAULI – X Gate is viewed as similar gate like classical not Gate. It changes qubit state from qubit state 0 to qubit state 1 and qubit state 1 to qubit state 0.

C. CNOT Gate

Controlled NOT gate (CNOT, for short) is a two qubit gate, where the value of the first qubit (called control) determines what will happen to the second qubit (called target) qubit.[6]

1) Matrix representation of a CNOT Gate

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (16)$$

2) Operations by CNOT Gate

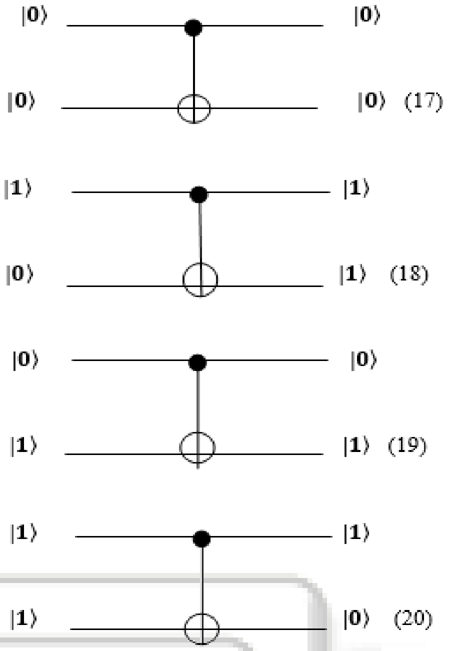


Fig. 4: CNOT Gate

3) Work of CNOT Gate

D. Swap Gate

This gate is two-qubit operation. the SWAP gate swaps the state of the two qubits.

1) Matrix representation of a swap gate

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (21)$$

2) Operations of SWAP Gate

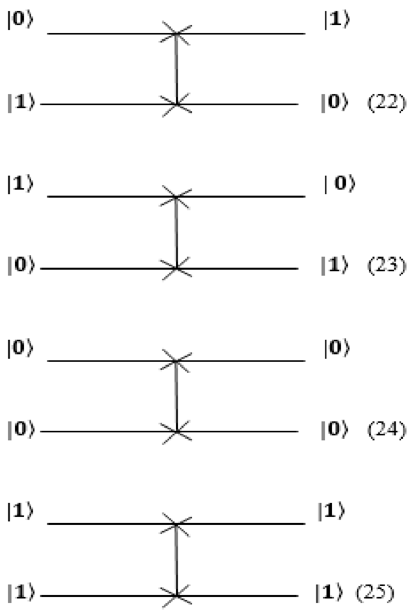
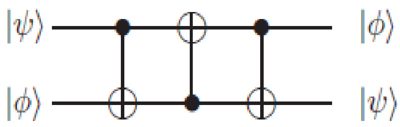


Fig. 5: Qubit Swap Opertion Using Swap Gate

3) Work of Swap Gate

Swap Gate is a two qubit Gate which swaps two qubits. the sequence of the three CNOT gate can implement the swap Gate

Below figure shows implementation of the swap gate implementing CNOT Gate Three Times.



(26)

Fig. 6: Swap Gate Using Three CNOT Gate

IV. Conclusion

Quantum Computers are being developed based on quantum physics of electrons and photons. Quantum computers are useful to solve specific problems only and not for all problems which classical computer does solve. Quantum computing has raised hope in so many fields like Banking, Air trafficking , optimization problem solution, Secure Communication, new Medicine discovery, simulation of a nature and Machine Learning.

References

[1] Sebastiano, Fabio, et al. "Cryo-CMOS electronic control for scalable quantum computing." Proceedings of the 54th Annual Design Automation Conference 2017. ACM, 2017.
[2] Li, Ming, Shao-Ming Fei, and Xianqing Li-Jost. "Quantum entanglement: separability, measure, fidelity of teleportation, and distillation." Advances in Mathematical Physics 2010 (2010).
[3] Valiron, Benoît. "Quantum computation: a tutorial." New Generation Computing 30.4 (2012): 271-296.
[4] De Wolf, Ronald. "Quantum computing: Lecture notes." (2013).
[5] Horodecki, Ryszard, et al. "Quantum entanglement." Reviews of modern physics 81.2 (2009): 865.
[6] Vedral, Vlatko, and Martin B. Plenio. "Basics of quantum computation." Progress in Quantum Electronics 22.1 (1998): 1-39.