Introduction to Quantum Computing

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Introduction to Quantum Computing

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- **What is Quantum Computing ?**
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Introduction to Quantum Computing

- **Prerequisites of Quantum Computing.**

1. Knowledge of Complex Number.
2. Basics of Linear Algebra
3. Probability Theory
4. Some Knowledge of Modern Physics
5. Basics of Quantum Mechanics.

Need of Quantum Computing

What is Quantum Computing?

- Quantum computing is an interdisciplinary domain that integrates elements from computer science, physics, and mathematics.
- It leverages the principles of quantum mechanics to address intricate problems more efficiently than classical computers.
- This expansive field encompasses both hardware exploration and the development of practical applications..

What is the advantage of Quantum Computing ?

- Currently, no quantum computer can perform a useful task faster, cheaper, or more efficiently than a classical computer but Q.C Theories suggest when it is available it can solve complex problems, Massive data processing and simulate the nature/ Advanced AI.
- Quantum advantage is the threshold where we have built a quantum system that can perform operations that the best possible classical computer cannot simulate in any kind of reasonable time.(Based on Best possible theoretical/Mathematical Justification)

Quantum Supremacy Claims by Scientists:

Supremacy Defines as

Quantum Computer. time <<<… Classical Computing. time

- 2019 article google claims this for a complex problem

google Q.C cikamo model (Approximately 200 sec) <<<<.. IBM Super Computer summit (Approximately10,000 days)

Later on IBM says its not 10000 days it is just 2.5 day.

- In 2020 China claims they made a Q.C modal which can solve the problem which super computer can be solved in 6 millions of years.
- Quantum Supremacy: How the Quantum Computer Revolution Will Change Everything Hardcover – May 2, 2023 by Michio Kaku (Author) :This Books reveals how quantum Computing may supercharge artificial intelligence, solve some of humanity's biggest problems, like global warming, world hunger, and incurable disease, and eventually illuminate the deepest mysteries of science

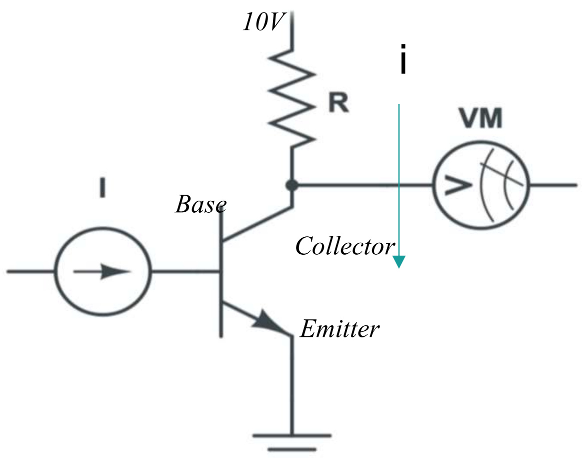
Classical Computing vs Quantum Computing

Fundamental Difference on the basis of their computational Unit: Classical bit Vs Qubit

Classical Bit:

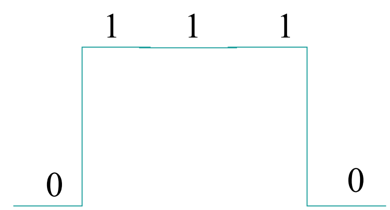
- A classical binary bit is always in one of two states — 0 or 1.
- Binary Number Systems: 001011001100.....
  - This stream of 0s and 1s is translated into some physical property of the device.

transistor



ON/OFF
switch

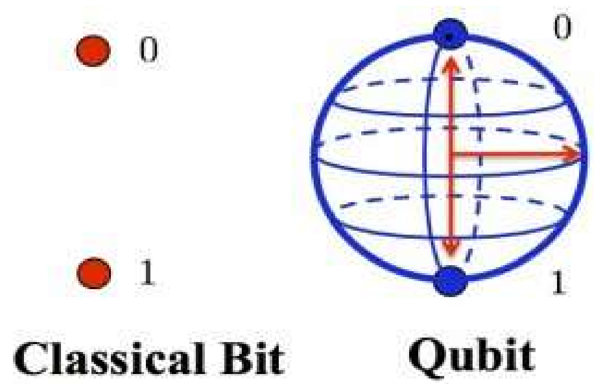
0V, 10V, 10V, 10V, 0V....



Classical Computing vs Quantum Computing

Quantum Bit or Qubit:

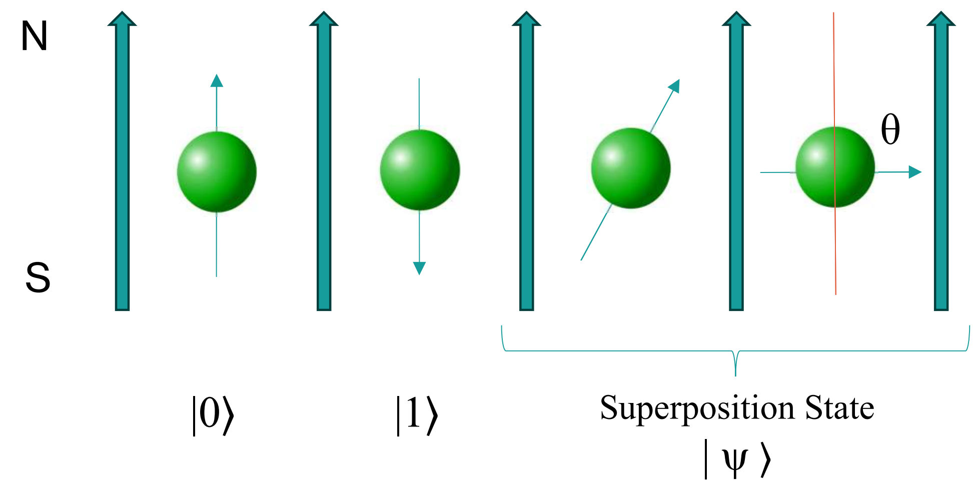
- A classical binary bit is always in one of two states — 0 or 1 — while a quantum bit or qubit exists in both of its possible states at once, a condition known as a superposition.
- An operation on a qubit thus exploits its quantum weirdness by allowing many computations to be performed in parallel.
- A two-qubit system would perform the operation on 4 values, a three-qubit system on 8 and so forth.



Superposition (0 and 1 both at the same time

Realization of Quantum bit States through Quantum Particles

Protons:



$\boxed{|\psi\rangle = C1\,|0\rangle + C2|1\rangle}$ based on z-basis

(Linear Combination)

C1,C2 – Complex Number

$|\psi\rangle = C1|0\rangle + C2|1\rangle$

$|\psi\rangle = \cos(\theta/2)\,|0\rangle + \sin(\theta/2)\;e^{-i\Phi}|1\rangle$

when $\theta = 90°$, $\boldsymbol{\phi=0}$

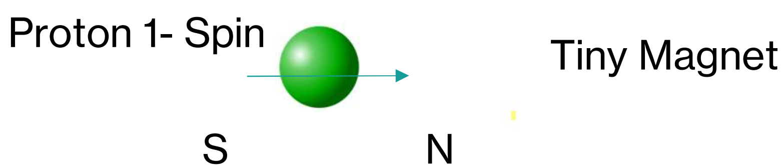
$|\psi\rangle = (1/\sqrt{2})\,|0\rangle + (1/\sqrt{2})|1\rangle$

when $\theta = 0°$, $\boldsymbol{\phi=0}$

$|\psi\rangle = |0\rangle$

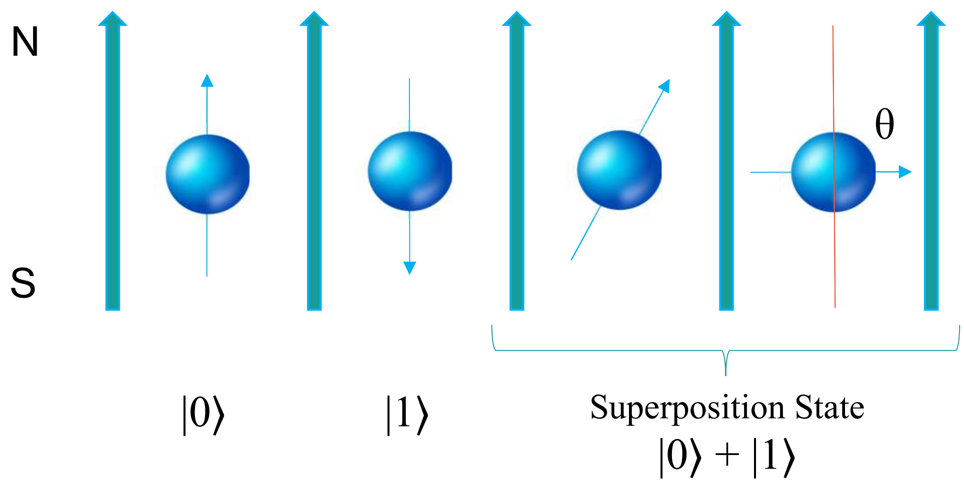
when $\theta = 180°$, $\boldsymbol{\phi=0}$

$|\psi\rangle = |1\rangle$

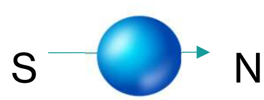


Realization of Quantum bit States through Quantum Particles

Electrons:



Electron 1/2- Spin



Tiny Magnet

$|\psi\rangle = C1\ |0\rangle + C2|1\rangle$(Linear Combination)

C1,C2 – Complex Number

$|\psi\rangle = C1|0\rangle + C2|1\rangle$

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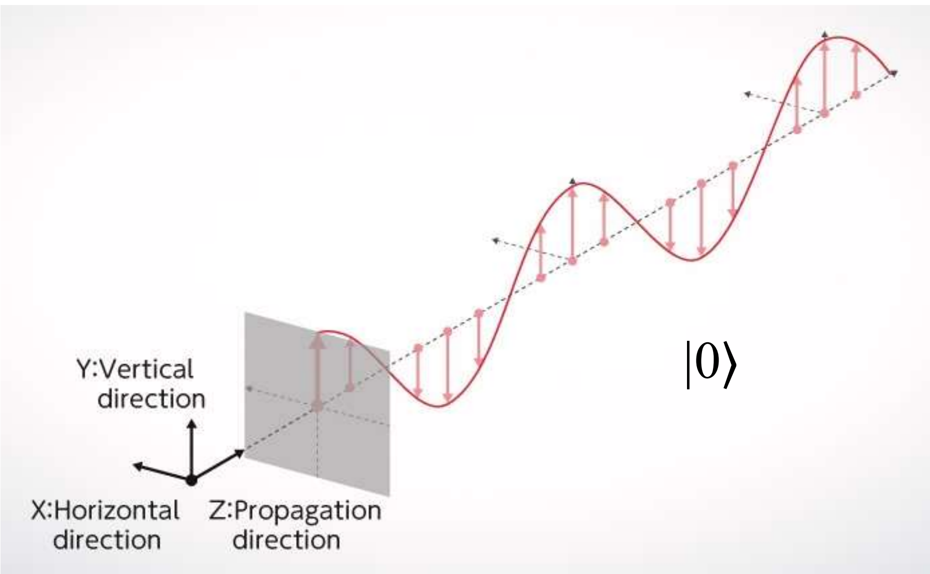
when $\theta = 180°$, $\boldsymbol{\phi = 0}$

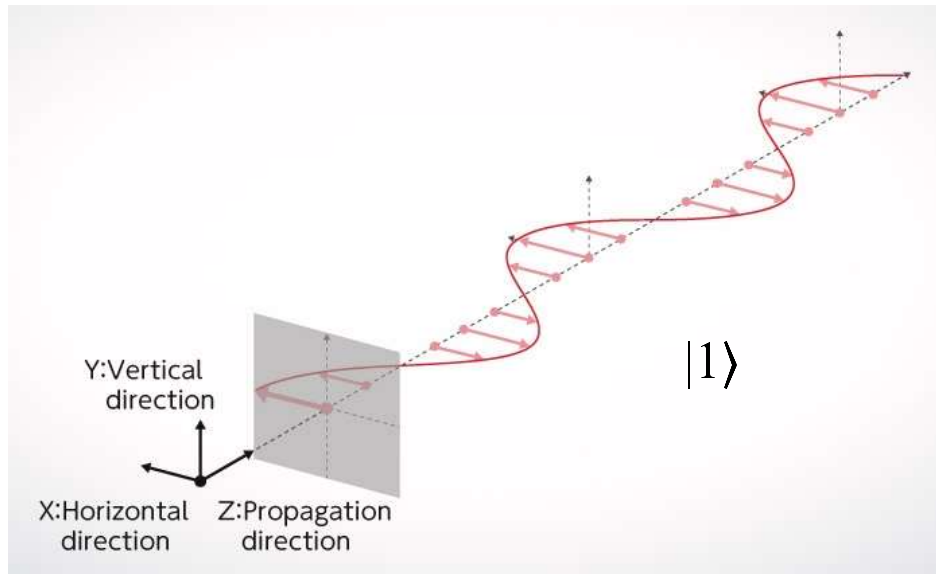
$|\psi\rangle = |1\rangle$

Realization of Quantum bit States through Quantum Particles

***Photons**: Polarization of light*

$$\boxed{|\psi\rangle = C_1\,|0\rangle + C_2\,|1\rangle}$$

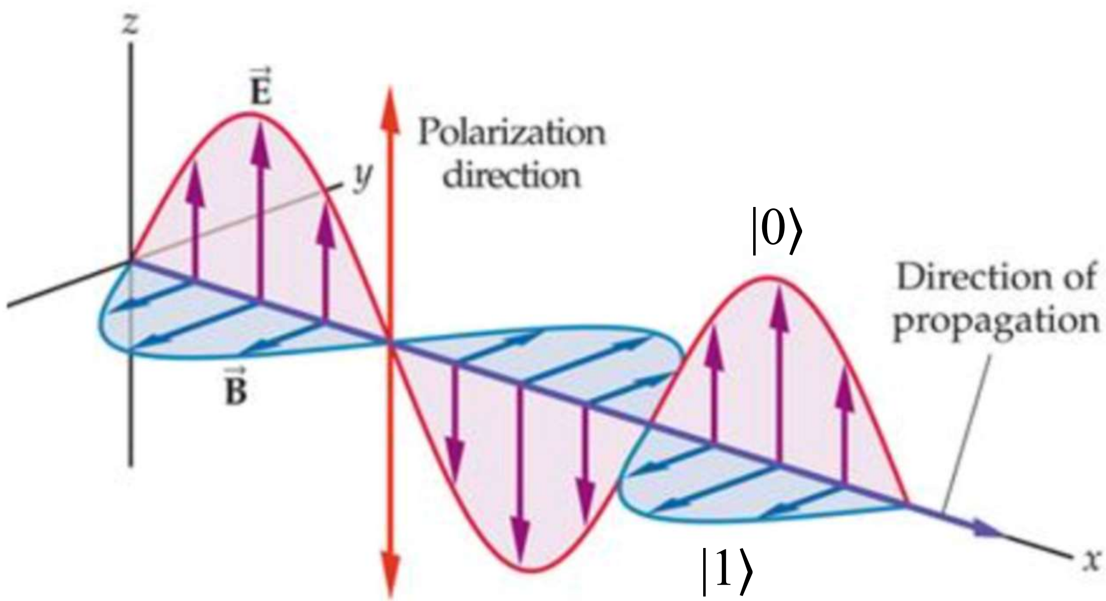




Realization of Quantum States through Quantum Particles

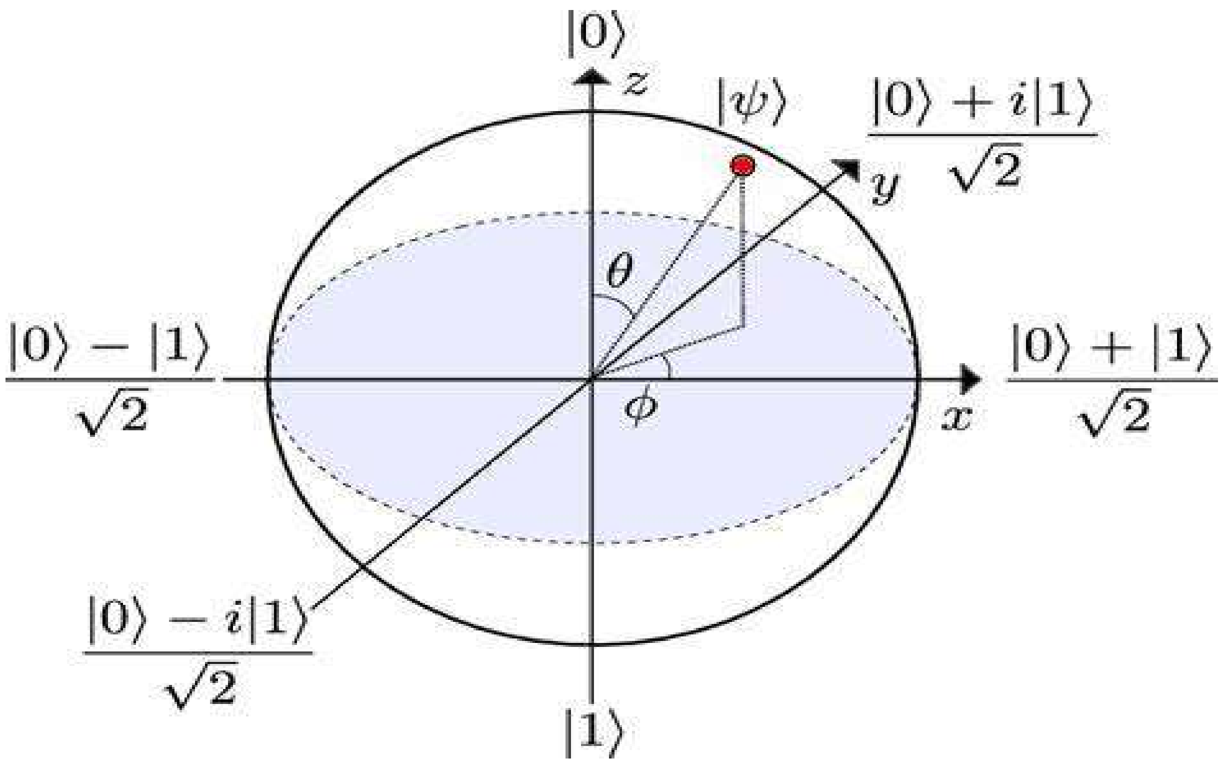
Photons:

$$\boxed{|\psi\rangle = C1\,|0\rangle + C2\,|1\rangle}$$



Bloch Sphere Representation of Qubit

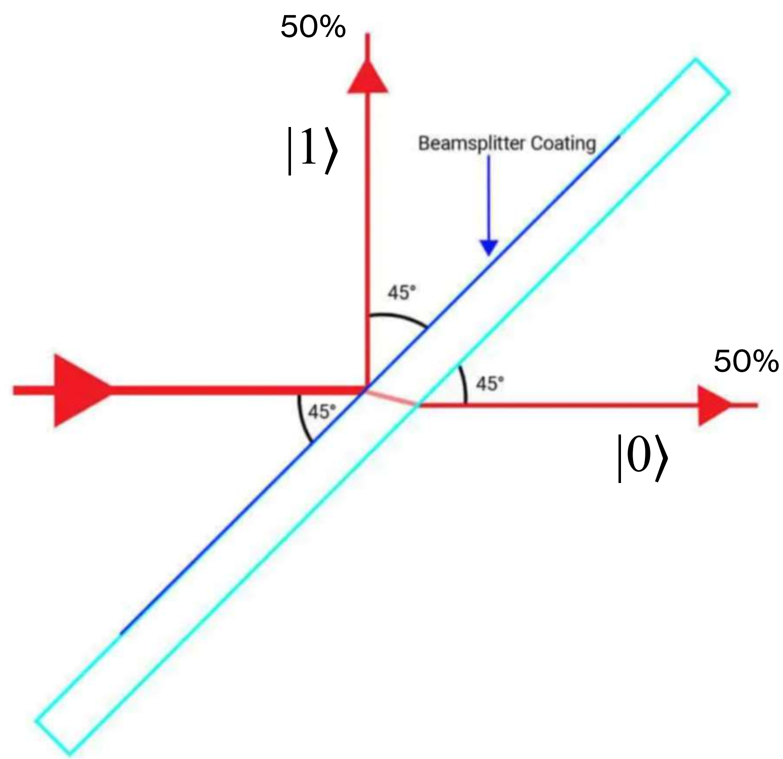
$|\psi\rangle = \cos(\theta/2)\,|0\rangle + \sin(\theta/2)\; e^{-i\Phi}|1\rangle$ (Measuring Spin of Electron in Arbitrary Direction)



Physical Manifestation of Qubits

1. **Beam Splitter (50-50):**

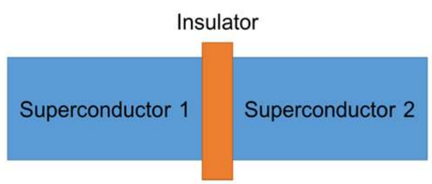
- A beam splitter is a device that splits a beam of light into two different beams.
- The incident light usually hits the beam splitter at some angle.
- If the beam splitter is designed to split the beam in a 50/50 ratio, then half of the beam will be transmitted through the beam splitter and half of the beam will be reflected off its surface and travel perpendicular to its original direction.

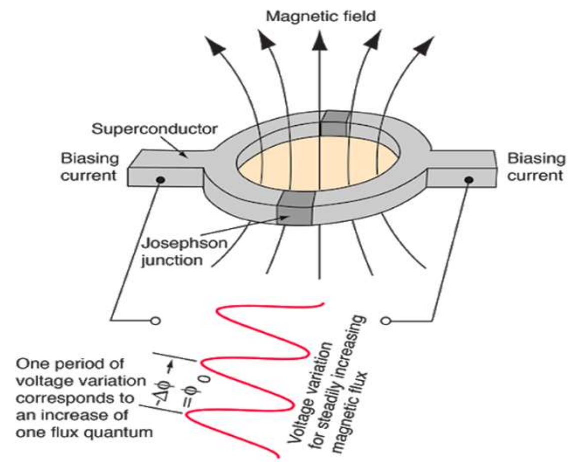


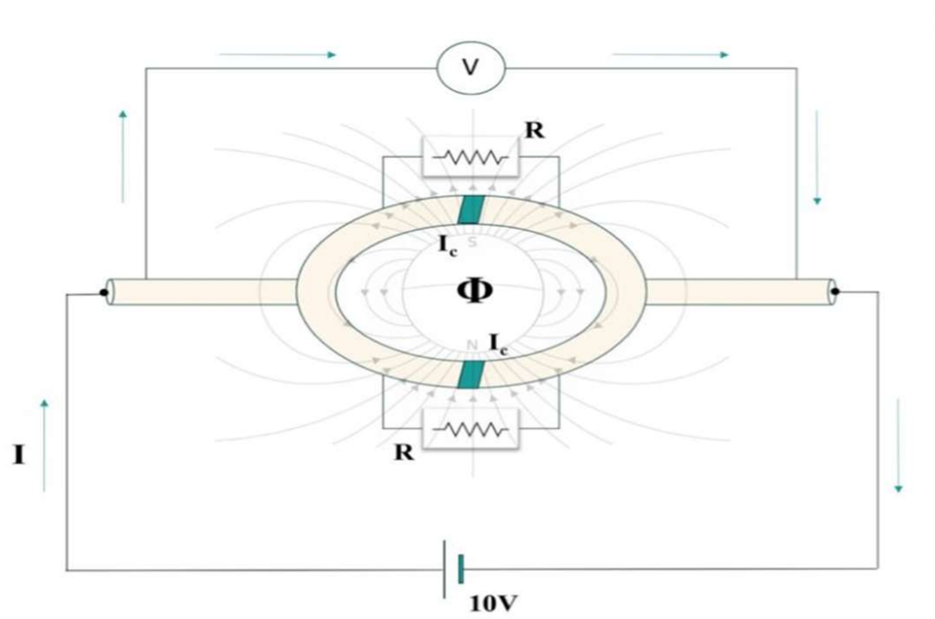
2. Superconducting Quantum Interference Device (SQUID):

- A **SQUID** (**superconducting quantum interference device**) is a very sensitive magnetometer used to measure extremely weak magnetic fields, based on superconducting loops containing Josephson Junctions.

- A Josephson junction consists of two superconductors separated by an insulating material.

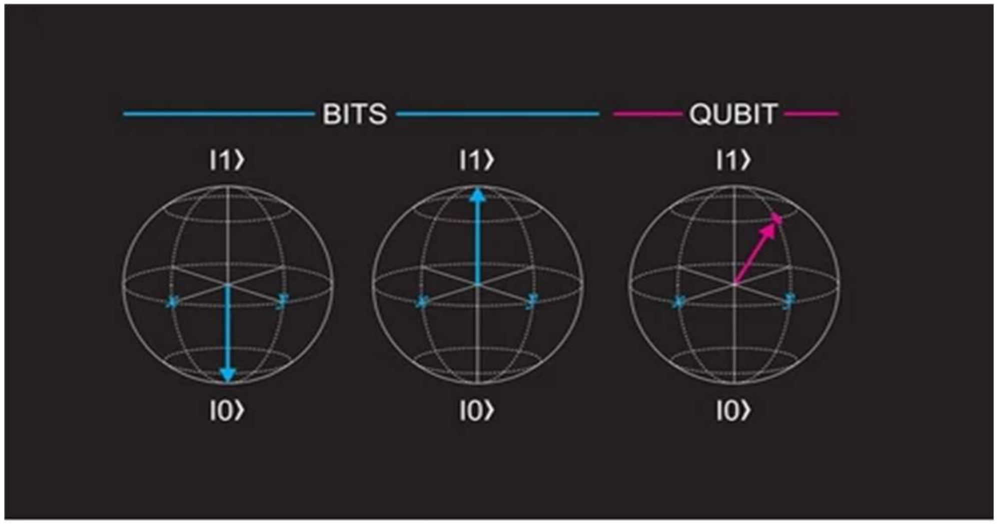






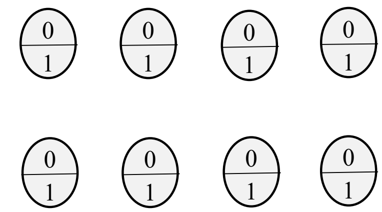
Information carrying capacity comparison

- K – Classical bit at a time represent K bit information.
- K- qubit at time can represents 2 pow K bit information but can be measured as K bits.
- Example: 3 classical bit can represent one of these number at a time: 000, 001, 010, 011, 100, 101, 110, 111. But 3 Qubit represent all eight combination simultaneously when these are in superposition and entanglement.

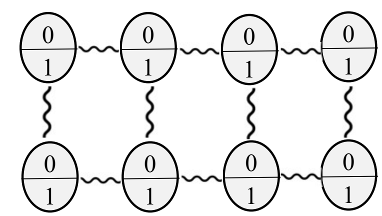


How does Quantum Computer work?

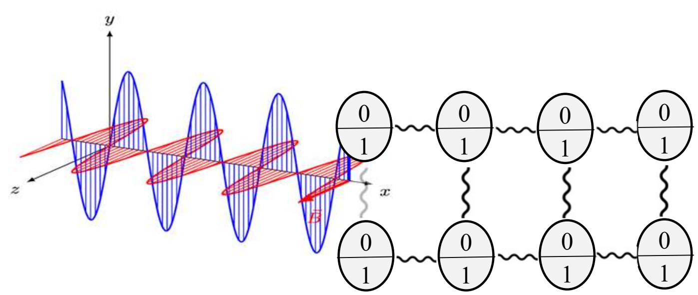
Quantum Computing mainly works on 3 principles i.e.,



- **Superposition:** Superposition states that, much like waves in classical physics, you can add two or more quantum states and the result will be another valid quantum state. Conversely, you can also represent every quantum state as a sum of two or more other distinct states. This superposition of qubits gives quantum computers their inherent parallelism, allowing them to process millions of operations simultaneously.



- **Entanglement:** Entanglement is physical phenomena observed in quantum world when pair or group of particles interact in such a way that their individual quantum states cannot be described independently and only a quantum state can be given to the system as a whole. The interesting fact is that once entangled, the particles preserves the quantum states even when they are separated wide apart.



- **Interference:** In a quantum system, the particles exist as a probability wave of possible positions. These probability waves can interact so that, when the system is measured, some outcomes are more likely and other outcomes are less likely. This is known as an interference pattern. There are 3 types of interference:
  1. Constructive Interference
  2. Destructive Interference
  3. Combined Interference

References

1. Michael A. Nielsen and Isaac L. Chuang. Quantum Computation and Quantum Information, 10th Anniversary Edition – 2010, Cambridge University Press.
2. David McMahon. Quantum Computing Explained, Ist Edition – 2008, John Wiley and Sons Inc.

Thanks