Workshop Presentation

Exploring Quantum Physics and Quantum Computing

Global Quantum Project

Womanium 2023

Modern College of Professional Studies

Chaudhary Charan Singh University

History

At the end of 19^{th} century, physics consisted essentially of Newton's Classical Mechanics and Maxwell's theory of electromagnetism.

https://en.wikipedia.org/wiki/Isaac_Newton

Sir Isaac Newton

https://en.wikipedia.org/wiki/James_Clerk_Maxwell

James Clark Maxwell

The overwhelming success of classical physics and classical electromagnetic phenomenon made us believe that the ultimate description of nature has been achieved and every physical phenomenon can be explained in the general framework of radiation and matter.

In the 20th century, classical physics has been challenged by two major fonts:

1. Relativistic domain(speed is greater than or equal to the speed of light)
2. Microscopic domain(10^{-6} range)

1900

- Max Planck introduced the concept of quantization of energy to explain the phenomenon of Black body radiation.
- E = hϑ

1905

- Einstein postulated that light is made up of discrete bits of energy called photons or quanta of energy.

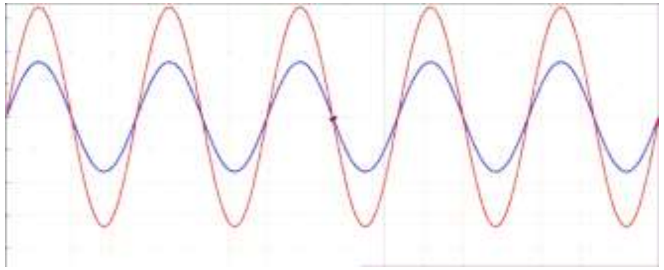
1923

- De-Broglie postulated that radiation exhibits both wave like and particle like properties.
- Proven by Davisson and Germer experimentally in 1927.

All these progressions led the foundation of Quantum Mechanics.

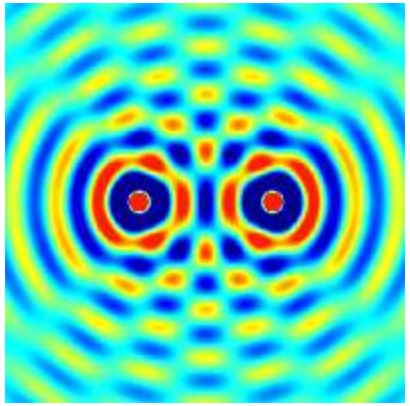
Interference

Interference is the phenomenon based on the superposition of two or more propagating coherent waves.



https://en.wikipedia.org/wiki/Wave_interference

Examples:

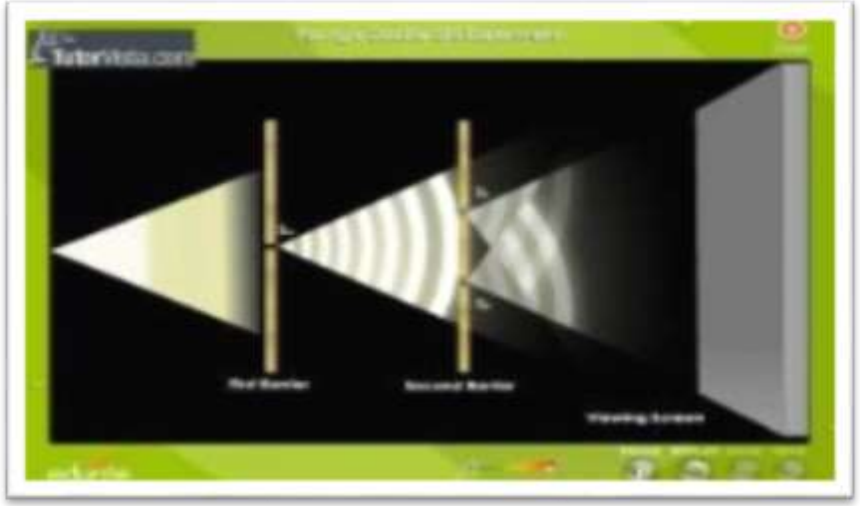


https://en.wikipedia.org/wiki/Wave_interference

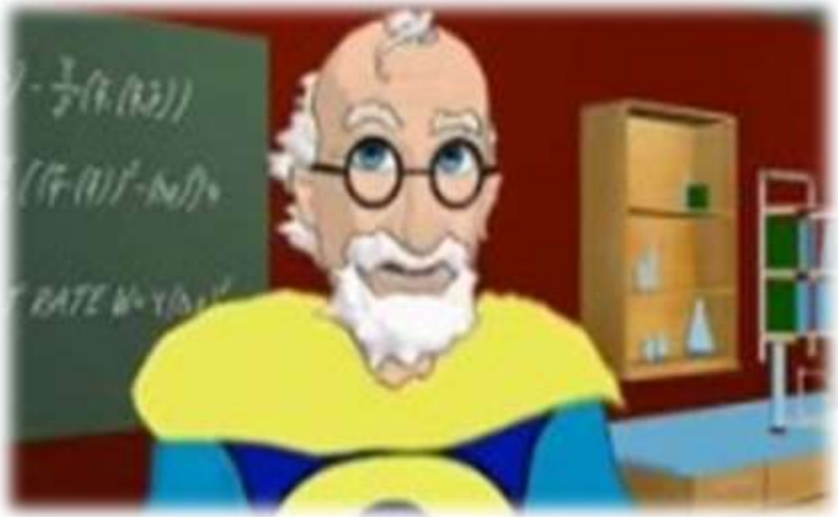
Interference of two point sources

Interference in water

[Double Slit interference with waves]



[What do you expect with particles?]



Introduction to Quantum Physics

Quantum Mechanics: Real Black Magic Calculus
-Albert Einstein

“If you are not confused by quantum physics then you haven’t really understood it” –Neils Bohr

And Richard Feynman also remarked, “I can safely say that nobody understands quantum mechanics”

Conclusion

- All the particles with mass show wave like properties.
- All the information regarding their position and momentum is stored in the wave function.
- The exact position of the particle cannot be predicted we can only talk in terms of probability.
- State of the system is the superposition of all the possible state each with having a certain probability of occurrence.

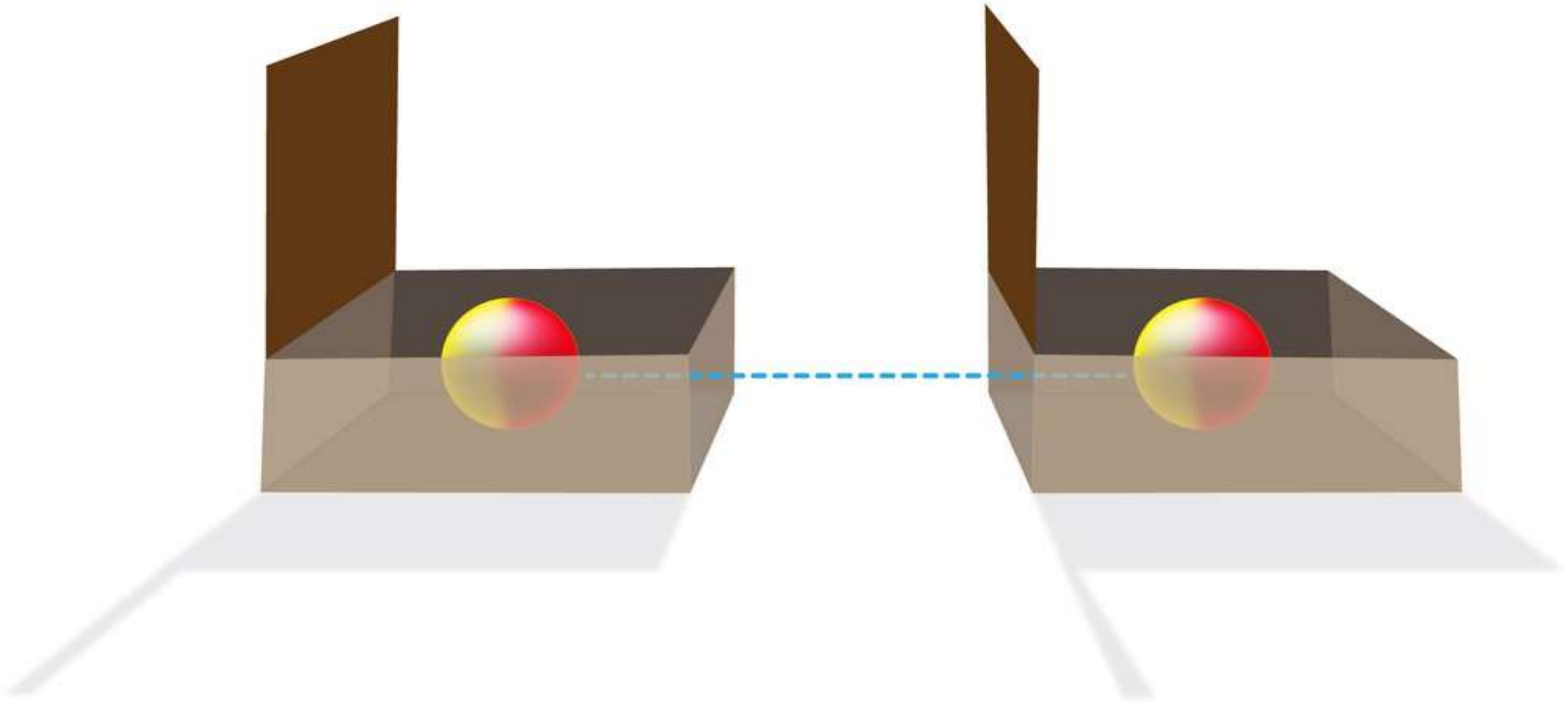
Superposition

Superposition means linear combination of all possible states.

Entanglement

- It is defined as “spooky action at a distance”.
- Entangled bodies posses the property of unbreakable correlation between them.
- The beauty of entanglement is that knowing the state of one particle automatically tells you something about its companion, even when they are far apart.

Let's say you have two entangled balls, each in its own box. In this metaphor, the balls can be either yellow or red once observed. For now, they are in a state of superposition, or both yellow and red at the same time . . .



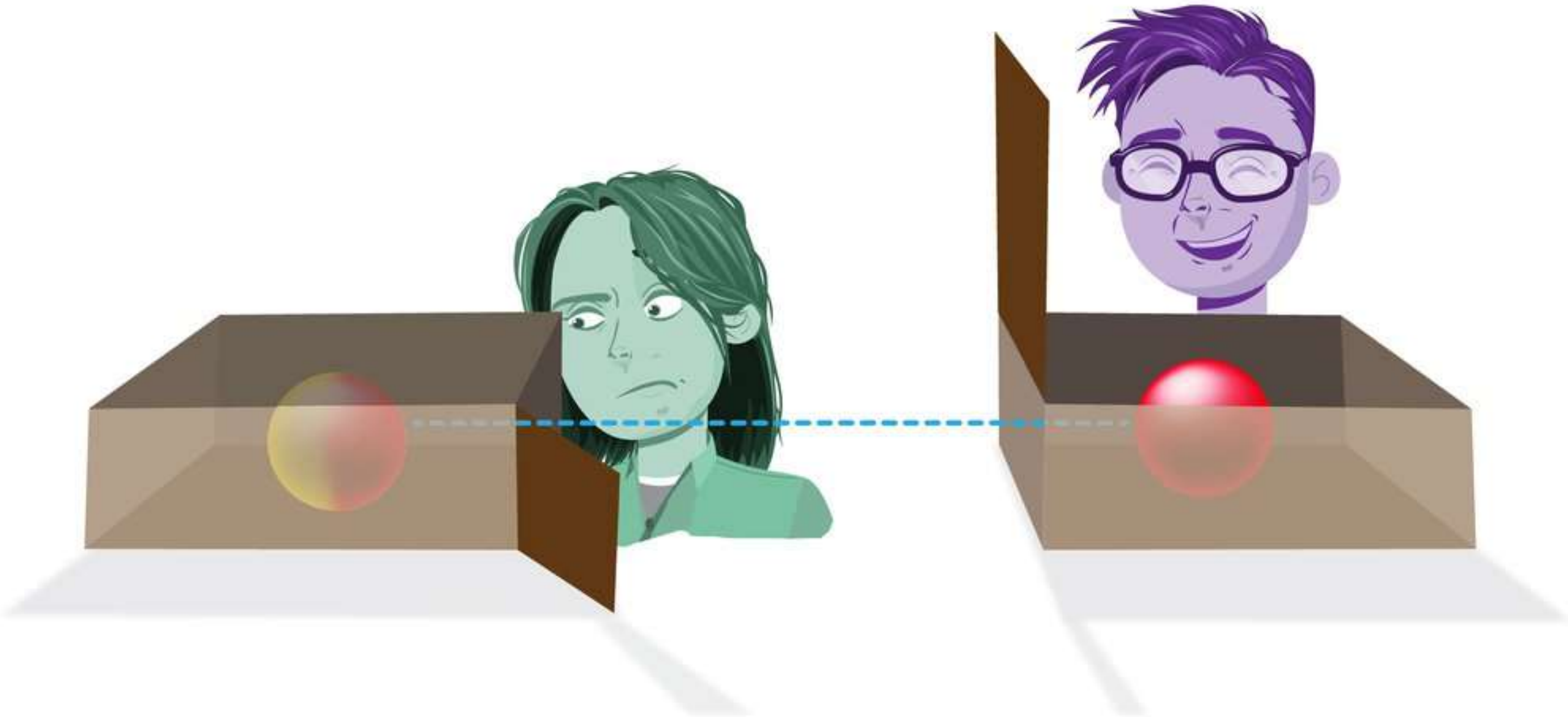
https://scienceexchange.caltech.edu/topics/quantum-science-explained/entanglement

...until you observe the balls.

The objects remain connected even over vast distances. Scientists think of entangled objects as really being a single object.

https://scienceexchange.caltech.edu/topics/quantum-science-explained/entanglement

But what if one observer decides to look at their ball from a different angle or side of the box? The balls would revert back to a state of superposition and have a 50 percent chance of being yellow and 50 percent chance of being red.

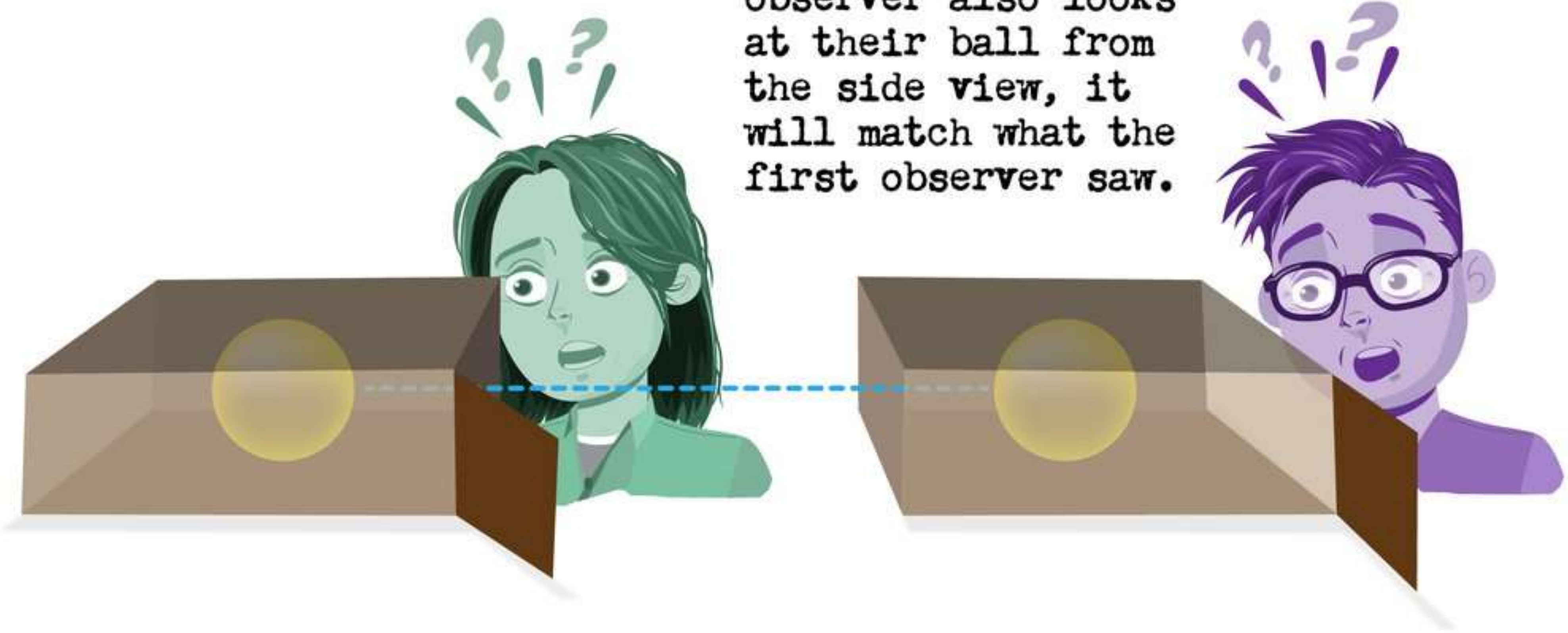


https://scienceexchange.caltech.edu/topics/quantum-science-explained/entanglement

The viewer might find a yellow ball now, even though the pair of balls had previously both been red!

https://scienceexchange.caltech.edu/topics/quantum-science-explained/entanglement

Now, if the second observer also looks at their ball from the side view, it will match what the first observer saw.



The balls are still entangled, but what the viewer sees depends on how they look at the ball. This is because the entangled information about color does not lie within any one ball but exists in the connection between the balls.

https://scienceexchange.caltech.edu/topics/quantum-science-explained/entanglement

Quantum Computing and it’s power is in talk everywhere…..

News > India News > India Approves National Quantum Mission. It Will Cost ₹ 6,000 Crore

India Approves National Quantum Mission. It Will Cost ₹ 6,000 Crore

National Quantum Mission was approved at a meeting of the Union Cabinet chaired by PM Modi. India will be the sixth country to have a dedicated quantum mission after the US, Austria, Finland, France and China.

Asur-2 last episode

From Heart of Stone movie 2023

Note: The concepts shown in the movies have nothing to do with real quantum concepts and they are just fictitious

Introduction to Quantum Computing

- Quantum Computing completely relies on the phenomenon of **interference** and **entanglement** between quantum bodies.
- A promising field that aims to go beyond scale of transistors to achieve more computational power and achieve better time complexity.
- Solve problems which are harder for todays computers at your home and even large supercomputers like travelling salesman problem.
- It has applications in various fields like medicine, machine learning and making research even for faster.

Dirac Notation

Bra-Ket notation is Dirac's Notation

|A> (Ket Vector)

<B| (Bra Vector)

|0> and |1> state in matrix notation:

$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ $|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

A quantum state is linear combination or superposition of |0> and |1> and is written as:

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Where α and β represents the probability of occurrence of |0> and |1>

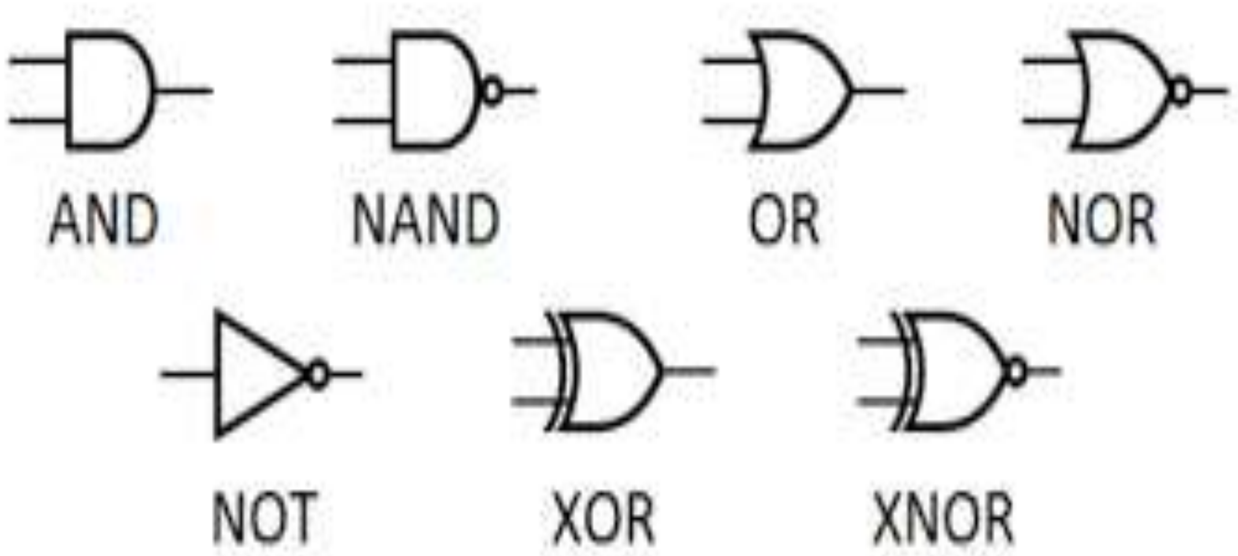
Qubit

- Quantum Bit i.e. basic building block of quantum computers as bit is of classical computer
- It can be both |0> and |1> at the same time as exits in superposition.
- Qubits are made from physical systems like superconductors, Si based qubits, neural atom, photons, ion-traps and many others.
- Superconducting qubit are the celebrities of today as they are most talked about.

Measurement

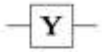
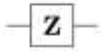
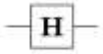
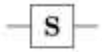
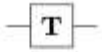
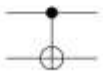
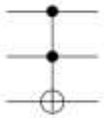
- Measurement destroys the state of the qubit and results in |0> and |1> with definite probabilities.
- Measurement destroys the original state of the quantum system.

Classical Gates



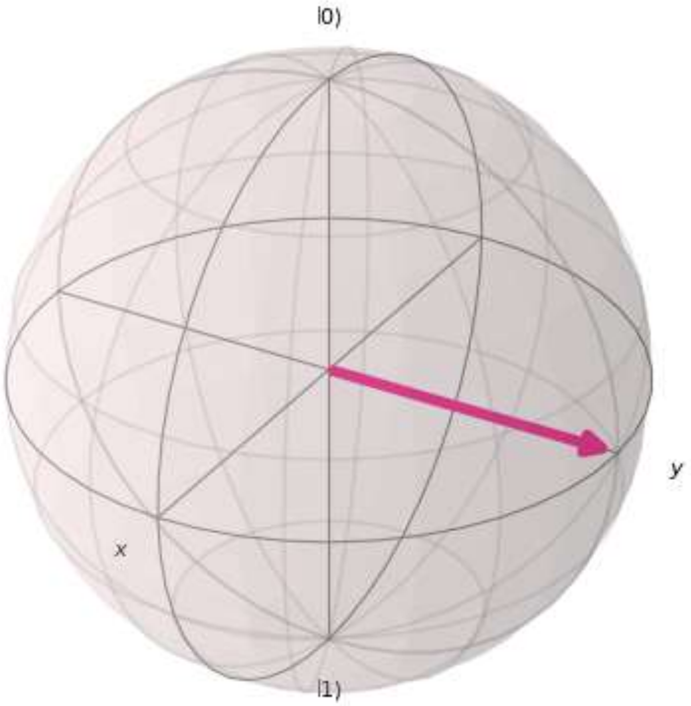
https://www.google.com/search?sca_esv=559664296&rlz=1C1GCEA_enIN933IN933&sxsrf=AB5stBjTmjZOJrU4kdaRl7N81XYhhe65fA:1692866181126&q=classical+gate+computer%0Aclassical+gate+computer&tbm=isch&source=lnms&sa=X&ved=2ahUKEwjI_IL78fSAAxXh-jgGHcK5AIwQ0pQJegQIDhAB&biw=1536&bih=715&dpr=1.25#imgrc=1Z2SuRzNC-ZRDM

Quantum Gates

Operator	Gate(s)	Matrix
Pauli-X (X)		$\begin{bmatrix}0 & 1\\1 & 0\end{bmatrix}$
Pauli-Y (Y)		$\begin{bmatrix}0 & -i\\i & 0\end{bmatrix}$
Pauli-Z (Z)		$\begin{bmatrix}1 & 0\\0 & -1\end{bmatrix}$
Hadamard (H)		$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
Phase (S, P)		$\begin{bmatrix}1 & 0\\0 & i\end{bmatrix}$
$\pi/8$ (T)		$\begin{bmatrix}1 & 0\\0 & e^{i\pi/4}\end{bmatrix}$
Controlled Not (CNOT, CX)		$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{bmatrix}$
Controlled Z (CZ)		$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&-1\end{bmatrix}$
SWAP		$\begin{bmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&1\end{bmatrix}$
Toffoli (CCNOT, CCX, TOFF)		$\begin{bmatrix}1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&0&0&0&0&0&1\\0&0&0&0&0&0&1&0\end{bmatrix}$

For solving:

Bloch Sphere

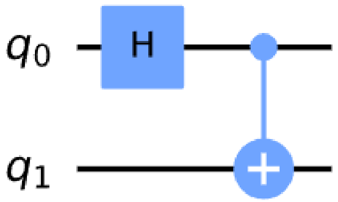


State of a qubit is represented on a bloch sphere

https://qiskit.org/documentation/stubs/qiskit.visualization.plot_bloch_vector.html

Quantum Circuits

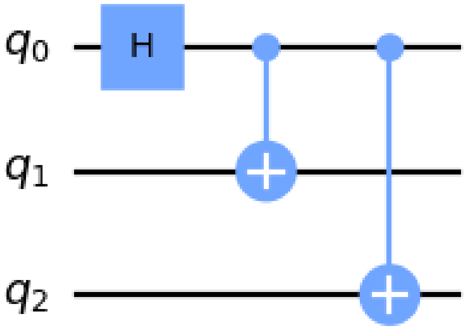
- Quantum Circuits are the collection of quantum gates connected with wire.
- The actual structure of a quantum circuit, the number and types of gates, as well as interconnection scheme are dictated by unitary transformation, U, carried out tby the circuit.



Bell State

$|\Psi\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$

https://learn.qiskit.org/course/ch-gates/multiple-qubits-and-entangled-states



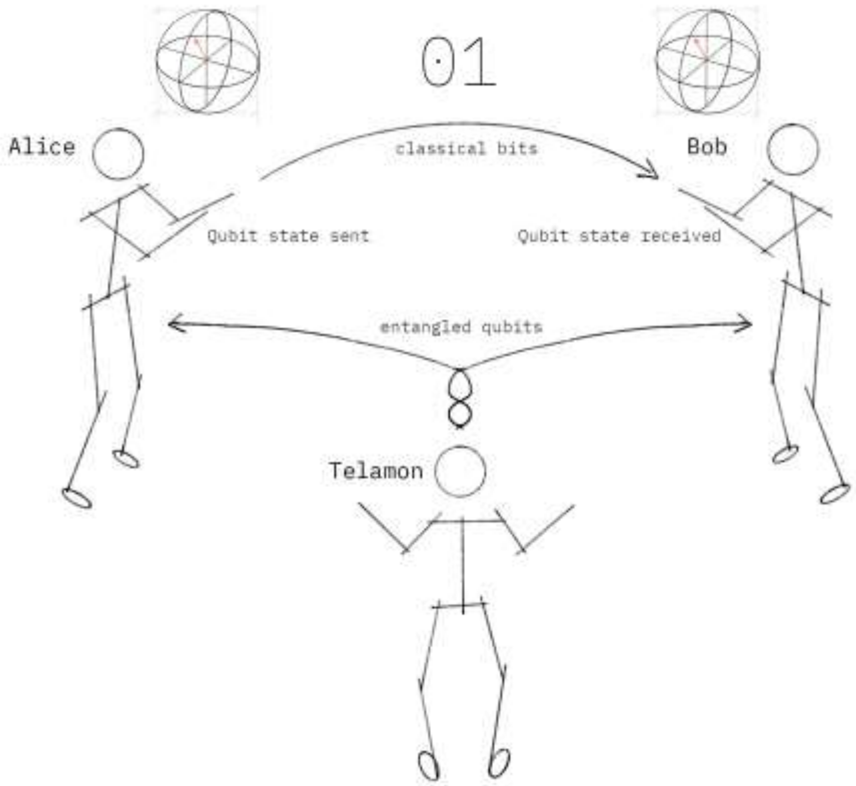
GHZ State

$|\Psi\rangle = (|000\rangle + |111\rangle)/\sqrt{2}$

https://qiskit.org/documentation/apidoc/circuit.html

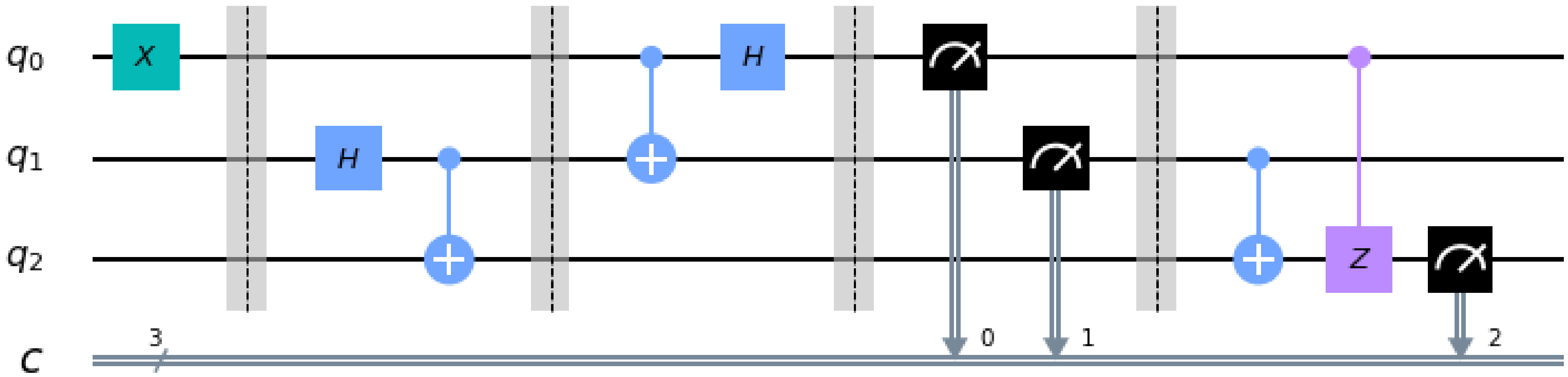
Algorithm: Teleportation

Transmission of quantum information on a classical channel.



https://learn.qiskit.org/course/ch-algorithms/quantum-teleportation

Teleportation Circuit



https://learn.qiskit.org/course/ch-algorithms/quantum-teleportation

How qubits are made?

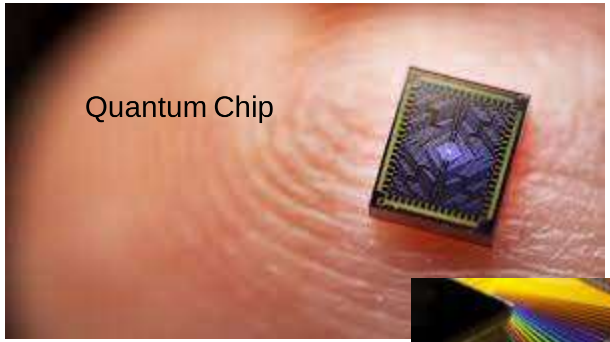
Today qubits are made using the following:

1. Electron
2. Neutral atom
3. Superconductors
4. Photons
5. Silicon-based qubits
6. Quantum annealers

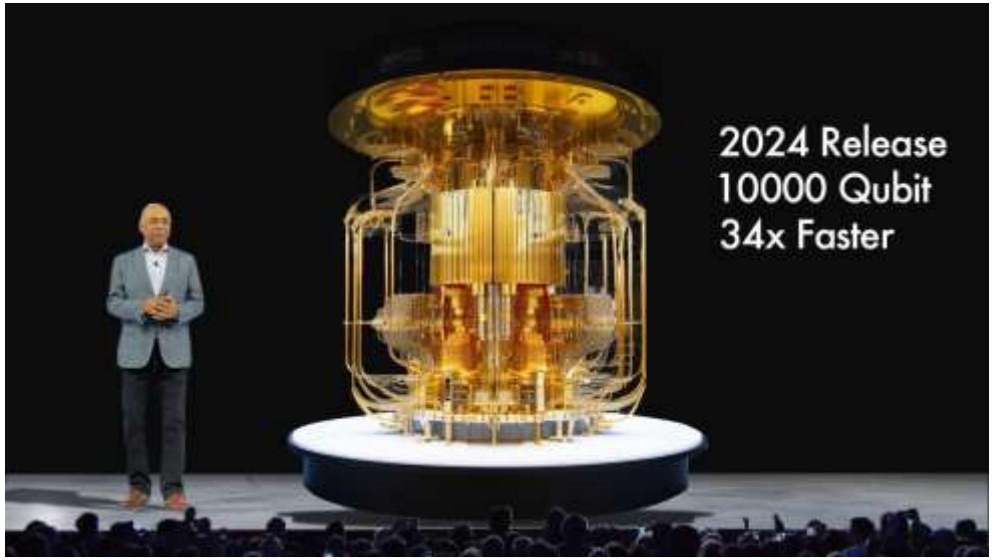
Refers to electron spin

https://www.istockphoto.com/photos/electron-spin

How Today's Quantum Computers look like?



By IBM



https://www.youtube.com/watch?v=lY3jhUhVxK0

https://www.google.com/search?sca_esv=559674773&rlz=1C1GCEA_enIN933IN933&sxsrf=AB5stBjV6N3ryL7-GQmV1CUt_JQfk0iL5g:1692866850961&q=quantum+computing+rooms&tbm=isch&source=lnms&sa=X&ved=2ahUKEwixv7a69PSAAxXMGlgKHTwJAHgQ0pQJegQIDRAB&biw=1536&bih=715&dpr=1.25#imgrc=BXZpkNKKFweoaM

What makes quantum computing so challenging?

1) Qubit Decoherence: Qubits are extremely sensitive to there environment, and even small disturbances can cause them to loose there quantum properties.
2) Scalability: Irrespective of there impressive performance for some tasks, they are very less as compared to classical computers. Scaling up to thousands of qubits while maintaining high level of coherence and maintain low error rates still remains challenging.
3) Error Correction: Quantum Computers are extremely sensitive to noise and errors caused by the interaction with their environment. This can cause error to accumulate and degrade the quality of computation. So, developing error correcting techniques is crucial for practical quantum computing.
4) Hardware Development: Developing high quality quantum hardware, such as qubits and control electronics is a major challenge.
5) Software Development: Quantum algorithms and software tools are still in their infancy, and there is need for new programming languages, compilers and optimizations tools to utilize the power of quantum computers.

https://thequantuminsider.com/2023/03/24/quantum-computing-challenges/