

## UNIT- III Fundamentals of quantum computation and quantum circuit design

### Quantum Computer

A quantum computer is a machine that performs calculations based on the laws of quantum mechanics, which is the behavior of particles at the sub-atomic level.

### Quantum Computing

Quantum computing is an emerging field in computer science that uses the principles of quantum mechanics to perform computational tasks.

### Classical Computing vs Quantum Computing

In classical computing, data is represented using bits, which can be either 0 or 1.

Quantum computing uses quantum bits or qubits, which can exist in a superposition of states. This makes quantum computers capable of parallel processing and solving certain problems exponentially faster.

### Difference between Bits and Qubits in Quantum Computing:

S.NO	BITS	QUBITS
1.	The device computes by manipulating those bits with the help of logical gates (AND, OR, NOT).	The device computes by manipulating those bits with the help of quantum logic gates.
2.	A classical computer has a memory made up of bits where each bit hold either a one or zero.	A qubits (quantum bits) can hold a one, a zero or crucially a superposition of these.
3.	Bits are used in classical computers.	Qubits(Quantum bits) are use in quantum computer
4.	Information is stored in bits, which take the discrete values 0 and 1.	Information is stored in quantum bits, or qbits. A qbit can be in states labelled $ 0\rangle$ and $ 1\rangle$ , but it can also be in a superposition of these states, $a 0\rangle + b 1\rangle$ , where a and b are complex numbers. If we think of the state of a qbit as a vector, then superposition of states is just vector addition.

S.NO	BITS	QUBITS
5.	For example, if storing one number takes 64 bits, then storing N numbers takes N times 64 bits.	For example, for every extra qbit you get, you can store twice as many numbers. For example, with 3 qbits, you get coefficients for $ 000\rangle$ , $ 001\rangle$ , $ 010\rangle$ , $ 011\rangle$ , $ 100\rangle$ , $ 101\rangle$ , $ 110\rangle$ and $ 111\rangle$ .
6.	Bits are slow.	Qubits are faster.
7.	Its circuit behaviour based on classical physics.	Its circuit behaviour based on quantum mechanics.

## INTRODUCTION TO QUANTUM COMPUTATION

Quantum computing is a modern way of computing that is based on the science of quantum mechanics and its unbelievable phenomena. It is a combination of physics, mathematics, computer science and information theory. It provides high computational power, less energy consumption and exponential speed over classical computers by controlling the behavior of small physical objects i.e. microscopic particles like atoms, electrons, photons, etc.

The basic working of quantum computing and the quantum properties it follows like superposition, entanglement and interference.

### Superposition –

In classical computing bits has two possible states either zero or one. In quantum computing, a qubit (short for “quantum bit”) is a unit of quantum information—the quantum analogue to a classical bit. Qubits have special properties that help them solve complex problems much faster than classical bits. One of these properties is superposition, which states that instead of holding one binary value (“0” or “1”) like a classical bit, a qubit can hold a combination of “0” and “1” simultaneously. Qubits have two possible outcomes zero or one but those states are superposition of zero and one. In quantum world qubit don’t have to be in one of those states. It can be in any proportion of those states. As soon as we measure its value, it has to decide whether it is zero or one. This is called superposition. It is the ability of the quantum system to be in multiple states at same time.

In classical computing for example there are 4 bytes. The combination of 4 bytes can represent  $2^4=16$  values in total and one value a given instant. But in a combination 4 qubits all 16 combination are possible at once.

- Qubits exhibit superposition, allowing them to exist in multiple states simultaneously.
- A qubit can exist in a linear combination of the 0 and 1 states. This is represented as  $|0\rangle$  and  $|1\rangle$ .
- Mathematically, **the wavefunction of a qubit in superposition** is represented as,

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

where  $\alpha$  and  $\beta$  are coefficients of both the states.

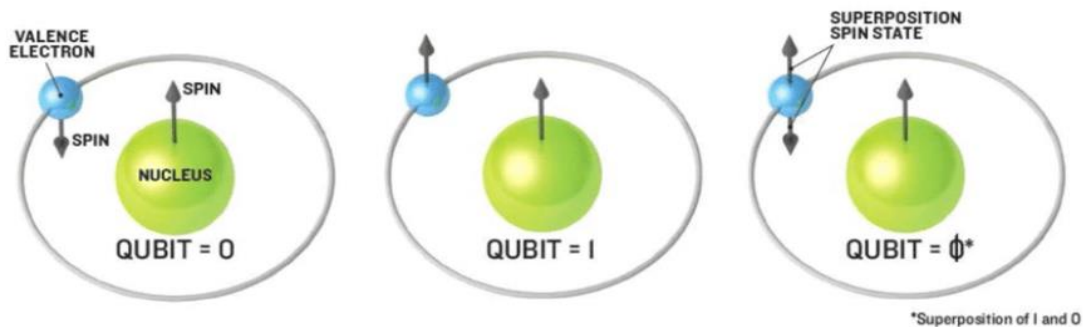
The probability of the state is directly proportional to the square of the magnitude of its coefficient.

$|\alpha|^2$  is the probability of identifying the qubit state 0 and  $|\beta|^2$  is the probability of identifying the qubit state 1. These probabilities when summed up must give a total of 1 or say 100% mathematically, i.e.

$$|\alpha|^2 + |\beta|^2 = 1.$$

### Measurement:

- When a qubit in superposition is measured, it collapses into one of the basis states  $|0\rangle$  or  $|1\rangle$ .
- The outcome of the measurement is probabilistic, with the probabilities determined by the squared magnitudes of the two coefficients.



In many quantum computing schemes, the qubit is represented by the spin state of a particle.

Spin, a quantum property of particles is typically in any of two directions, up or down. But it can be put into a superposition state so it is up and down at the same time.

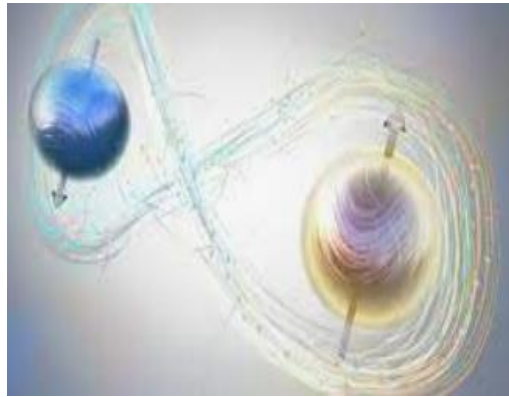
### Significance of Superposition:

Superposition enables qubits to explore multiple possibilities simultaneously.

This allows quantum computers to process vast amounts of information in parallel, potentially solving complex problems much faster than classical computers.

### **Entanglement –**

Entanglement is an extremely strong correlation that exists between quantum particles — so strong, that two or more quantum particles can be linked in perfect unison, even if separated by great distances.



- Two qubits are entangled through the action of a laser.
- Once they have been entangled, they are in an indeterminate state.
- The qubits can then be separated by any distance, but they will remain linked.
- When one of the qubits is manipulated—say, to perform a step in a quantum computer program—the manipulation happens instantly to its entangled twin as well.

If the manipulation includes reading the state of one of the qubits, the entanglement ends, and both qubits' states are revealed.

### **Interference -**

All subatomic particles along with light pose dual nature, i.e. particle and wave nature both. The quantum particle may experience interference. If each particle goes through both the slits (Young's double-slit experiment) simultaneously due to superposition, they can cross its own path interfering with the path direction. The idea of interference allows us to intentionally bias the content of the qubit towards the needed state. However, it can also result in a quantum computer to combine its various computations into one making it more error-prone

Quantum computing has the potential to revolutionize various fields, including cryptography, optimization, drug discovery, and material science. However, building practical and scalable quantum computers is a complex and ongoing challenge due to issues like qubit stability, error correction, and decoherence. Researchers and companies are actively working to develop quantum hardware and software to harness the power of quantum computing for a wide range of applications.

## QUANTUM BIT OR QUBIT

Quantum Bit or Qubit is the fundamental unit of quantum information that represents subatomic particles such as atoms, electrons, etc. as a computer's memory while their control mechanisms work as a computer's processor. It can take the value of 0, 1, or both simultaneously. It is a million times more powerful than today's strongest supercomputers. Production and management of qubits are tremendous challenges in the field of engineering. They acquire both, digital as well as analog nature which gives the quantum computer their computational power. Their analog nature indicates that quantum gates have no noise limit and their digital nature provides a norm to recover from this serious weakness. Therefore, the approach of logic gates and abstractions created for classical computing is of no use in quantum computing. Quantum computing may adopt ideas only from classical computing. But this computing needs its own method to overcome the variations of processing and any type of noise. It also needs its own strategy to debug errors and handle defects in design.

Qubit has two quantum states similar to the classical binary states. The qubit can be in either state as well as in the superposed state of both states simultaneously. There is a representation of these quantum states also known as Dirac notation.

In this notation, the state label is kept between two symbols  $|$  and  $\rangle$ . Therefore, states are written as  $|0\rangle$  and  $|1\rangle$  which are literally having analog values and both are participating to give any value between 0 and 1 given that sum of probability of occurrence of each state must be 1. Thus any quantum bit wave function can be expressed as a two-state linear combination each with its own complex coefficient i.e.  $|w\rangle = x|0\rangle + y|1\rangle$  where  $x$  and  $y$  are coefficients of both the states. The probability of the state is directly proportional to the square of the magnitude of its coefficient.  $|x|^2$  is the probability of identifying the qubit state 0 and  $|y|^2$  is the probability of identifying the qubit state 1. These probabilities when summed up must give a total of 1 or say 100% mathematically, i.e.  $|x|^2 + |y|^2 = 1$ .

### **The fundamental characteristics of qubits are:**

**1. Superposition:** A qubit can exist in a superposition of multiple states, meaning it can represent both 0 and 1 (or any combination of these states) at the same time. This enables quantum computers to perform multiple calculations in parallel.

**2. Entanglement:** Qubits can be entangled, which means that the state of one qubit is correlated with the state of another, even when they are separated by a significant distance. Entanglement allows for the creation of quantum systems in which changes to one qubit's state affect the state of another, offering potential advantages in quantum computation and communication.

**3. Measurement:** When a qubit is measured, it collapses from its superposition of states to a single, definite state (0 or 1). The probability of measuring a particular state depends on the coefficients of the superposition.

Qubits are typically realized using various physical systems, including:

- ✓ Superconducting circuits: Qubits are implemented using tiny loops of superconducting material.
- ✓ Trapped ions: Ions are trapped and manipulated using electromagnetic fields to serve as qubits.
- ✓ Quantum dots: Nanoscale semiconductor structures can be used to encode qubit information.
- ✓ Photons: Individual photons can also be used as qubits for quantum communication and quantum key distribution.

The superposition and entanglement properties of qubits make quantum computers well-suited for certain types of problems, such as factorization, optimization, and simulations of quantum systems, where classical computers may struggle or require a significant amount of time. However, building and maintaining stable qubits while mitigating the effects of decoherence and errors remain ongoing challenges in the development of practical quantum computers.

### **BLOCH SPHERE REPRESENTATION OF A QUBIT:**

The Bloch sphere is a geometric representation that provides a visual depiction of the state of a single qubit in quantum mechanics. It is a useful tool for understanding and visualizing the concept of superposition, which is one of the fundamental properties of qubits.

The Bloch sphere represents a single qubit in a three-dimensional space. The state of a qubit can be described by a quantum state vector, typically denoted as  $|\psi\rangle$ , and it can be expressed in terms of two complex probability amplitudes,  $\alpha$  and  $\beta$ :

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

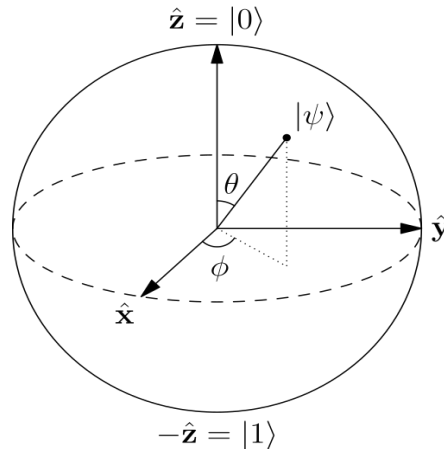
Here,  $|0\rangle$  and  $|1\rangle$  are the basis states representing the classical 0 and 1 states, and  $\alpha$  and  $\beta$  are complex numbers.

The Bloch sphere visualization of a qubit involves mapping this quantum state vector to a point on the surface of a sphere. The Bloch sphere has the following properties:

1. The north pole of the sphere represents the  $|0\rangle$  state.
2. The south pole of the sphere represents the  $|1\rangle$  state.

3. Any point on the surface of the sphere represents a valid qubit state.

The Bloch vector, which starts at the origin of the sphere (the center) and ends on the surface of the sphere, represents the state of the qubit. The direction and length of this vector determine the state of the qubit. The angle  $\theta$  (polar angle) represents the probability of measuring the state  $|0\rangle$ , and the angle  $\phi$  (azimuthal angle) represents the phase relationship between  $|0\rangle$  and  $|1\rangle$ .



To show this correspondence, consider the qubit description of the Bloch sphere; any pure state  $\psi$  can be written as a complex superposition of the ket vectors  $|0\rangle$  and  $|1\rangle$ ; moreover since global phase factors do not affect physical state, we can take the representation so that the coefficient of  $|0\rangle$  is real and non-negative. Thus  $\psi$  has a representation as

$$|\psi\rangle = \cos \theta/2 |0\rangle + e^{i\phi} \sin \theta/2 |1\rangle.$$

The range of values for  $\theta$  and  $\phi$  such that they cover the whole sphere (without “repetitions”) is  $\theta \in [0, \pi)$  and  $\phi \in [0, 2\pi)$ . Angle  $\theta$  corresponds to *latitude* and angle  $\phi$  corresponds to *longitude*.

### Examples:

- Assume that  $\theta = 0$ .

This means that:  $|\psi\rangle = 1 \cdot |0\rangle + e^{i\phi} \cdot 0 \cdot |1\rangle = |0\rangle$ .

- Now assume that  $\theta = \pi$ ;

Similarly we get:  $|\psi\rangle = 0 \cdot |0\rangle + e^{i\phi} \cdot 1 \cdot |1\rangle = e^{i\phi} \cdot |1\rangle = |1\rangle$

- Assume that  $\theta = \pi/2$  and  $\phi = 0$ .

Then,  $|\psi\rangle = 1/\sqrt{2} \cdot |0\rangle + e^{i0}/\sqrt{2} \cdot |1\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$  while for  $\phi = \pi$ ,

we get  $|\psi\rangle = 1/\sqrt{2} \cdot |0\rangle + e^{i\pi}/\sqrt{2} \cdot |1\rangle = (|0\rangle - |1\rangle)/\sqrt{2}$

When the qubit is measured, it collapses to one of the two poles. Which pole depends exactly on which direction the arrow in the Bloch representation points to: If the arrow is closer to the north pole, there is larger probability to collapse to that pole; similarly for the south pole. Observe that this introduces the notion of probability in the Bloch sphere: the angle  $\theta$  of the arrow with the vertical axes corresponds to that probability. If the arrow happens to point exactly at the equator, there is 50-50 chance to collapse to any of the two poles.

### **The Bloch sphere provides the following interpretation:**

- The poles represent the classical bits, let us use the notation  $|0\rangle$  and  $|1\rangle$ . However, while these are the only possible states for the classical bit representation.
- Quantum bits cover the whole sphere. i.e, rotating a vector w.r.t. the z-axis results into a phase change, and does not affect which state the arrow will collapse to, when we measure it. This rotation is achieved by changing the  $\phi$  variable.

### **MULTIPLE QUBITS:**

When working with multiple qubits in a quantum system, you can extend the Bloch sphere representation to describe the combined state of the qubits. For two qubits, you would need to work in a four-dimensional space, which makes the visualization more challenging. A complete description of the combined state of multiple qubits is usually represented using a quantum state vector that incorporates all possible combinations of the individual qubit states.

When add more qubits to the system, the space required to represent the combined state grows exponentially, making it increasingly difficult to visualize. Nevertheless, the principles of superposition and entanglement that apply to individual qubits still hold for multi-qubit systems, and quantum computing algorithms take advantage of these properties to perform complex computations efficiently. Visual representations like the Bloch sphere can help with conceptual understanding but may become less practical as the number of qubits in a system increases.

### **SINGLE-QUBIT GATES**

Single-qubit gates are fundamental quantum gates that operate on individual qubits, modifying their quantum states. A single-qubit has two basis states  $|0\rangle$  and  $|1\rangle$ .

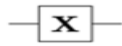
#### **Commonly used single-qubit gates are:**

1. **Pauli-X Gate ( $\sigma_x$  or "NOT" gate):**

The Pauli-X gate is equivalent to the classical NOT gate and performs a bit-flip operation on the qubit's state. Mathematically, it is represented by the following matrix:

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

The circuit representation of Pauli-X Gate:

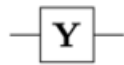


## 2. Pauli-Y Gate ( $\sigma_y$ ):

The Pauli-Y gate is a combination of a bit-flip and a phase-flip operation. Mathematically, it is represented as follows:

$$\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

The circuit representation of Pauli-Y Gate:

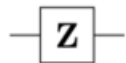


## 3. Pauli-Z Gate ( $\sigma_z$ ):

The Pauli-Z gate introduces a phase flip without changing the qubit's basis states. Mathematically, it is represented as follows:

$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

The circuit representation of Pauli-Z Gate:

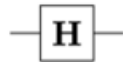


## 4. Hadamard Gate (H-gate):

The Hadamard gate introduces superposition by transforming the basis states into equal superpositions. Mathematically, it is represented as:

$$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

The circuit representation of Hadamard Gate :



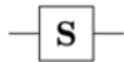
### 5. Phase Shift S-gate:

The S-gate introduces a  $\pi/2$  phase shift. It is represented as:

$$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{2}} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$

The circuit representation of S-gate:

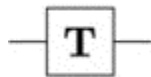


### 6. Phase Shift T- gate:

The T-gate introduces a  $\pi/4$  phase shift. It is represented as:

$$\begin{bmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{bmatrix}$$

The circuit representation of T-gate:



### 7. Identity Gate (I-gate):

The identity gate leaves the qubit state unchanged. It is represented as:

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

## MULTIPLE-QUBIT GATES:

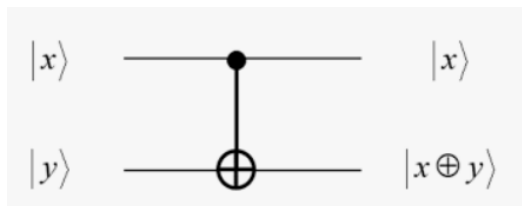
A two-qubit system has 4 computational basis states denoted as  $|00\rangle$ ,  $|01\rangle$ ,  $|10\rangle$ ,  $|11\rangle$ . A multi-qubit system of  $N$  qubits has  $2^N$  basis states. Multiple-qubit gates are operations that act on two or more qubits simultaneously.

**Commonly used multiple-qubit gates are:**

### 1. Controlled NOT gate (or CNOT)

CNOT gate acts on 2 qubits, and performs the NOT operation on the second qubit only when the first qubit is  $|1\rangle$ , and otherwise leaves it unchanged.

The circuit representation of CNOT gate is given by,



Truth Table for CNOT gate is given by,

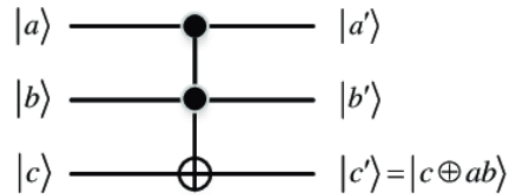
INPUT		OUTPUT	
x	y	x	y
0	0	0	0
0	1	0	1
1	0	1	1
1	1	1	0

### 2. Toffoli Gate (or CCNOT Gate)

The Toffoli gate is named after Tommaso Toffoli and also called as Controlled Controlled NOT (CCNOT) gate.

CCNOT gate acts on 3 qubits and performs the NOT operation on the third qubit only when the first two qubits are in  $|1\rangle$  state, and otherwise leaves it unchanged.

The circuit representation of CCNOT gate is given by,



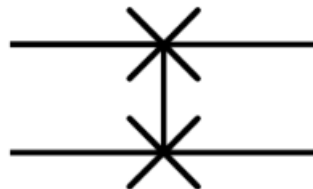
Truth Table for CCNOT gate is given by,

Inputs			Outputs		
$a$	$b$	$c$	$a'$	$b'$	$c'$
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	1	1
1	0	0	1	0	0
1	0	1	1	0	1
1	1	0	1	1	1
1	1	1	1	1	0

### 3. SWAP Gate:

The SWAP gate is a two-qubit gate. If the two qubits are in states  $|00\rangle$  and  $|11\rangle$ , the gate has no effect on them. If the qubits are in states  $|01\rangle$  and  $|10\rangle$ , the gate will swap their states. After applying the Swap gate, the qubits will be in states  $|10\rangle$  and  $|01\rangle$ , respectively.

The circuit representation of SWAP gate is given by,



Truth Table for SWAP gate is given by,

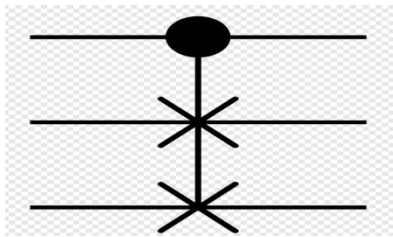
INPUT		OUTPUT	
a	b	a <sup>1</sup>	b <sup>1</sup>
0	0	0	0
0	1	1	0
1	0	0	1
1	1	1	1

#### 4. Fredkin Gate (or CSWAP Gate):

The Fredkin gate, also known as the Controlled-SWAP (CSWAP) gate, is a three-qubit quantum gate. The Fredkin gate is named after its inventor, Edward Fredkin.

The Fredkin gate has three inputs and three outputs that transmits the first bit unchanged and swaps the last two bits if, and only if, the first bit is 1.

The circuit representation of Fredkin gate is given by,



Truth Table for Fredkin gate is given by,

input			output		
A	B	C	A	B	C
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	1	1
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	1	0	1
1	1	1	1	1	1

## **QUANTUM CIRCUIT**

A quantum circuit is a graphical representation of a quantum computation or algorithm that operates on qubits. It is a collection of quantum gates interconnected by quantum wires. Quantum circuits are fundamental to quantum computing and can efficiently solve certain problems that would be impractical for classical computers.

## **DESIGN OF QUANTUM CIRCUITS**

Steps involved in designing a quantum circuit are:

### **Define the Problem:**

The first step in designing a quantum circuit is to clearly define the problem you want to solve more efficiently using quantum computing.

### **Choose the number of Qubits:**

Determine the number of qubits required for your computation.

### **Select Quantum Gates:**

Choose the quantum gates that will be applied to the qubits in your circuit. Common gates include the Hadamard gate, Pauli-X, Pauli-Y, Pauli-Z gates, and the CNOT (Controlled-NOT) gate.

### **Design the Circuit:**

Arrange the selected quantum gates in a sequence to create the quantum circuit. The order and placement of gates are crucial, as they determine how the quantum information is manipulated.

### **Consider Initialization and Measurement:**

Decide how qubits will be initialized (often in the  $|0\rangle$  state) and where measurements will be placed in the circuit. Measurements are typically performed at the end of the circuit to extract classical information.

### **Optimize the Circuit:**

Quantum circuit design often involves optimizing the circuit to minimize the overall complexity. This can lead to more efficient quantum computations.

### **Simulate and Test:**

Before running a quantum circuit on a physical quantum computer, it is common to simulate the circuit on a classical computer to verify its correctness and understand its expected behaviour.

### **Quantum Error Correction:**

Error correction techniques to be incorporated to mitigate the effects of noise and errors in quantum computations.

### **Run on Quantum Hardware:**

If available, we can run our quantum circuit on quantum hardware, such as a quantum processor. Quantum computers are still in the early stages of development, so access may be limited.

### **Analyze Results:**

After running the quantum circuit, analyze the measurement results to obtain the desired output for your problem or algorithm. Quantum measurements are probabilistic, so we may need to repeat the computation multiple times to obtain statistically significant results.

## **ADVANTAGES OF QUANTUM COMPUTERS**

### **➤ Faster computations**

These type of computers can perform computation at a much faster rate than normal computers. Quantum computers have computation power higher than supercomputers also. They can process data at 1000 times faster than normal computers and supercomputers. Some calculations if performed by a normal computer can take 1000 years is done by quantum computers in a few seconds.

### **➤ Best for simulation**

Quantum computers are best for doing data simulation computing. There are many algorithms created that can simulate various things like weather forecasting, chemical simulation etc.

### **➤ Medicine creation**

These type of computers can work better in the medical field. They can detect diseases and can create a formula for medicines. Different type of diseases can be diagnosed and tested in scientific laboratories using these computers.

### **➤ Google search**

Quantum computers are used by Google to refine searches. Now every search on Google can speed up by using these computers. Most relevant results can be populated using quantum computing.

➤ **High privacy**

These computers can make high encryption and is good at cryptography. It is impossible to break the security of quantum computers. Recently China has launched a satellite that uses quantum computing and china claimed that this satellite cannot be hacked.

➤ **Used in radar making**

Quantum computing is also used in making radar missiles. The accuracy of radar weapons can be improved by using this technology.

➤ **Used in artificial intelligence**

These type of computers perform well in artificial intelligence. They can make decisions more precisely than normal computers. Scientists can do better research using these computers.

➤ **Machine learning**

Quantum computing is applied nicely by using machine learning techniques. Users can use less code and uses machine learning process for improving outcome.

## **DISADVANTAGES OF QUANTUM COMPUTERS**

➤ **Algorithm creation**

For every type of computation, it needs to write a new algorithm. Quantum computers cannot work as classical computers, they need special algorithms to perform tasks in their environment.

➤ **The low temperature needed**

As the processing in these computers is done very deeply so it needs a temperature of negative 460 degrees F. This is the lowest temperature of the universe and it is very difficult to maintain that temperature.

➤ **Not open for public**

Due to the high range price they are not available for public use. Also, the errors in these type of computers are high because they are still in the development phase. Quantum computers work fine in 10 qubits but after increasing qubits like 70 qubits, the accuracy is not right. There are experiments already going on to make the results of these computers precise.

## ➤ Internet Security

It is assumed by the scientists that if a quantum computer is implemented in the best way then whole internet security breaks. This is due to the facts that these computers can decrypt all the codes on the internet.

## Applications of quantum computing

- Cryptography
- Optimization Problems
- Artificial Intelligence
- Better batteries
- Cleaner fertilization
- Cybersecurity
- Drug development
- Electronic materials discovery
- Financial modeling
- Solar capture
- Traffic optimization
- Weather forecasting and climate change
- Quantum Simulation

It could also have commercial applications in areas such as medical and healthcare fields, chemical catalysts, storage of energy, pharmaceutical advancement and device displays.

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*Note:*

### *Difference between classical computers and quantum computers*

<i>Comparison key</i>	<i>Classical computer</i>	<i>Quantum computer</i>
<i>Basis of computing</i>	<i>Large scale integrated multipurpose computer based on classical physics</i>	<i>High speed parallel computer based on quantum mechanics</i>
<i>Information storage</i>	<i>Bit based information storage using voltage/ charge</i>	<i>Quantum bit (qubit) based information storage using electron spin</i>
<i>Bit values</i>	<i>Bits having a value of either 0 or 1</i>	<i>Qubits having a value of 0,1 or sometimes</i>

<b>Comparison key</b>	<b>Classical computer</b>	<b>Quantum computer</b>
	<i>and can have a single value at any instant</i>	<i>negative and can have both values at the same time</i>
<b>Number of possible states</b>	<i>The number of possible states is 2 which is either 0 or 1</i>	<i>The number of possible states is infinite since it can hold combinations of 0 or 1 along with some complex information</i>
<b>Output</b>	<i>Deterministic- (repetition of computation on the same input gives the same output)</i>	<i>Probabilistic- (repetition of computation on superposed states gives probabilistic answers)</i>
<b>Gates used for processing</b>	<i>Logic gates process the information sequentially, i.e. AND, OR, NOT, etc.</i>	<i>Quantum logic gates process the information parallel</i>
<b>Scope of possible solutions</b>	<i>Defined and limited answers due to the algorithm's design</i>	<i>probabilistic and multiple answers are considered due to superposition and entanglement properties</i>
<b>Operations</b>	<i>Operations use Boolean Algebra</i>	<i>Operations use linear algebra and are represented with unitary matrices.</i>
<b>Circuit implementation</b>	<i>Circuits implemented in macroscopic technologies (e.g. CMOS) that are fast and scalable</i>	<i>Circuits implemented in microscopic technologies (e.g. nuclear magnetic resonance) that are slow and delicate</i>