1) Explain the difference between a classical bit and a qubit. [2M] L1

A classical binary bit can only represent a single binary value, such as 0 or 1, meaning that it can only be in one of two possible states. A qubit, however, can represent a 0, a 1, or any proportion of 0 and 1 in superposition of both states, with a certain probability of being a 0 and a certain probability of being a 1.

2) What is Quantum computing? [2M] L1

Quantum computing uses specialised technology including computer hardware and algorithms that take advantage of quantum mechanics to solve complex problems that classical computers or supercomputers can't solve, or can't solve quickly enough.

3) Distinguish between Classical and quantum Computing. [4M] L2

Conventional Computing	**Quantum Computing**
The conventional computing system is based upon the classic phenomenon that electrical circuits are either on or not at any given time.	Quantum computing relies on quantum mechanical phenomena such as superposition, entanglement, and the possibility of being in multiple states at once.
The "bit" is the basis for information storage and manipulation. It is based on voltage or charge. Low is 0 and High is 1.	Quantum Bits, or "qubits", are used to store and manipulate information. They work by using the spin of an electron or the polarisation of a single photon.
Classical physics governs the circuit behaviour.	Quantum physics and quantum mechanics govern the circuit behaviour.
The basic building blocks for conventional computers are CMOS transistors.	Quantum computers are built using SQUID (Superconducting Quantum Interference Devices) or Quantum Transistors.
Data processing in conventional computers is performed by the Central Processing Unit or CPU. This unit consists of an Arithmetic and Logic Unit, processor registers, and a control module.	Quantum computers process data in Quantum Processing Units or QPUs, which are made up of interconnected qubits.

4) Describe in simple terms, what is quantum entanglement? [2M] L1

Quantum entanglement is a phenomenon in quantum physics where two or more particles become linked in such a way that the state of one particle directly affects the state of the other(s), no matter how far apart they are.
Imagine you have two particles that start off together and interact in a certain way. Even if you separate them by large distances, if you measure a property (like spin or polarisation) of one particle, the same property of the other particle will instantly be determined, as if they are communicating faster than the speed of light

5) Explain the quantum property of Superposition. [2M] L1

Superposition in quantum mechanics is the principle where a particle can exist in multiple states simultaneously. Only upon measurement does it 'collapse' into one state, making it a key concept in understanding quantum behaviour and phenomena.

6) Compare the concepts of quantum superposition and entanglement. [4M] L2

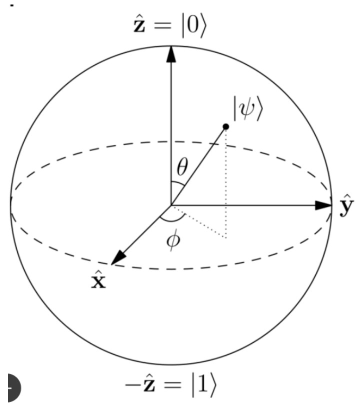
Feature	Quantum Superposition	Quantum Entanglement
Definition	A single particle exists in multiple states at once.	Two or more particles are linked so that the state of one affects the state of the other(s), no matter the distance.
Measurement Impact	Collapses the superposition into one definite state.	Measuring one particle instantly determines the state of the entangled partner(s).
Locality	It is a local property in case of Qubits.	It is usually a non-local (Distant) interaction.
Role in Quantum Computing	Enables qubits to represent multiple states simultaneously, boosting computational power.	Enables quantum communication and secure key distribution through phenomena like quantum teleportation.
Example	An electron in a superposition of spin-up and spin-down states.	Two entangled photons where measuring the polarisation of one determines the polarisation of the other.

7) What is the need for Quantum Computing? [4M] L2

Quantum computing addresses the limitations of classical computers in tackling intricate problems by exploiting the principles of quantum mechanics. With exponentially greater processing power, it can revolutionise fields such as cryptography, drug discovery, materials science, and optimization. Quantum algorithms excel in solving tasks like factoring large numbers, simulating quantum systems, and analyzing big data sets, offering unparalleled capabilities. Quantum computing is poised to drive innovation, unlock new scientific discoveries, and address challenges beyond the reach of classical computation.

8) Explain the significance of Bloch Sphere. [4M] L2

Bloch sphere is a geometrical representation of the pure state space of a two-level quantum mechanical system (qubit), named after the physicist Felix Bloch.



- The z-axis represents the probability of the qubit being measured as a 0 or a 1.
- The x-axis represents the real part of the state vector.
- The y-axis represents the imaginary part of the state vector.

It's significant because:

1. **Geometric Representation:** It provides a simple geometric representation of the state of a qubit, allowing us to visualise complex quantum states.
2. **Quantum States:** Each point on the sphere corresponds to a unique quantum state of the qubit, including classical states (0 and 1) and superposition states.
3. **Unitary Operations:** Quantum operations, like rotations, are represented as transformations on the Bloch sphere, aiding in understanding qubit manipulation.
4. **Measurement:** It illustrates how measurement collapses the state of a qubit onto the poles of the sphere, helping to understand measurement outcomes.
5. **Quantum Gates:** Quantum gates, essential for quantum computation, are represented as rotations on the Bloch sphere, facilitating quantum circuit design and analysis.

9) How are quantum gates different from Classical gates? [2M] L1

Quantum gates manipulate qubits using unitary operations, allowing for superposition and entanglement, enabling complex computations simultaneously. Classical gates, however, operate on bits with deterministic logic, performing binary operations sequentially

10) Explain single Qubit gates. [4M] L2

Single-qubit gates act on individual qubits, modifying their quantum states. There are several commonly used single-qubit gates in quantum computing, each with a different effect on the qubit state. By combining different single-qubit gates in specific ways, we can create complex quantum operations that can be used for a variety of applications.

Some of the most important single qubit gates are:

- **X gate:** This gate is analogous to the NOT gate in classical computing. It flips the state of the qubit from |0⟩ to |1⟩ or from |1⟩ to |0⟩.
- **Z gate:** This gate flips the phase of the |1⟩ state, leaving the |0⟩ state unchanged.
- **Y gate:** This gate is equivalent to applying both X and Z gates and a global phase.
- **Hadamard gate:** This gate creates a superposition state by transforming the |0⟩ state into an equal superposition of the |0⟩ and |1⟩ states.
- **T gate:** This gate is a 45-degree phase shift gate that introduces a phase shift of π/4 radians to the |1⟩ state.

11) Explain Multiple Qubit gates. [4M] L2

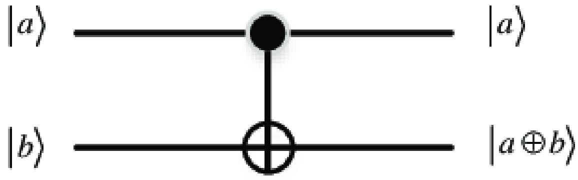
Multi-qubit gates are a type of quantum gate that act on two or more qubits simultaneously. Multi-qubit gates enable the creation and manipulation of entangled states, which are essential for performing complex quantum computations.

Some of the commonly used multi-qubit gates are:

- **CNOT (Controlled-NOT) gate:** A two-qubit gate that performs a NOT operation on the target qubit if - and only if - the control qubit is in the state |1⟩.
- **SWAP gate:** A two-qubit gate that swaps the states of two qubits.
- **Controlled-phase gate:** It introduces a phase shift on the target qubit depending on the state of the control qubit.

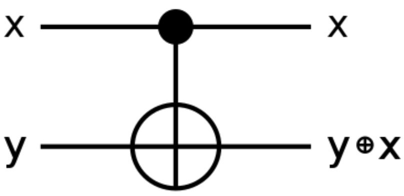
12) Draw circuit symbol of a Controlled NOT gate, state its matrix representation. [2M] L1

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



13) Describe the working of a Controlled NOT gate with a truth table. [4M] L2

The Controlled NOT (CNOT) gate operates on two qubits: a control and a target. If the control qubit is $|1\rangle$, the gate flips the target qubit's state. If the control qubit is $|0\rangle$, the target qubit remains unchanged. This gate is crucial for creating entanglement and implementing quantum algorithms

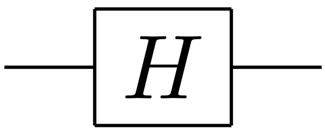


Here
x = Control Qubit
y = Target Qubit

input		output	
x	y	x	y⊕x
$|0\rangle$	$|0\rangle$	$|0\rangle$	$|0\rangle$
$|0\rangle$	$|1\rangle$	$|0\rangle$	$|1\rangle$
$|1\rangle$	$|0\rangle$	$|1\rangle$	$|1\rangle$
$|1\rangle$	$|1\rangle$	$|1\rangle$	$|0\rangle$

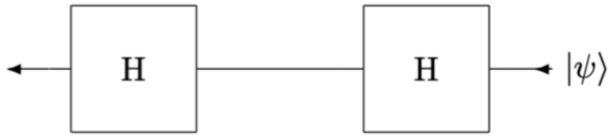
14) Draw the circuit symbol of a Hadamard gate, state its matrix representation. [2M] L1

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



15) Explain the output when two Hadamard gates are used in sequence. [2M] L1

Two Hadamard gates used in succession can be used as a NOT gate.



16) Enlist 4 Quantum Computing platforms with short descriptions. [4M] L2

Quantum computing can be realized in various platforms, each presenting unique advantages and challenges. Some of the leading platforms include:

1. **Superconducting Qubits:** Utilises superconducting circuits to create stable quantum bits (qubits) for quantum computing.
2. **Semiconductor Spins:** Controls the quantum states of electron spins in semiconductor materials to perform quantum operations.
3. **Nitrogen-Vacancy Centers:** Manipulates the quantum states of nitrogen- vacancy defects in diamond materials for quantum computation.
4. **Trapped Ions:** Uses laser-trapped ions to create long-lasting qubits capable of high-fidelity quantum operations.
5. **Neutral Atoms:** Employs neutral atoms, typically held in optical traps, as qubits for quantum computing applications.
6. **Photons:** The focus of this article is on the photonic platform. Photonic quantum bits (qubits) are flying qubits, and it is advantageous to measure them quickly after creation due to their high mobility. Unlike stationary qubits in other platforms, photons travel at the speed of light, necessitating a measurement-based quantum computing model to suitably harness their properties.

17) Explain the components of Quantum Computer as per DiVicenzo's criteria. [4M] L2

DiVincenzo's criteria outline the necessary components and requirements for constructing a practical quantum computer. Here are the key components as per DiVincenzo's criteria:

1. **Qubits:** The system must have scalable qubits that can be clearly defined and distinguishable.
2. **Initialization:** The system must be able to initialize the qubits to a known state, usually the $|0\rangle$ state, with high fidelity..
3. **Memory:** The qubits must have long decoherence times relative to the gate operation times. Decoherence is the process by which quantum information is lost to the environment.
4. **Control:** The system must be able to perform a universal set of quantum gates. This includes single-qubit gates and at least one entangling two-qubit gate, which together can perform any quantum computation.
5. **Readout:** The system must be capable of measuring the state of individual qubits without affecting the states of other qubits.

Additional criteria for quantum communication include:

1. **Receiving and Processing:** There must be a way to transfer quantum information between stationary qubits and flying qubits, such as photons.
2. **Communication:** The system should be capable of transmitting qubits over long distances without significant loss or decoherence, enabling quantum communication between distant nodes.

18) List four challenges to realise a practical quantum computer. [4M] L2

Building a practical quantum computer faces numerous technical, theoretical, and engineering challenges, which includes:

1. **Quantum Decoherence:** Quantum systems are highly susceptible to environmental noise, which causes quantum information to degrade rapidly.
2. **Error Correction:** Quantum computers are extremely sensitive to noise and errors caused by interactions with their environment
3. **Scalability:** While quantum computers have shown impressive performance for some tasks, they are still relatively small compared to classical computers.
4. **Hardware Complexity:** Quantum computers require sophisticated hardware, including control systems, cryogenic cooling, and precise calibration mechanisms. Integrating these components into a cohesive and reliable system presents significant engineering challenges.
5. **Measurement and Readout:** Accurately measuring and reading out the state of qubits without disturbing their quantum coherence is challenging. Developing high-fidelity measurement techniques that minimise errors and disturbance is critical for quantum computing.

19) Explain Photonic Quantum Computing [4M] L2

Photonic quantum computing employs photons, particles of light, as qubits to perform quantum computations. Photons travel at the speed of light and can encode quantum information in their polarization, path, or other properties. They exhibit low noise and interference, making them promising candidates for quantum computing. Photonic quantum computers manipulate qubits using optical components such as beam splitters, phase shifters, and detectors. This approach holds potential for scalable quantum computing due to the ease of manipulating photons and their ability to transmit quantum information over long distances via optical fibres.

20) Whats are the advantages and challenges of Photonic Quantum Computer [4M] L2

Advantages of Photonic Quantum Computing:

1. **Low Susceptibility to Decoherence:** Photons have long coherence times compared to other qubit implementations, reducing errors caused by decoherence.
2. **High-speed Operations:** Photons travel at the speed of light, enabling fast quantum operations and communication between distant qubits.
3. **Scalability:** Photonic systems can potentially be scaled up more easily due to the ability to generate and manipulate multiple photons simultaneously.
4. **Room-temperature operation:** Photonic quantum processors can operate at room temperature, which makes them more practical and more accessible to scale up than other types of quantum computers.

Challenges of Photonic Quantum Computing:

1. **Qubit Manipulation**: Manipulating individual photons to perform quantum operations, such as gates and measurements, requires precise control over optical components and can be technically demanding.
2. **Qubit Loss**: Photon loss due to absorption and scattering in optical components can degrade the performance of photonic quantum systems, necessitating advanced photonics designs for loss mitigation.
3. **Error correction**: Quantum computers are susceptible to errors, which means that error correction techniques need to be developed to ensure the accuracy of calculations.

21)List four potential applications of quantum computing. [2M] L1

OR

22) List eight potential applications of quantum computing. [4M] L2

1. **Cryptography**: Breaking classical encryption methods and creating secure quantum cryptographic protocols.
2. **Drug Discovery**: Simulating molecular structures and interactions to accelerate the discovery of new pharmaceuticals.
3. **Optimization Problems**: Solving complex optimization problems more efficiently in logistics, finance, and manufacturing.
4. **Material Science**: Designing new materials with specific properties by simulating atomic and molecular structures.
5. **Machine Learning**: Enhancing machine learning algorithms with quantum speed-ups for training and inference.
6. **Climate Modeling**: Improving the accuracy and efficiency of climate models by simulating complex systems.
7. **Financial Modeling**: Performing risk analysis, portfolio optimization, and derivative pricing more effectively.
8. **Quantum Chemistry**: Simulating chemical reactions and processes at the quantum level for better understanding and innovation.
9. **Supply Chain Management**: Optimizing supply chain logistics and operations with greater efficiency.
10. **Artificial Intelligence**: Accelerating AI development through faster data processing and enhanced algorithm performance.