

Science and Technology Class 10

Previous Class Topic

- **Big data:** Large, diverse datasets and the search for patterns and correlations using analytics tools.
- **Key concepts of quantum mechanics:** Dual nature of particles, uncertainty principle.

Network Slicing and Edge Computing

Network Slicing

- Divides a network into virtual segments (*slices*) dedicated to different services or applications.
- Enables more efficient and tailored use of network resources for various purposes.
- The technical details of implementation are less relevant; its importance lies in providing dedicated performance and capabilities over a shared infrastructure.

Edge Computing

- Allows computation and data processing nearer to data sources rather than relying on centralized data centers.
- Localized data centers are not essential for edge computing; smaller devices like WiFi routers or components within IoT systems can perform edge tasks.
- Improves speed and efficiency by processing data closer to where it is generated.

Communication Devices and Big Data

Modem

- A device enabling digital communication by modulating and demodulating signals between digital devices and analog transmission mediums.
- Essential for many communication infrastructures, acting as a gateway between computers and larger networks.

Big Data

- Denotes extremely large datasets, often originating from unrelated fields such as tourism patterns and food delivery trends.
- Analysis focuses on identifying meaningful patterns or correlations that may not be apparent initially.
- Analytical tools play a critical role for large-scale organizations to draw actionable insights from such data.

5G Testbed

- Refers to an environment for testing 5G network technology and evaluating its real-world performance before full-scale deployment.
- Analogous to clinical trials in medicine—used to check system efficiency as infrastructure evolves.
- Involves experimenting with different parameters, network components, and user scenarios to optimize 5G performance.

Quantum Mechanics: Foundations and Principles

Understanding "Quantum"

- The term **quantum** functions as a proper noun describing the branch of science focused on the smallest scales of nature.
- Investigates physical laws governing atoms and subatomic particles.
- Human sensory limitations restrict intuition regarding quantum phenomena, as most are far removed from everyday experience.

Fundamental Concepts

Nature of Measurement and Intuition

- Human intuition, based on macro-scale experiences, does not align well with quantum-scale behaviors.
- Natural laws at very small (or fast-moving) scales exhibit complexity and unpredictability.

Mathematical Nature

- Uses highly abstract and mathematical equations to describe reality.
- Solutions are tested and verified through experimental results, affirming theoretical predictions.

Dual Nature of Particles

- Every object possesses both wave and particle characteristics (*wave-particle duality*).

Uncertainty Principle

Principle	Description
Position-Momentum	It is impossible to precisely measure both position and momentum of a particle at once.
Measurement Limitation	Not due to experimental errors but a fundamental feature of nature.
Implication	No experiment to date has disproved this principle.

- If violated, foundational physics would require revision.

Schrödinger's Equation

- Developed by Erwin Schrödinger to mathematically describe quantum systems.
- Applied for understanding electron properties like position, momentum, and energy.
- Unlike Newtonian physics, solutions do not yield deterministic single values but probabilities of different outcomes.

Probability in Quantum Mechanics

- Quantum solutions give probability distributions (e.g., 60% chance of an electron being in one region and 40% in another).
- Probability emerges not from measurement error but as a fundamental aspect—results are reproducible in repeated experiments.
- Probability theory is deeply integrated into real-world applications, including daily decision-making processes.

Quantization and Quantum States

- Schrödinger's equation only allows certain discrete ("**quantized**") outcomes, explaining the term "quantum."
- Systems can exist in superpositions—multiple states at the same time—with probabilities assigned to each.

Superposition

- **Quantum superposition:** A system (like an electron) exists in multiple states or positions simultaneously until measured.
- Measurement forces the system into a definite state (*state collapse*).
- This non-intuitive property distinguishes quantum behavior from classical behavior.

Measurement Problem

- The process where measurement "collapses" a quantum state into one definite outcome remains an unresolved conceptual issue.
- Why measurement triggers collapse is not explained by existing theories.

Pauli Exclusion Principle

- Explains why two solid objects cannot pass through each other; the repulsive force arises from quantum mechanics principles.

Schrodinger's Cat Thought Experiment

- A scenario in which a cat in a box may be considered both alive and dead until the box is opened.
- Illustrates the concept of superposition and the unresolved measurement problem.

Young's Double Slit Experiment

- Demonstrates the wave behavior of particles like electrons or photons when not observed.
- Observation collapses quantum behavior into classical particle-like outcomes.

Quantum Entanglement

- Two or more particles can become linked so that changes to one instantly influence the other, even when separated by large distances.
- Experimental evidence confirms its existence, surpassing earlier skepticism.

Quantum Technology Domains

Four primary domains shape quantum technology:

- Quantum computing
- Quantum communication
- Quantum sensing & metrology
- Quantum materials & devices

Gol in 2023 announced National Quantum Mission (2023-31) to be implemented by Department of Science and Technology with focus on following domains of quantum technology -

- > Quantum Computing
- > Quantum Communication
- > Quantum Sensors and Metrology
- > Quantum Materials and Devices

Quantum technologies are based on quantum mechanics (branch of Science which explains nature at very small or very cold things.)

Overview Table

Domain	Brief Description
Quantum Computing	Utilizes quantum superposition and entanglement for enhanced processing power; qubits are the basic units.
Quantum Communication	Employs quantum principles for securely transmitting information including Quantum Key Distribution (QKD).
Quantum Sensing/Metrology	Uses quantum effects to achieve precise measurement (e.g., atomic clocks, sensors).
Quantum Materials/Devices	Develops hardware and materials supporting other quantum technologies.

Quantum Computing

Nature of Quantum Computers

- Use **qubits** (quantum bits) instead of classic binary bits.
- Qubits exploit superposition to represent both 0 and 1 simultaneously.
- Typically stored on chips **requiring extremely low temperatures** (near absolute zero, e.g., 0.1 Kelvin) to maintain their quantum state.

Technological Implementation

- Modern quantum computing laboratories (Google, IBM, Microsoft) maintain ultra-cold rooms to preserve qubit coherence.
- Achieving temperatures very close to 0 Kelvin is essential, as any heat disrupts fragile quantum states.

Differences from Classical Computing

- Classical (super and normal) computers use binary bits and standard programming languages.
- Quantum computers necessitate entirely new programming languages, operating systems, and algorithms due to underlying differences.

Reasons for Quantum Computers

Limits of Supercomputers

- Certain problems—especially those involving complex encryption or the simulation of molecular/atomic behavior—are intractable for even the most advanced supercomputers.
- While supercomputers excel at many tasks, quantum computers can outperform them for specific scenarios.

Data Storage and Processing Table

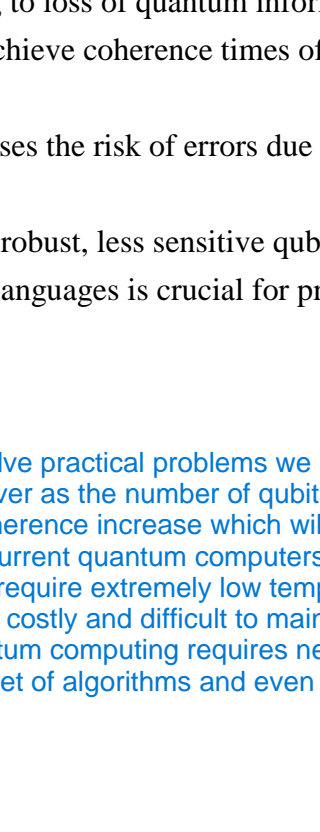
Classical Computer	Quantum Computer
Uses bits (0/1)	Uses qubits (0, 1, both in superposition)
Binary programming	Quantum-specific algorithms
Deterministic	Probabilistic, superposed

Applications

- **Breaking Encryption:** Quantum computers can efficiently break certain modern encryption algorithms (e.g., via Shor's algorithm) that rely on mathematical problems like prime factorization.
- **Public Key Cryptography:** Current encryption methods, such as those using large primes for keys, are rendered vulnerable by quantum computation.
- **Quantum Key Distribution (QKD):** Provides a method for theoretically unbreakable key exchange, alerting parties of any eavesdropping.
- **Post-Quantum Cryptography:** Research is underway to develop algorithms secure against attacks from quantum computers.
- **Simulation of Atoms and Molecules:** Can simulate molecular and atomic interactions with potential applications in new material design, drug and fertilizer discovery, and pesticide development.
- **Additional Potential Domains:** May outperform supercomputers in supply chain optimization, climate modeling, financial forecasting, and advanced artificial intelligence.

Challenges in Quantum Computing

- **Decoherence:** Qubits are highly sensitive to environmental disturbances such as heat, electromagnetic radiation, and cosmic rays, leading to loss of quantum information.
- **Coherence Time:** Quantum computers currently achieve coherence times of 5-6 seconds, requiring computations to finish within this period.
- **Scaling Issues:** Increasing the number of qubits raises the risk of errors due to increased interactions.
- **Hardware and Software Ecosystem:** Developing robust, less sensitive qubits along with specialized hardware, software, and programming languages is crucial for practical quantum computing.



To solve practical problems we need lakhs or millions of qubits however as the number of qubits increase the chances of decoherence increase which will lead to errors in calculation. The current quantum computers based on superconducting qubit require extremely low temperature very close to 0 kelvin this is costly and difficult to maintain. Quantum computing requires new programming languages, new set of algorithms and even new skills.

Summary Table of Quantum Computing Concepts

Challenge	Explanation	Current Status
Decoherence	Qubits lose information due to environmental noise	Major obstacle
Coherence Time	Limited window for error-free computation (5-6 secs)	Actively being extended
Scaling Qubits	More qubits equal more errors due to increased interactions	Not yet resolved
Specialized Ecosystem	New hardware, software, and languages are required	In early phases

Quantum Communication

Fundamentals

- Utilizes quantum principles for secure information transfer.
- Main applications include Quantum Key Distribution (QKD) and quantum teleportation.

Quantum Key Distribution (QKD)

- Allows two parties to generate a shared, random secret key for encryption and decryption.
- Eavesdropping inevitably disturbs the quantum state, making interception detectable.
- Offers security even against attacks from quantum computers.

Quantum Teleportation

- Transfers only the *state* of a qubit between two locations using entanglement, not the physical qubit itself.
- Does not allow faster-than-light communication.
- Utilizes quantum entanglement for instantaneous state transfer.

Quantum Sensing and Metrology

Metrology

- Refers to the science of precise measurement (distinct from meteorology, which concerns weather).
- Essential for all experimentation and scientific advancement.

Applications

Atomic Clocks

Clock Type Mechanism		Accuracy Impact
Quartz Clocks	Uses vibration of quartz crystals for timing	Subject to aging and environmental effects
Atomic Clocks	Measures frequency of electron transitions in cesium or rubidium atoms (quantum basis)	Extremely high accuracy, vital for GPS and scientific purposes

- Atomic clocks define one second based on a fixed frequency of radiation emitted during specific atomic transitions.
- Uniformity of atomic behavior across the universe enables precise global synchronization (e.g., for GPS satellites).

Quantum Sensors

- Allow measurements of magnetic and gravitational fields with exceptional accuracy.
- Capable of detecting minor changes in the Earth's gravity or magnetic field.

Quantum Magnetometers and Sensors

- Used for location, navigation, and physiological measurements due to their exceptional precision.

Quantum Materials and Devices

- Foundational components required for quantum computers, quantum communication hardware, and quantum sensors/metrology equipment.
- Advancements in this domain enable progress across all areas of quantum technology.

National Quantum Mission: India's Objectives

Main Goals (as per DST)

- Develop intermediate-scale quantum computers with 50 to 1,000 physical qubits.
- Establish satellite-based secure quantum communication, including two systems up to a 2,000 km range.
- Achieve quantum key distribution between cities.
- Advance sensitive quantum sensors such as magnetometers and atomic clocks.

Key Terminology

- **Physical Qubit:** Representation of a quantum bit in hardware; the basic building block.
- **Logical Qubit:** A cluster of physical qubits functioning together for increased reliability in computation.

Current Technologies and Developments

- Recent advances by tech giants (Google, Microsoft) include new quantum chips and advanced qubit types.
- Claims of practical error correction and new qubit architectures are under evaluation for their impact on overcoming coherence and error challenges.

Topic to be Discussed in the Next Class

- **Artificial intelligence:** Comprehensive exploration of its foundations, technologies, and applications.
- **Blockchain technology and cryptocurrencies:** Technical overview and contemporary relevance in ICT.