



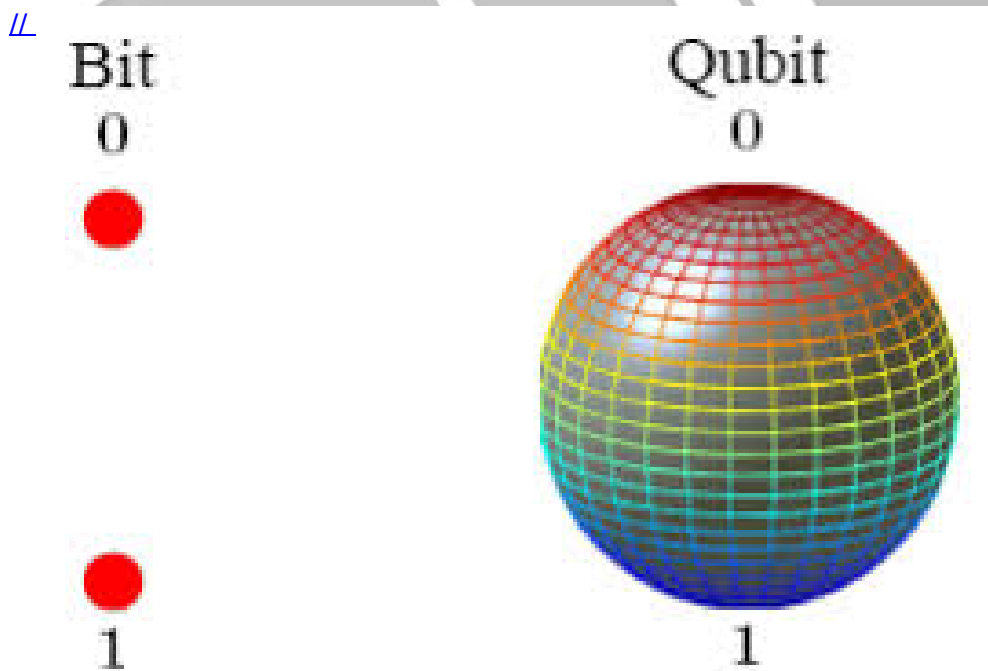
## Quantum Technology

**For Prelims:** [Quantum Computing](#), [National Quantum Mission](#), Centre for Development of Telematics (C-DOT), I-HUB Quantum Technology Foundation, Centre for Development of Advanced Computing (C-DAC), [Internet-of-Things](#), [Machine Learning](#)

**For Mains:** Significance of Quantum Computing, India's Initiative in Quantum Computing- Related Challenges, Opportunities and Way Forward

### What is Quantum Technology?

- **About:**
  - [Quantum computing/technology](#) refers to a **class of technologies** that **leverage the principles of quantum mechanics to perform computations** and achieve capabilities not possible with traditional technology.
- **Conventional Vs Quantum Computing:**
  - **Conventional Computing:**
    - **Conventional computing** processes information in "**bits**," which represent **either a 1 or a 0** at any given time, operating under the **principles of classical physics**.

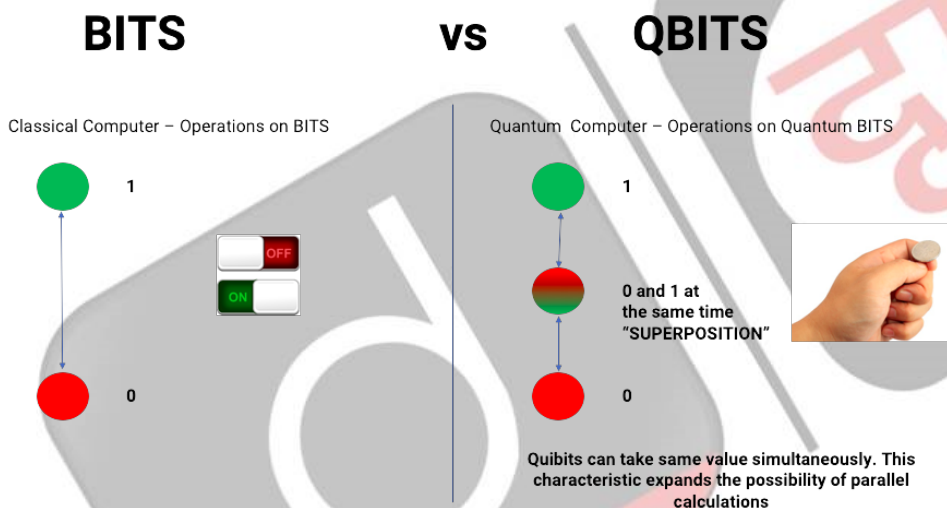


- **Quantum Computing:**

- Quantum computers **operate using "qubits" (quantum bits)**, which determine the behavior of matter at the atomic scale.
- These exhibit **probabilistic behavior**, enabling them to **achieve tasks beyond the scope of traditional technologies**, while **classical systems follow deterministic laws**.

#### ▪ Key Features:

- **Superposition:** Qubits can exist in a state of quantum superposition, meaning they can **represent both 1 and 0** simultaneously.
  - This unique property allows quantum computers, in theory, to perform computations as if multiple classical computers are working in parallel.
  - For instance, a coin in mid-air represents both heads and tails simultaneously until it lands. Similarly, an electron can exist in a quantum superposition until measured.
- **Entanglement:** Entanglement occurs when **two qubits exist in a shared quantum state**, such that a change in the state of one qubit instantaneously affects the other, regardless of the distance between them.
  - Albert Einstein referred to this phenomenon as **"spooky action at a distance."**
- **Decoherence:** Decoherence is the process in which **quantum particles and systems can decay, collapse or change**, converting into **single states** measurable by classical physics.
- **Interference:** Quantum interference allows particles (such as qubits) to be in multiple positions simultaneously due to superposition.
  - A single particle, like a photon, can interfere with its own trajectory, altering its path predictably.



### What are the Key Applications of Quantum Technology?

#### ▪ Pharmaceuticals:

- Quantum computers can **simulate molecular behavior, accelerating the development of life-saving drugs and treatments**.
- It aids in **studying protein folding**, with potential applications in treating diseases like [Alzheimer's](#) and [Parkinson's](#).

#### ▪ Chemistry:

- Quantum particles can enhance chemical processes, such as **improving catalysts for petrochemical alternatives and reducing harmful emissions**.
- These are also crucial for **developing high-temperature superconductors**.

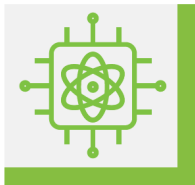
#### ▪ Improving Advanced Technologies:

- Quantum materials are used in **advanced technologies** such as **energy-efficient devices, solar cells, batteries, and healthcare diagnostics**.
  - Quantum materials are substances that exhibit **unique and complex properties at the quantum level**. These materials are characterized by their behavior, which

is governed by **quantum mechanics**.

- **Example:** Fluorescent quantum dots aid in multicolour bioimaging and cellular protein labelling, **QLED (Quantum Dot Light Emitting Diode)**
- **Enhancing Machine Learning:**
  - Quantum computing can **enhance machine learning** by developing **innovative algorithms** that **analyze complex data patterns** beyond the reach of traditional methods.
  - Quantum algorithms can **optimize AI models, accelerating tasks and reducing energy consumption**.
- **Disaster Management:**
  - **Tsunamis, drought, earthquakes** and **floods** may become more predictable with quantum applications.
  - The collection of data regarding **climate change** can be streamlined in a better way through quantum technology.
- **Secure Communication:**
  - China's quantum communications satellite, **Micius, launched in 2016**, became the world's first to demonstrate secure quantum communication links between ground stations and satellites.
  - This advancement is crucial for **satellites, military, and cybersecurity**, offering the potential for **ultra-fast computing and unhackable communication**, ensuring **high levels of security** for users.
- **Quantum Cryptography:**
  - Quantum cryptography **strengthens cybersecurity** by **creating encryption that is theoretically unbreakable**, safeguarding sensitive data from the decryption capabilities of future quantum computers.

Three key quantum use cases: Computing, communication, and sensing



#### Quantum computing

Quantum computing solves advanced computational problems by leveraging quantum phenomena to process information and make calculations.

Enterprise use of quantum computers is expected to ramp up over the next several years, likely growing dramatically within a decade with the appearance of fault-tolerant quantum machines.



#### Quantum communication

Quantum communication creates secure, theoretically tamper-proof communication networks that can detect interception or eavesdropping.

Several quantum communication networks either have been deployed or are in progress, but it likely will be several years before they can overcome the unpredictability of quantum particles.



#### Quantum sensing

Quantum sensing devices provide higher responsiveness, accuracy, and performance than conventional sensors, due to the nature and sensitivity of subatomic particles.

Quantum sensors are available today for limited production use cases and their availability and capability likely will increase substantially within five to 10 years.

Source: Deloitte analysis.

## What is Quantum Mechanics?

- **About:**
  - Quantum mechanics is a **fundamental theory in physics** that describes the **behavior of matter and energy** at **very small scales**, such as **atoms and subatomic particles**.
  - It **differs significantly from classical physics**, which governs the behavior of objects at **macroscopic scales**.
  - Quantum mechanics **provides the framework for understanding phenomena that**

cannot be explained by classical physics.

▪ **Applications:**

- **Quantum Computing:** Exploiting superposition and entanglement to perform computations at speeds unimaginable with classical computers.
- **Quantum Cryptography:** Providing theoretically unbreakable encryption methods using the principles of quantum mechanics.
- **Quantum Sensors:** Enhancing measurement precision beyond classical limits, with applications in medical imaging, navigation, and environmental monitoring.
- **Quantum Simulation:** Allowing the simulation of complex quantum systems to study chemical reactions, material properties, and biological processes.

## What is the National Quantum Mission?

▪ **About:**

- The **National Quantum Mission (NQM)** is an initiative of the Government of India which aims to **advance scientific and industrial research in Quantum Technology (QT)**, fostering **economic growth** and establishing India as a global leader in **Quantum Technologies and Applications (QTA)**.
- It is administered under the **Ministry of Science & Technology** and set to be implemented from **2023 to 2031**.
- With the launch of this mission, India will be the seventh country to have a dedicated quantum mission after the **US, Austria, Finland, France, Canada and China**.

▪ **Key Objectives:**

- **Development of Quantum Computers:** Create intermediate-scale quantum computers with **50-1000 physical qubits over 8 years**, using platforms like **superconducting** and photonic technologies.
- **Secure Communications:**
  - Satellite-based secure quantum communication between ground stations over 2000 km within India.
  - Long-distance secure quantum communications with other nations.
  - Inter-city quantum key distribution over 2000 km.
  - Establishment of a multi-node quantum network with quantum memories.
- **Quantum Sensing and Metrology:**
  - Development of **high-sensitivity magnetometers** and **atomic clocks** for precision timing, communications, and navigation.
- **Quantum Materials and Devices:**
  - The mission supports designing quantum materials like **superconductors and topological materials** for quantum devices, and developing **single-photon sources, detectors, and entangled photon sources** for quantum applications.

▪ **Establishment of Thematic Hubs (T-Hubs):** Set up 4 T-hubs in top academic and national R&D institutes in the domains of:

- **Quantum Computing**
- **Quantum Communication**
- Quantum Sensing & Metrology
- Quantum Materials & Devices

# NATIONAL QUANTUM MISSION

Aims to put India among the top six leading nations involved in the R&D in quantum technologies

Presently, R&D works in quantum technologies are underway in the US, Canada, France, Finland, China and Austria

- Duration: 2023-24 to 2030-31
- Nodal Ministry: Ministry of Science & Technology
- Highlights of the Mission:
  - Four Thematic Hubs (T-Hubs) in different domains across the country
  - Wide-scale applications ranging from healthcare and diagnostics, defence, energy and data security
  - Strengthening of indigenously building quantum-based computer
  - Help develop magnetometers with high sensitivity in atomic systems and atomic clocks
  - Support design and synthesis of quantum materials

A huge boost to National priorities like digital India, Make in India, Skill India, Stand-up India, Start-up India, Self-reliant India and SDGs

## Quantum Technology

Works by using the principles of quantum mechanics (the physics of sub-atomic particles), including quantum entanglement and quantum superposition

**Quantum Superposition**

The ability of a quantum system to be in multiple states simultaneously

While digital computers store data as bits (the ones and zeros of binary), quantum computers use qubits that exist as one, zero or both at the same time

This superposition state creates a practically infinite range of possibilities, allowing for fast simultaneous and parallel calculations

**Quantum Entanglement**

It means the two members of a pair (Qubits) exist in a single quantum state

If you change the properties of one of them, the other changes instantly

This can be used to create a secure encryption key in quantum cryptography

If an eavesdropper tries to intercept the transmission, the entangled state of the particles will be disturbed, making the attempt detectable



## Initiatives Related to Quantum Technology in India

- Quantum Lab:** The Indian Army established the **Quantum Lab** at the Military College of Telecommunication Engineering in Madhya Pradesh to lead research and training in quantum technologies.
- QuEST Initiative:** The Department of Science and Technology launched the **QuEST (Quantum-Enabled Science and Technology) initiative** to develop research facilities for quantum technology.
- QSimToolkit:** An indigenously developed toolkit, QSimToolkit, enables researchers and students to **learn and understand quantum computing**, facilitating skill development in quantum coding and hardware design.
- Centre for Development of Telematics (C-DOT):** C-DOT has developed **Quantum Key Distribution (QKD)** products and continues to pursue research in quantum communication.
- Private Sector Involvement:** Tech giants like **Google and International Business Machines (IBM)** have dedicated programs in India for quantum computing, while Indian **startups** such as **BosonQ, QRDLab, and QpiAI** are working on quantum-based applications.
- I-HUB Quantum Technology Foundation:** The Department of Science and Technology, along with 13 research groups from IISER Pune, launched the **I-HUB Quantum Technology Foundation** to promote the growth of quantum technologies.

### Note:

- The **United Nations (UN)** has decided to observe the year **2025** as the **International Year of Quantum Science and Technology (IQST)**.

## What are the Challenges in Adoption of Quantum Technology in India?

- **Regulation and Standards:** Currently, there is **absence of standards for quantum hardware, software, and communication interfaces** to ensure compatibility and interoperability.
  - Also, there is no clear **intellectual property** ownership and licensing frameworks.
- **Infrastructure Issues:** Building and maintaining advanced labs, specialized equipment, and high-performance computing facilities **demand substantial resources**.
  - **Continuous infrastructure upgrades** are essential for progress.
- **Scalability and Technical Challenges:** **Scaling quantum systems to hundreds or thousands of qubits** while maintaining coherence and minimizing error rates remains a significant challenge.
  - Quantum computers need **extremely low temperatures** to preserve **qubits' quantum states**, as higher temperatures cause increased atomic movement, leading to decoherence and loss of quantum properties.
- **Limited R&D Investment:** **India's Gross Expenditure on R&D (GERD)** stands at **0.64% of its Gross Domestic Product (GDP) (as of 2020-21)**, which is **low compared to developed economies** like the US, South Korea, and China.
  - Additionally, the **private sector contributes around 36% to R&D**, lagging behind advanced nations like the US and China where private investment is over 70%.

## Way Forward

- **Encourage Private Investment:** Encourage private sector participation through **tax incentives, grants, and public-private partnerships** to boost quantum R&D investment.
- **Promote Regional Infrastructure Development:** **Allocate resources** to develop quantum research facilities across India, ensuring wider regional participation and talent distribution.
- **Establish a Dedicated Regulatory Body:** Set up a **central body to regulate quantum technologies**, draft relevant policies, and ensure their effective implementation.
- **Facilitate Technology Transfer:** Strengthen mechanisms to **bridge the gap between academic research and commercialization**, enabling private companies to leverage advanced quantum technologies.
- **Strengthen IPR Framework:** Develop **clear and efficient frameworks** for the ownership, licensing, and transfer of quantum-related intellectual property, promoting innovation and collaboration.

## UPSC Civil Services Examination Previous Year Question (PYQ)

### Prelims

**Q. Which one of the following is the context in which the term "qubit" is mentioned?**

- (a) Cloud Services
- (b) Quantum Computing
- (c) Visible Light Communication Technologies
- (d) Wireless Communication Technologies

**Ans: (b)**

### Mains

**Q. "The emergence of the Fourth Industrial Revolution (Digital Revolution) has initiated e-Governance as an integral part of government". Discuss. (2020)**

