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VISIONIAS
INSPIRING INNOVATION

Quantum Technology *in India*: *Exploring the possibilities ahead*

Introduction

Quantum technologies are among the most exciting and rapidly developing emergent technologies of the 21st century. It is expected that numerous commercial applications would emerge from the theoretical constructs which are developing globally in this field. Thus, countries who achieve an edge in this field may have a greater advantage in garnering multi-fold economic growth and dominant leadership role across the globe. This was one of the reasons why the **Government of India declared quantum technology as a "mission of national importance" in 2019,** which led to great deal of public and private investment going into the relevant core and applied research.

Given the pivotal role it is expected to play, it becomes important to first understand the basics of Quantum technology: What it means and what are the scientific principles related to it? What are the potential applications of Quantum technology and how are these applications expected to transform the human world? Further, we will examine why is it paramount for India to focus on Quantum technology? What measures have been taken in India to strengthen Quantum industry? What are the challenges associated with its development and use in India? What needs to be done further to facilitate a Quantum revolution in India? In this edition, we will attempt to answer these questions.

What is Quantum technology and and what are the main scientific principles related to it?

- Quantum technology is an emerging field of physics and engineering powered by the principles **defined by quantum mechanics.**
  - Quantum mechanics is a subfield of physics that explains the **nature and behaviour of matter and energy on the atomic and subatomic level.** Phenomena exhibited by such microscopic particles (like photons, electrons etc.), also known as quantum particles, are quite distinct from the way normal macroscopic objects behave.
- The goal of quantum technologies is to **control or manipulate properties of such particles to build computers and other technologies** that can substantially outperform the capabilities of our current technology.
- Two most crucial principles of quantum mechanics utilised for this transformation are-

Did you know?

In physics, a **quantum is the smallest possible discrete unit of any physical property.** It usually refers to properties of atomic or subatomic particles, such as electrons, neutrinos and photons.

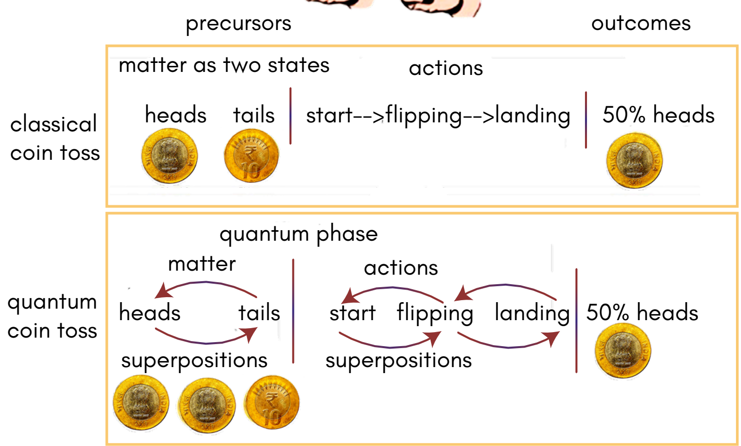
Superposition

It is the ability of a quantum particle to be in multiple states at the same time until it is measured.

Understanding the principle

Coin Toss

Let's say you are flipping the coin. If during the flip you were able to look at a coin and see both heads and tails at the same time, as well as every state in between, the coin would be in superposition. It is only when the coin lands that you will see either heads or tails.



Or

Schrödinger's Cat Experiment

The physicist Erwin Schrödinger stated that if you place a cat and something that could kill the cat (for e.g. a radioactive atom) in a box and sealed it, you would not know if the cat was dead or alive until you opened the box. So, until the box was opened, the cat was (in a sense) both "dead and alive".

Entanglement

It refers to a situation in which two or more quantum particles are linked in such a way that it is impossible for them to be described independently but measurements from one particle can be used to instantly draw conclusions about the others.

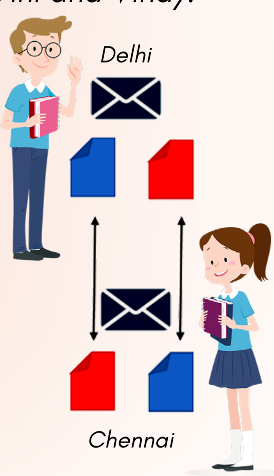
Did you know?

Entangled quantum particles separated by incredible distances seem to interact with each other instantaneously, even faster than the speed of light. Therefore, Albert Einstein famously described entanglement as **"spooky action at a distance."**

Understanding the principle

Entangled envelopes

Let's say we have two pieces of paper, one blue and one red. We put each paper into its own envelope and give the envelopes randomly to Vini and Vinay. Both are then sent to different locations, say Vinay to Delhi and the Vini to Chennai. They are both told that if they have the blue paper, the other has the red, and vice versa. Now, it could be said that as soon as Vinay opens his envelope, he will know not only the colour of his paper but also, instantaneously, the colour of Vini's paper and vice versa. So, we can say that both papers are entangled.



Or

Ordering takeaway at a fast food joint

If you order both a burger and a grilled cheese sandwich, you don't know which is which before opening the boxes. But as soon as you open one, you immediately know what's in the other without looking.

This is true regardless of how far away the second box is. It can therefore be said that both boxes are entangled.

Myth Busters!

Myth 1: We are currently witnessing a Quantum revolution for the first time.

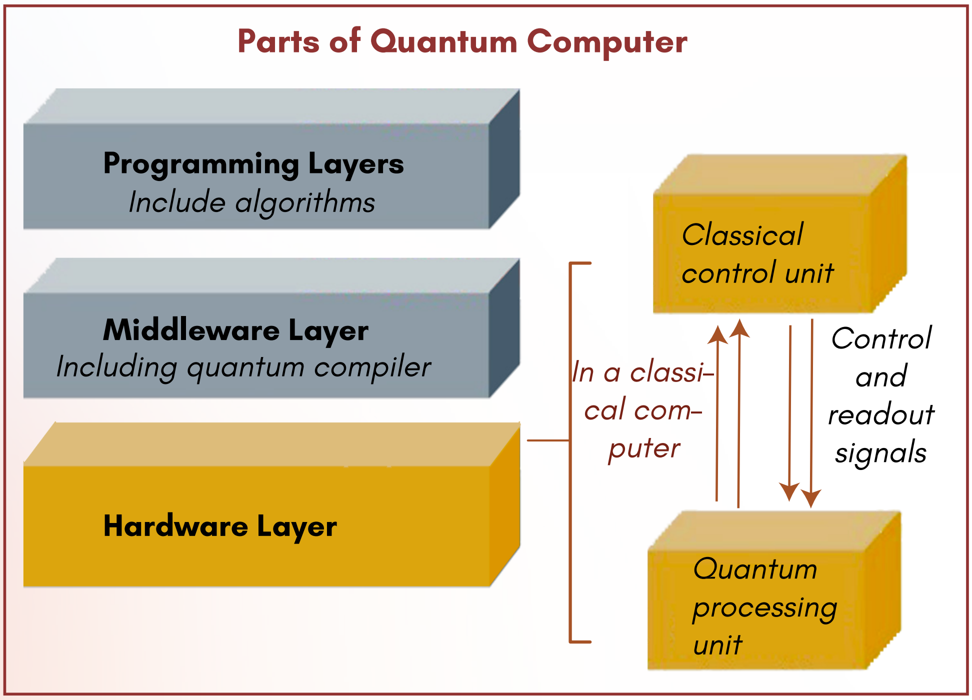
Fact: The world is presently observing a second wave of quantum revolution. The first quantum revolution occurred at the turn of the last century. It was based on the fundamental idea of wave-particle duality: in particular the idea that matter particles sometimes behaved like waves, and that light waves sometimes acted like particles. By the end of the 20th century, this first revolution of quantum mechanics had evolved into many of the core technologies underpinning modern society like Transistors, Magnetic Resonance Imaging (MRI) scanners, Lasers, LEDs among others.

What are the potential applications of Quantum technology?

Currently, the technological developments in this field are in nascent stages, meaning they have no proven practical applications. But in the future, Quantum technology is expected to open up new frontiers with wide-spread applications, especially in the domains of computing, communications, simulation and sensing.

Quantum Computing

- Quantum computers harness the unique behaviour of quantum mechanics and apply it to computing. This introduces new concepts to traditional programming methods and allows for a quantum computer to **perform a multitude of applications at the same time,** at a much faster rate, surpassing the processing ability of a conventional computing system.
- **Quantum computing use qubits** as its the basic unit of information instead of binary bits (0 and 1) used by classical computers.



- Due to their ability to solve complex problems, such computers are expected to have widespread applications in the field of aero-space engineering, numerical weather prediction, drug development, advanced manufacturing, health, agriculture, education etc.

Myth Busters!

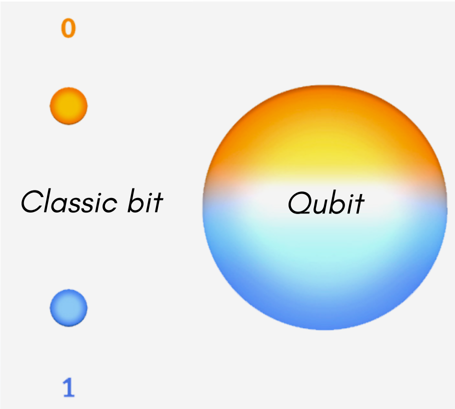
Myth 2: Quantum Computing will mean the end of normal computing.

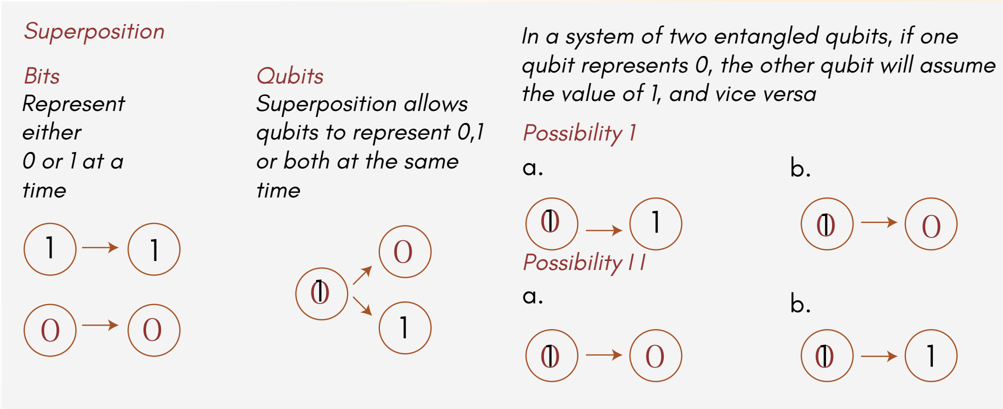
Fact: Quantum computers aren't being developed to take over normal computers. It's more accurate to think of them as a new kind of technology designed to carry out high-precision, specialized activities. For everyday use activities ranging from streaming high-definition videos to writing this article- quantum computers remain largely useless as of now.

Pondering Ahead

What are Qubits and how they differ from binary bits?

- **Qubits are typically subatomic particles** such as electrons or photons, while **a bit represents a stream of electrical or optical pulses** representing 1s or 0s.
- They play a similar role in quantum computing as bits play in classical computing, but they behave very differently.
- While **bits can hold only a position of 0 or 1, qubits can hold a superposition of all possible states.**





- The above shown properties of Qubits and a connected group of them can provide way more processing power than the same number of binary bits.

Quantum communication

Quantum communication applies the laws of quantum mechanics to data protection. It uses quantum bits, typically photons of light, for transmitting data along optical cables. Following are the most common technologies of quantum communication which are in different stages of development-

- **Quantum key distribution:** QKD is a secure communications technology that enables two parties to share random secret keys that are known only to them and can be used to encrypt or decrypt messages.
  - It involves sending encrypted data as classical bits over networks, while the keys to decrypt the information are encoded and transmitted in a quantum state using qubits.
  - A remarkable feature of QKD is that it can **detect if a third party tries to eavesdrop** on a communication link.
- **Quantum Random Number Generation (QRNG):** Random numbers are mainly used as seed in cryptosystems (cryptographic algorithms needed to implement a particular security service such as encryption) to generate keys. The strength of these keys depends on randomness of the input.
  - QRNG detects random quantum events and converts those into a stream of binary digits. Quantum mechanics has the inherent potential of providing true random numbers and thus has become the preferred option for scientific applications requiring randomness.

Quantum simulation

A quantum simulator is a specially designed quantum computer constructed for the purpose of **simulating materials or chemical reactions of the physical world.**

- Simulation allows new processes or properties to be explored as a tool to know the outcomes before the actual materials are designed or the chemical processes are conducted.
- Possible applications of quantum simulation include drug design, superconducting materials, complex molecular formations etc.

Quantum sensing and metrology

- Quantum sensing aims to use individual particles such as **photons and electrons** as sensors in current technologies related to measurements of forces, gravitation, electric fields etc.
  - It exploits quantum superposition and/or entanglement to detect minute changes in information and achieve a **higher sensitivity and resolution in such measurements.**
- Further, Quantum sensing and metrology can be used to develop Quantum clocks, an upgraded version of present atomic clocks used for keeping time with extreme accuracy.

Other applications that lie ahead: A peek into the world of ongoing Quantum research

- **Quantum internet:** In simple terms, it will involve sending qubits across a network of multiple quantum devices that are physically separated. Such an internet would be able to transmit large volumes of data across immense distances at a rate that exceeds the speed of light and achieve ultra-secure communications.
- **Quantum Teleportation:** Quantum teleportation is a technique for transferring quantum information from a sender at one location to a receiver some distance away. The particles themselves are not really teleported, but the state of one particle is destroyed on one side and extracted on the other side, so the information that the state encodes is communicated.
  - While teleportation is portrayed in science fiction as a means to transfer physical objects from one location to the next, quantum teleportation only transfers quantum information so as to achieve secure communication.

How are these applications expected to transform the human world?

Various applications of Quantum Technology have been envisioned to bring disruptive changes in modern day technologies with widespread impacts in the different fields and sectors. Most of these impacts will facilitate enhanced efficiency in human activities, but there are some foreseeable risks a well.

How Quantum technology will be beneficial to humans?

- **Solving complex problems:** Quantum computers will exponentially increase the processing capabilities of a modern-day computer enabling them to **analyse large data sets more accurately** and thus **solve complex problems** (problems with lots of variables interacting in complicated ways). This, in turn, will seed breakthroughs in several fields such as-
  - **Machine learning and artificial intelligence (AI):** Faster machine learning to augment AI solutions.
  - **Financial services:** Improve financial forecasting, deeper analytics, faster trading possibilities, more accurate risk assessments, ultra-secured transactions etc.
  - **Weather Forecasting:** Enhancing weather system modelling allowing scientists to predict the changing weather patterns in no time and with excellent accuracy.
  - **Logistics:** Improved data analysis and robust modelling to optimise logistics and scheduling workflows associated with supply-chain management such as traffic management, fleet operations, air traffic control, freight and distribution.
  - **Energy:** Solving challenging large-grid data optimization issues, providing high-fidelity sensing etc.
  - **Scientific research:** Derive solutions to problems in fields like mathematics, physics, chemistry etc. that cannot be solved using conventional computers due to their complexity, thereby supporting new discoveries in science.
  - **Others-** Big data analysis of unstructured data searches, development of superconductors, pharmaceutical research, efficient design of aircraft, buildings, cars etc.

- **Improved geological mapping and exploration:** Powerful quantum sensors can be used to measure local variations in gravitation to find minerals, water or embedded pipelines and develop advanced warning systems for earthquakes and volcanic eruptions.
- **Combating Cybersecurity threats:** Quantum networks can potentially enable un-hackable communications, enhancing privacy and security of personal and other confidential data across the globe.
- **Improvement in positioning, navigation and timing:** Higher precision of the quantum clock will increase the accuracy of positioning and navigation.
- **Improved medical diagnosis and care:** Quantum simulators will allow the discovery and design of new drugs, and quantum imaging can enable biological processes mapping, 3-D mapping of individual protein molecules etc. Such interventions can be used to provide **non-invasive and accurate diagnosis and development of personalised medicine.**

Pondering ahead

What role can quantum computers play in Climate change mitigation and adaptation?

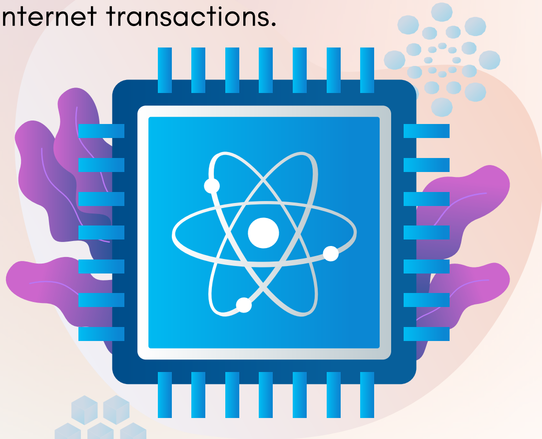
Quantum computers can potentially help to solve some of the grand challenges of climate change, like-

- Accelerating the discovery of new CO_2 catalysts that would ensure efficient carbon dioxide recycling whilst producing useful gasses such as hydrogen and carbon monoxide.
- Helping meteorologists to generate and analyse more detailed climate models and provide greater insight into climate change and its impacts and ways to adapt to or mitigate it.
- Creating more efficient batteries or fertilisers.
- Optimizing traffic flows in a city to minimize traffic jams and wasted fuel for automobiles.

Further, they will help in reducing carbon emissions as the technologies that are used to build Quantum computers take much less power than the transistors used in today's classical computers.

What are the associated risks pertaining to Quantum technology?

- **Threat of Quantum warfare:** Quantum technology is a **dual-use technology** with potential application in both defence and commercial production. Thus, misuse of its military applications can threaten national security, especially for countries lagging behind.
- **Quantum attacks on data being transported by the current communication infrastructure:** Quantum computers will start to become powerful enough to pose a threat to most of the public key encryption schemes and could theoretically crack much of the encryptions used to secure e-mails and other internet transactions.



Pondering ahead

What are the potential Military applications of Quantum technology?

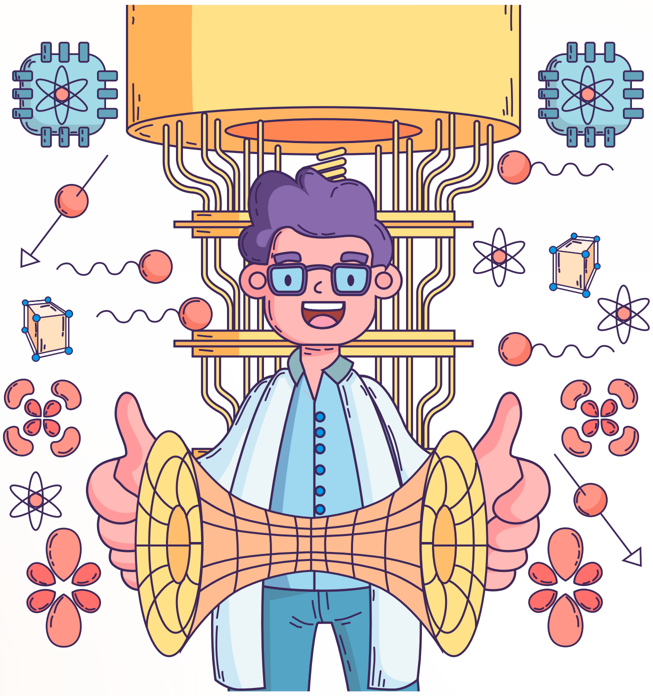
- Quantum metrology can help create **new forms of cameras, radars, etc., which can provide more capable means of acquiring new intelligence data,** detecting everything from-stealth aircraft (quantum RADAR) to submarines (quantum ghost imaging) to underground facilities (quantum gravimetry).
- Quantum AI tools can provide **autonomous weapons and mobile platforms,** such as drones, **with heightened sensing, navigation, and positioning options in GPS-denied areas.**
- Quantum computing can be used to **intercept and easily break codes of Defence communication lines** of other countries if they have not deployed quantum-safe encryption.

- Without quantum-resistant security solutions, all regulations and laws regarding privacy, data management etc. would be nearly impossible to uphold.

- **Environmental risk:** The fabrication/manufacturing of materials/ resources and chips for quantum computers might pose certain risks to the environment such as pollution from mining, overextraction etc.
- **Monopolization:** Due to the high cost and technical expertise associated with quantum computers, only a handful of actors will be able to build them, and hence there is a risk of monopolization of quantum technologies.
- **Ethical concerns** such as human DNA manipulation, development of intrusive AI, unequal access to benefits and applications to developing nations, deprioritization of socially beneficial use cases in favour of applications that confer a competitive or geostrategic advantage to a particular group etc.

Quantum technology is therefore envisaged to bring dramatic and innovative advancements in the field of medicine, finance, energy, transportation, communication, disaster management and even climate change. But these advancements come along with the threats of its hostile use.

Why is it paramount for India to focus on Quantum technology?



- **Staying ahead of the disruption:** Quantum computing is among the emerging and most disruptive technologies, expected to re-write the world economic order. It has become imperative both for government and industries to be prepared to achieve a beginner's edge in this emerging field.
- **National security:** Adversarial use of quantum computers can put the present-day encryption at risk, which can pose a threat to a country's critical cyber infrastructure, financial and private data and confidential military and strategic information, thereby, putting its national security at stake.
- **Potential threat from China:** Researchers in China have already claimed to achieve quantum supremacy and constructed a 15-user quantum secure direct communication network. Due to the dual use nature of the technology, such advancements pose geopolitical risks to India's national security.
- **Boost translational research:** By promoting advanced research in quantum science and technology, technology development and higher education in science, technology and engineering disciplines in India can be brought at par with other advanced countries.
- **Foster economic growth:** As a part of overall growth, India can also become an important market for quantum R&D, software development, and equipment manufacturing. Quantum tech can add up to $310 billion to the Indian economy by 2030 (Nasscom report).
- **Drive societal progress and improve the overall quality of life:** Quantum technology can play a revolutionary role in fields like health, energy, industry, innovation and infrastructure, helping India to raise its living standards and achieve sustainable development goals.
- **Encourage entrepreneurship and start-up ecosystem development:** The transition of quantum science and technology from a field of research to its application in day-to-day life is the opportune moment that provides the space for many startup companies to form and develop.

In Conversation!

What does quantum supremacy mean?

Vini: *Hey Vinay! How are you? What's that book you're reading there?*

Vinay: *Hey Vini! It's one of the books from The Feynman Lectures on Physics series.*

Vini: *Oh! Yes, I've heard about them. What's it about?*

Vinay: *This one is about Quantum mechanics.*

Vini: *Interesting! I didn't know you were interested in Quantum mechanics. This reminds me, I recently heard that some Chinese scientists have claimed that they have achieved Quantum supremacy. So, can you tell me what that exactly means?*

Vinay: *Sure. First let me ask, do know anything about supercomputers?*

Vini: *Yes. They are extremely powerful computers with very high-level computational capacities. They are specifically designed to solve complex scientific and industrial challenges.*

Vinay: *Correct. So, imagine a computer that is able to perform computations nearly 100 trillion times faster than the world's most advanced supercomputers and can even solve problems that remain out of their reach.*

Vini: *Is it even possible?*

Vinay: *Well not with our classical computers. But several scientists are presently trying to develop quantum computers which can solve complex problems that a classical computer, even the most powerful supercomputers, cannot. For a quantum computer to demonstrate this ability is described as quantum supremacy.*

Vini: *Thanks for explaining Vinay!*

What measures have been taken in India to strengthen quantum industry?

Government of India is reportedly planning to develop a quantum computer with about 50 qubits by 2026. To accomplish this task and promote overall developments in the field, the Government has taken several steps like-

- **National Mission on Quantum Technologies & Applications (NMQTA):** The mission was announced in the 2020 budget speech with a total budget outlay of Rs 8000 Crore for a period of five years to be implemented by the Department of Science & Technology (DST).
  - It aims to develop quantum computers with highly secured quantum communication, quantum key distribution (QKD), quantum clocks, sensors, imaging devices, and with startup collaboration.
- **Several labs and centres were setup to facilitate research in different domains. For instance:**
  - Indian Army set up a quantum computing laboratory and an AI centre at a military engineering institute at Mhow, Madhya Pradesh, backed by the National Security Council Secretariat (NSCS).
  - Defence Institute of Advanced Technology (DIAT) and the Centre for Development of Advanced Computing (C-DAC) agreed to collaborate and develop quantum computers.
  - DST and about 13 research groups from IISER Pune launched **I-HUB Quantum Technology Foundation (I-HUB QTF)** to further enhance the development of quantum technology.
  - MeitY established a **Quantum Computing Applications Lab** in collaboration with Amazon Web Services (AWS) to facilitate quantum computing-led research and development.
  - Raman Research Institute (RRI) in Bengaluru has joined hands with the Indian Space Research Organisation (ISRO) to develop the quantum technologies that ISRO's satellites would need.

- **Quantum-Enabled Science and Technology (QuEST) initiative:** It was launched by DST to invest INR 80 crores to lay out infrastructure and to facilitate research in the field.
- **Quantum Frontier mission** of the Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC) aims to initiate work in the understanding and control of quantum mechanical systems.
- **QSim – Quantum Computer Simulator Toolkit**: It was launched by the Ministry of Electronics and Information Technology (MeitY) to allow researchers and students to write and debug Quantum Code that is essential for developing Quantum Algorithms and carry out research in in the field in a cost-effective manner.

Features of QSim

Pre-loaded Quantum algorithms and Examples
- It comes loaded with Quantum programs and algorithms providing a head start to the users. E.g. QFT, Deutsch Jozsa, Grovers etc.

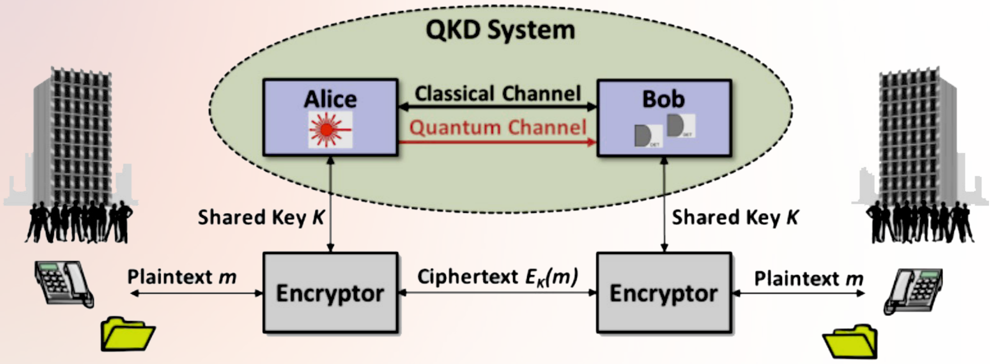
Intuitive User Interface (UI)
- It allows students / researchers to create Quantum programs, visualize the instant circuit generation and simulated outputs.

Simulate noisy Quantum logic circuit
- Helps simulate Quantum circuits with and without noise and test how well various algorithms work with imperfect quantum components in real-life conditions.

Integrated with High Performance Computing (HPC)
- The quantum simulations are performed on powerful HPC resources allowing multiple users to submit jobs simultaneously with different QuBit configurations.

Dedicated efforts have led to the following achievements in India-

- A team of scientists from DRDO and IIT Delhi successfully demonstrated the **Quantum Key Distribution (QKD) link between Prayagraj and Vindhyachal**, Uttar Pradesh, a distance of more than 100 kilometers.
- ISRO has successfully demonstrated **free-space Quantum Communication over a distance of 300 m.**



- The DRDO Young Scientist Laboratory for Quantum Technologies (DYSL-QT), a DRDO facility based in Mumbai, has successfully **developed a Quantum Random Number Generator.**

What are the challenges associated with development and use of Quantum technology in India?

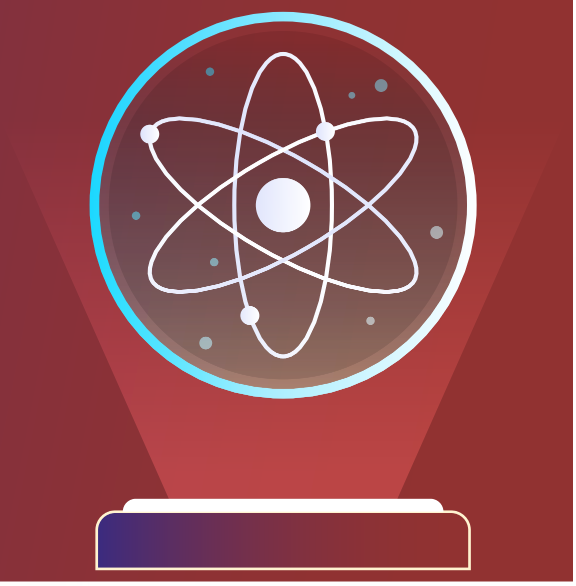
- **Loosely built research ecosystem:** A comprehensive multi-stakeholder research network is amiss in India with limited participation of private sector. Further, country's expenditure on research and development (R&D) remains low compared to competing nations such as China and U.S.A.
  - Out of approximately 100 projects in quantum technologies initiated in India, about 92% are government sponsored.
- **Lack of clarity on goals:** Metrics to assess the outcomes of India's quantum efforts are not clearly defined. It is not clear whether India will focus on near-term quantum applications or long-term applications or both.
- **Human resource gap:** India has a small pool of skilled professionals in the realm of quantum technology.
- **Unstructured research:** In the absence of a common platform, at present, research is carried out in silos and knowledge exchange is not structured.
- **Absence of indigenous development of critical quantum components** such as superconducting materials, physical qubits, a data plane, chips, processors, and fabrication labs.
- **Industry-academia gap:** Most quantum-related research and development is carried out at university campuses. Industry connect is essential for developing them into scalable applications.
- **Other issues:**
  - Low patent applications in India.
  - Lack of set of common standards, principles, and protocols for global governance of quantum technologies.
  - Limited participation in international collaborations.
- **Inherent Technological challenges associated with Quantum technology:**
  - **Achieving and maintaining quantum superposition and entanglement long enough to complete a task is difficult:** Quantum states of superposition and entanglement are extremely fragile and without the right temperature and environmental conditions, they lose their qualities quickly and behave erratically. This process is known as **decoherence.**
    - This is why quantum computers are shielded electromagnetically and cooled down to almost absolute zero, which is quite costly to maintain.
  - **Upscaling the number of qubits on a processor chip:** Like a traditional computer's bit processor (i.e., 32-bit or 64-bit processor), quantum computers need qubit processors with hundreds or even millions of qubits to complete complex computations accurately. Controlling such a large number of qubits is a difficult task.
  - **Need of special infrastructure:** Building quantum communication links for long distances will need a special infrastructure to safeguard the information and limit disturbances, such as quantum routers, etc.
  - **Quantum attacks:** A fully quantum internet may ultimately become vulnerable to new attacks that are themselves quantum based.

What needs to be done further to facilitate a Quantum revolution in India?

- **Creation of a dedicated quantum community:** Entrepreneurship, innovation, university courses, scholarships, training programmes etc. will be crucial towards developing a knowledge ecosystem and bridging the skill gap.
  - It will also help create crucial intellectual property (IP) infrastructure that can be used for the country's benefit.
- **Dedicated centres for research:** Establishing centres of excellence dedicated to quantum science and technology within academic institutions as well as government research institutes.
- **Setting priorities to safeguard national security:** It is essential to develop cryptographic systems (also known as post-quantum cryptography) that are secure against both quantum and classical computers, and can interoperate with existing communication protocols and networks.
- **Effective coordination between the central and state governments:** Establishment of "quantum innovation hubs" in partnership with selected state governments can help direct investments efficiently and also serve as centres of collaboration between academia and the private sector.
- **Focussing efforts on translating research into real-world applications:** For this purpose, India can harness the power of Quantum tech corporations and startups and Big Tech corporations based in India.
  - For instance, several Indian startups such as QNu Labs, BosonQ, and Qulabs.ai are doing remarkable work in developing quantum-based applications for cryptography, computing, and cybersecurity.
- **Facilitating International cooperation:** It is imperative for India to win critical technology transfer deals, get external technical advice or mentoring, and establish state-of-the-art facilities for joint R&D on quantum technologies. For this, the government can engage with its allies in key groupings such as Quad and BRICS.
- **Promoting domestic manufacturing facilities and units for development of quantum components:** For instance, support can be provided to market players through production-linked incentive schemes like the Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors.
- **Revisit and rework National policies:** For instance, Quantum warfare will require an update, modification or creation of new military doctrines, military scenarios and plans to develop and acquire new technologies and weapons for the quantum age.
  - Further, ethical guidelines will be needed to prevent misuse of such technologies.

Conclusion

The quantum technology ecosystem in India is growing, led by government intervention, academic participation, service providers, and the startup community. With a solid research base and workforce founded on significant and reliable government support, it can lead to the creation of innovative applications by industries, stimulation of economic growth, and creation of potential solutions for complex and currently unsolvable human problems.



TOPIC-AT-A-GLANCE

Quantum technology
An emerging field of physics and engineering powered by the principles **defined by quantum mechanics** which is a subfield of physics that explains the nature and behaviour of matter and energy on the atomic and subatomic level.

Scientific principles utilised for Quantum Technologies

Superposition: Ability of a quantum particle to be in multiple states at the same time until it is measured.

Entanglement: A situation in which two or more quantum particles are linked in such a way that it is impossible for them to be described independently but measurements from one particle can be used to instantly draw conclusions about the others.

Potential applications of Quantum technology

Quantum Computing: Uses qubits (typically subatomic particles) as its the basic unit of information instead of binary bits.

Quantum simulation: Specially designed quantum computer constructed for the purpose of simulating materials or chemical reactions of the physical world.

Quantum communication: Uses quantum bits, typically photons of light, for transmitting data along optical cables. Includes technologies like- Quantum key distribution and Quantum Random Number Generation (QRNG).

Quantum sensing and metrology: Uses individual particles such as photons and electrons as highly sensitive sensors in current technologies related to measurements of forces, gravitation, electric fields etc.

Expected impacts of emerging Quantum Technologies on Human World

Predicted Benefits

- **Solution to complex problems:** seeding breakthroughs in fields like- Machine learning and artificial intelligence, Financial services, Weather Forecasting, Logistics, Energy, Scientific research etc.
- **Improved geological mapping and exploration.**
- **Combatting Cybersecurity threats** with un-hackable communications.
- **Improved medical diagnosis and care.**
- **Solving grand challenges of climate change adaptation and mitigation.**

Predicted Risks

- **Threat of Quantum warfare** linked with potential military applications of quantum technologies.
- **Quantum attacks on data being transported by the current communication infrastructure.**
- **Environmental risk** associated with building Quantum computers and its components.
- **Monopolization of quantum technologies** by a few actors.
- **Ethical concerns** such as human DNA manipulation, development of intrusive AI etc.

Significance of Quantum technology for India

- **Staying ahead of the disruption** and achieving a beginner's edge in this emerging field.
- **Preparing for tackling National security risks** posed by adversarial use of quantum computers.
- **Boosting Translational research.**
- **Fostering economic growth** by developing market for quantum R&D, software development, and equipment manufacturing.
- **Driving societal progress and improving the overall quality of life** enabled by applications of Quantum technology.
- **Encouraging entrepreneurship and start-up ecosystem development.**

Measures taken in India to strengthen quantum industry

- **National Mission on Quantum Technologies & Applications (NMQTA)** with a total budget outlay of Rs 8000 Crore.
- **Quantum-Enabled Science and Technology (QuEST) initiative**
- **QSim – Quantum Computer Simulator Toolkit**
- **Quantum Frontier mission**
- **Setting up of dedicated labs and centres** like quantum computing laboratory and an AI centre at a military engineering institute at Mhow, Madhya Pradesh, Quantum Computing Applications Lab established by MeitY etc.

Constraints faced by India

- **Loosely built research ecosystem** with limited participation of private sector.
- **Lack of clarity on goals.**
- **Small pool of skilled professionals in the field.**
- **Unstructured research** and absence of a common platform.
- **Absence of indigenous development of critical quantum components.**
- **Industry-academia gap** hindering translation of research into scalable applications.
- **Other issues:** Low patent applications, Lack of protocols for global governance, Low international collaborations etc.
- **Inherent Technological challenges:**
  - **Difficulty in achieving and maintaining quantum superposition and entanglement** long enough to complete a task is due to decoherence.
  - **Challenges in upscaling the number of qubits on a processor chip.**
  - **Need of special infrastructure.**
  - **Threat of Quantum attacks.**

Way Forward

- **Creation of a dedicated quantum community** through Entrepreneurship, innovation, university courses, scholarships, training programmes etc.
- **Establishing dedicated centres for research.**
- **Setting priorities to safeguard national security** such as investing in post-quantum cryptography.
- **Effective coordination between the central and state governments.**
- **Focussing efforts on translating research into real-world applications.**
- **Facilitating International cooperation.**
- **Promoting domestic manufacturing facilities and units for development of quantum components.**
- **Revisit and rework National policies** like military doctrines, ethical guidelines etc.