India’s Quantum Leap

This editorial is based on **“Our Quantum Leap”** which was published in The Indian Express on 19/05/2023. It talks about the significance of Quantum Materials and technology and talks about the Significance of National Quantum Mission.

For Prelims: **National Quantum Mission**, Quantum Technology,.

For Mains: National Quantum Mission and its role in developing Quantum Technology, Quantum Technology: Application, Challenges and Way Forward.

India is getting serious about building her own technology base and **National Quantum Mission** could be a game changer in multiple sectors, from defence, energy, and environment to healthcare and civil applications. Any technology is first devised and then thrives on material innovation, and quantum technology is no exception.

For India, investments in quantum materials and devices promise far more dividends than meets the eye. The process can generate a cadre of highly skilled workforce. As India gears to become the world’s third-largest economy by 2027, a strongly networked material infrastructure in the country will be crucial. It will cater to not just quantum technologies but also other major scientific megaprojects ranging from the semiconductor mission to neutrino observatory and gravitational wave detection. The infrastructure will play a key role in building self-reliance in energy and electronics industries.

What are Quantum Materials?

- Quantum materials are a class of matter or systems that allow us to exploit some of the unique properties of quantum physics and accomplish tasks that classical technology is incapable of.
- The concept of “quantum materials” was originally introduced to identify some of the exotic quantum systems, including unconventional superconductors, heavy-fermion systems, and multifunctional oxides.
- It has now morphed into a powerful unifying concept across diverse fields of science and engineering, including solid state physics, cold atoms (atoms cooled to close to absolute zero whereby their quantum mechanical properties are unveiled), materials science and quantum computing.

What are the applications of Quantum Materials?

- **Energy:** Quantum materials can be used to create **new types of batteries, solar cells, and other energy-efficient devices.** For example, graphene, a two-dimensional material made of carbon atoms, has been shown to have excellent electrical conductivity, which could make it a promising material for use in batteries.

    - Graphene is a one-atom-thick layer of carbon atoms arranged in a hexagonal lattice. The electrons in graphene behave as massless particles, which gives graphene its unique properties, such as high electrical conductivity and transparency.
- **Biomedical:** Quantum materials can be used to **create new types of medical devices, such as sensors and imaging devices.** For example, quantum dots can be used as fluorescent probes for bioimaging and biosensing of cells and tissues.
- **Information Technology:** Quantum materials can be used to create new types of computers and other information technology devices. For example, **quantum computers**, which are based on the principles of quantum mechanics, could be used to solve problems that are currently impossible for traditional computers to solve.
- **Defence:** Quantum materials can be used to create new types of weapons and defence systems. For example, quantum sensors could be used to detect and track enemy missiles, and quantum computers could be used for enhanced security.
- **Agricultural:** Quantum materials **can also enhance agricultural productivity, quality, and security** by exploiting quantum effects such as biosensing, bioimaging, and nano delivery. For example, quantum dots can be used as biosensors for detecting pathogens and toxins in crops and livestock.

What is National Quantum Mission?

- **About:**
    - It'll be implemented by **the Department of Science & Technology (DST)** under the Ministry of Science & Technology.
    - The mission **planned for 2023-2031** aims to seed, nurture, and scale up scientific and industrial R&D and create a vibrant & innovative ecosystem in **Quantum Technology (QT).**
    - 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.
- **Salient features of NQM:**
    - It will target developing **intermediate scale quantum computers with 50-100 physical qubits in 5 years and 50-1000 physical qubits in 8 years.**
        - Just like bits (1 and 0) are the basic units by which computers process information, **'qubits' or 'quantum bits' are the units of process by quantum computers.**
    - The mission **will help develop magnetometers** with high sensitivity for precision timing (atomic clocks), communications, and navigation.
    - It will also support design and synthesis of quantum materials such as **superconductors, novel semiconductor structures** and topological materials for **fabrication of quantum devices.**
    - The mission will also help developing:
        - **Satellite based secure quantum communications** between ground stations over a range of 2000 km within India.
        - **Long distance secure quantum communications** with other countries
        - **Inter-city quantum key distribution** over 2000 km
        - **Multi-node Quantum network** with quantum memories
- **Significance:**
    - This will **accelerate QT led economic growth** and make India one of the leading nations in the development of Quantum Technologies & Applications (QTA) ranging from healthcare and diagnostics, defence, energy and data security.
    - It will work towards **indigenously building quantum-based computers which are far more powerful** and are able to solve the most complex problems in a highly secure manner.

What are the Challenges associated with Quantum Materials?

- **Bioaccumulation**: Quantum materials may pose health and environmental risks due to their

potential toxicity and bioaccumulation. For example, quantum dots made of heavy metals such as cadmium or lead may cause oxidative stress, inflammation, and DNA damage in living cells and organisms.

- **Complex & Expensive:** Quantum materials **may also be expensive and difficult to synthesize, purify, and characterize due to their complex structure and composition**. They require high-temperature and high-pressure reactions, multiple purification steps, and sophisticated analytical techniques.
- **Security**: Quantum materials may also pose security and ethical challenges due to their potential applications in cryptography, surveillance, and warfare. For example, quantum computers may be able to break existing encryption schemes, quantum sensors may be able to detect stealth aircraft, and quantum weapons may be able to cause mass destruction.
- **Societal:** Quantum materials may also have societal implications due to their impact on human cognition, communication, and culture. For example, quantum-powered artificial intelligence may be able to surpass human intelligence.
- **Quantum Decoherence**: This can be a major challenge for quantum computing and other applications that rely on quantum mechanics. For example, quantum dots may lose their fluorescence or change their color due to oxidation, aggregation, or photobleaching.
    - **Quantum decoherence** is the process by which quantum information is lost due to interactions with the environment.

What should be the Way Forward?

- **Enhance the Investment:** Quantum technology requires substantial investment in research and development, infrastructure, and human resources to achieve its full potential.
    - India has taken a step in this direction by launching the **National Quantum Mission** with a budget of Rs. 6000 crores.
    - However, more public and private funding is needed to support the growth of quantum start-ups, service providers, and academic institutions.
- **A Regulatory Framework is a must:** Quantum technology also poses ethical, legal, and social challenges that need to be addressed before it becomes widely available. For example, quantum sensing may infringe on privacy rights, and quantum weapons may cause mass destruction.
    - Therefore, it would be prudent to develop a regulatory framework for quantum technology that balances innovation and security.
- **Promote Quantum Education:** Quantum technology also requires skilled and trained professionals who can understand and apply its principles and methods. Therefore, it is essential to promote quantum education and awareness among students and researchers across various disciplines.
    - This can be done by introducing quantum courses in schools and colleges, organizing workshops and seminars, and creating online platforms and resources.
- **Collaboration among Various Stakeholders:** For better understanding of Quantum technology, it is required to have a proper collaboration and cooperation among various stakeholders, such as government agencies, industry players and institutions.
    - This can foster knowledge sharing, innovation, and standardization across different domains and applications of quantum technology.
    - It can also enable India to participate in global initiatives and networks on quantum technology.

Drishti Mains Question:

The government has recently launched the National Quantum Mission. Discuss the significance of the mission and the challenges it faces.