5. Quantum Mechanism- Science & Technology

For semiconductors and GPS, thank C V Raman, Satyendra Nath Bose, Einstein — and hay fever in 1925. UNESCO has declared 2025 the International Year of Quantum Science and Technology to commemorate 100 years of quantum mechanics, specifically honoring Werner Heisenberg's 1925 Helgoland breakthrough. The initiative aims to highlight the field's evolution from theoretical physics to practical applications like quantum computing, sensing, and secure communication, while addressing challenges like decoherence and scalability.

International Year of Quantum Science and Technology (2025)

1. Context and Significance

Global Declaration- UNESCO has officially declared 2025 as the International Year of Quantum Science and Technology.

Significance- It marks exactly 100 years since the formal development of quantum mechanics began in 1925.

Commemoration- The year specifically honors the "Helgoland breakthrough" by Werner Heisenberg, which established the mathematical foundations of modern quantum theory.

Quantum Mechanics

Definition- It is the branch of physics that explains the behavior of matter and energy at atomic and subatomic scales.

Core Departure- It represents a fundamental shift away from classical Newtonian physics.

Key Principles

1. **Quantisation of Energy-** Energy is not continuous but exists in discrete packets.
2. **Wave–Particle Duality-** Objects exhibit characteristics of both particles (tiny pieces of matter) and waves (energy transfer disturbances).
3. **Uncertainty Principle-** There are precision limits when measuring pairs of physical properties simultaneously.
4. **Superposition-** A phenomenon where objects can exist in multiple states simultaneously until measured.

3. Domains of Quantum Technologies

(Comparison of distinct functionalities)

Domain	Description & Primary Utility
Quantum Communication	Uses quantum physics properties to ensure superior security and improve long-distance communication systems.
Quantum Simulation	Uses a controllable quantum system to simulate the behavior of another complex quantum system (e.g., for chemical interactions).
Quantum Computation	Utilizes quantum mechanics to perform specific calculations vastly more efficiently than classical computers.
Quantum Sensing & Metrology	Leverages quantum principles to achieve highly precise measurements of physical quantities.

4. Evolution of Quantum Theory (Timeline)

1. 1900 (Max Planck)- Proposed that energy is emitted in discrete packets called quanta (explaining black-body radiation).
2. 1905 (Albert Einstein)- Used quantum theory to explain the photoelectric effect, establishing that light consists of photons.
3. 1913 (Niels Bohr)- Applied quantum ideas to explain the structure of the hydrogen atom.
4. 1925 (Werner Heisenberg)- Formulated matrix mechanics during his stay at Helgoland; considered the first complete framework of quantum mechanics.
5. 1925–26 (Max Born & Pascual Jordan)- Provided the mathematical foundation using matrix algebra.
6. 1926 (Erwin Schrödinger)- Developed the wave equation, offering an alternative but equivalent formulation.

7. 1927 (Paul Dirac)- Unified quantum mechanics and relativity, describing it as a complete theory of dynamics.

5. Indian Contributions to Quantum Theory

Satyendra Nath Bose- His work led to the prediction of the Bose–Einstein Condensate. This state of matter was experimentally confirmed decades later.
C V Raman- Discovered the Raman Effect in 1928. Provided direct experimental proof of quantum interactions between light and matter. Earned India its first Nobel Prize in science in 1930.

6. Application of Quantum Technology

Electronics & Computing- Serves as the foundation for semiconductors, transistors, integrated circuits, and modern computers.
Communication & Navigation- Forms the basis of lasers, optical fiber, atomic clocks, and GPS systems.
Healthcare- Used in MRI scanners, nuclear imaging, radiation therapy, and advanced diagnostics.
Energy & Materials- Supports nuclear power generation and the development of advanced materials and sensors.
Emerging Technologies- Driving future quantum computing, ultra-secure data transmission, and precision sensing.

7. National Quantum Mission (NQM)

Approval- Approved by the government in 2023 for the period 2023-24 to 2030-31.
Aim- To seed, nurture, and scale up scientific/industrial R&D to create a vibrant Quantum Technology (QT) ecosystem.
Key Objectives- Develop intermediate-scale quantum computers with 50-1000 physical qubits in 8 years. Focus on platforms like superconducting and photonic technology.
Implementation- Setting up four Thematic Hubs (T-Hubs) in top academic and National R&D institutes.

8. Challenges and Way Ahead

Challenges

Decoherence- Quantum states are highly sensitive to the environment, leading to instability and loss of information.
Measurement & Control- Precise manipulation is difficult due to noise and the fragile nature of quantum states.
Scalability & Error Correction- Expanding systems for practical use requires complex mechanisms to correct errors.
Cost- Technologies are currently expensive and resource-intensive.

Way Ahead

1. **Strengthen Research-** Ensure sustained public funding for fundamental research.
2. **Capacity Building-** Develop skilled human resources through specialised courses and global collaboration.
3. **Public–Private Partnerships-** Encourage startups and industry participation to scale prototypes into commercial products.

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