Macroscopic Quantum Tunnelling

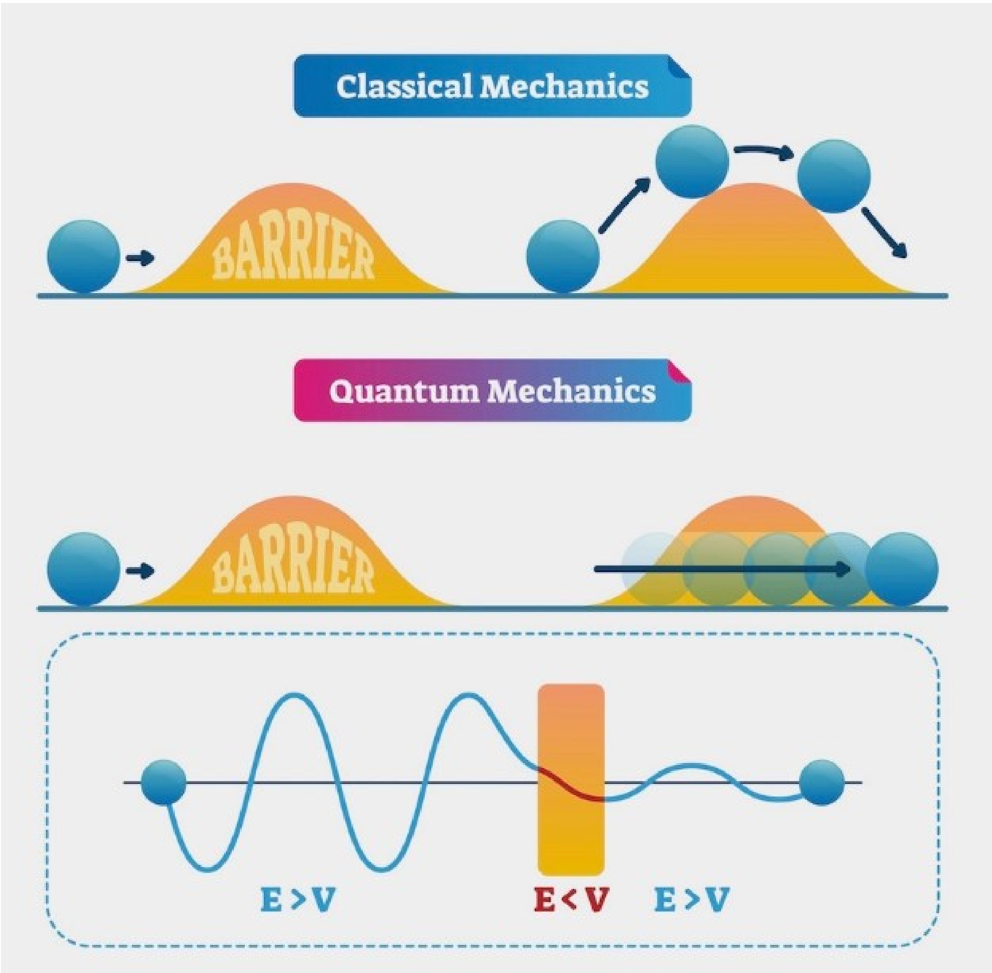
Mains: *GS III – Science and Technology*

Why in News?

Recently, The Nobel Prize in Physics 2025 is out, and the winners are John Clarke, Michel H Devoret, and John M. Martinis, for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit.

What is quantum tunnelling?

- **Quantum tunnelling** – It says that particles can sometimes cross barriers they don't have the energy to climb, like boring through a mountain instead of scaling it first.



- This process, called tunnelling, is common in nuclear and atomic physics.
- **Occurrence –** Such behaviour can occur not only in subatomic particles but also in an

electrical circuit made of superconductors.

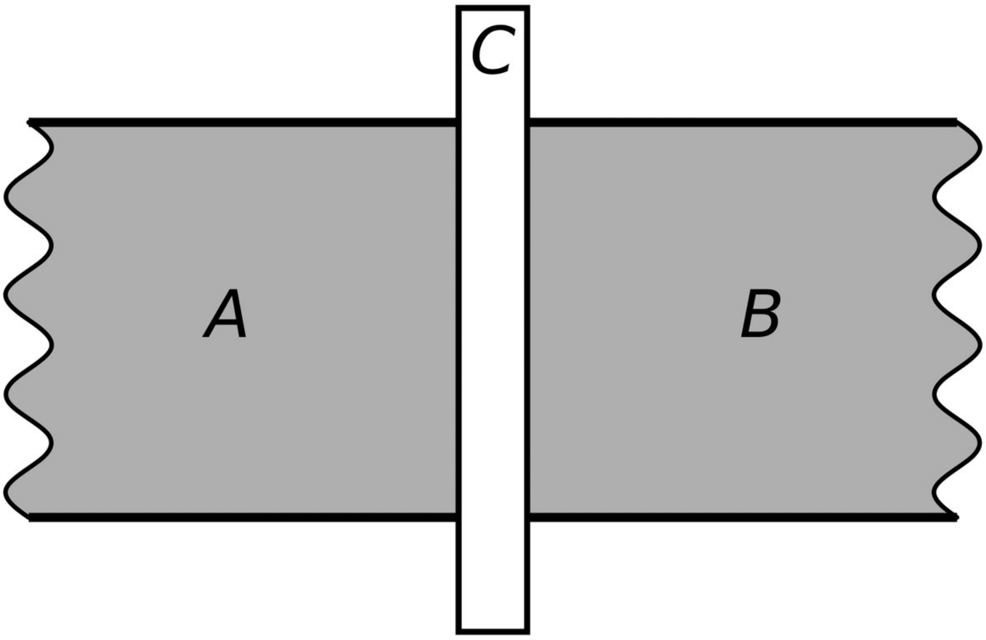
- **Prospects of the research** – The finding opens the door to new technologies set to transform the way we collect, study, understand, and use information from our surroundings.

The 2025 physics Nobel Prize laureates *– John Clarke, Michel Devoret, and John Martinis.*

- The scientists trio conducted the using a device called *josephson junction*.

What is a Josephson junction?

- **Components** – Here, two superconductors A and B are separated by a very thin insulator C.



- **Objective of the experiment** – The trio wanted to know if a parameter of the circuit as a whole, in this case the junction's phase difference, could behave like a single quantum particle.
- **Observations** – They came away from their experiments with a resounding 'yes', by observing both macroscopic quantum mechanical tunnelling and discrete energy levels in the circuit.
    - **Superconductors** – Here, many electrons pair up and move without resistance.
    - **Josephson junction** – Here, the relevant variable is the phase difference of the superconducting order parameter.
- Put differently, the superconducting order parameter is a macroscopic variable that trillions of electron pairs in the material share and which describes the state the system is in.
- **Prediction of the theory** – Theory predicts that the current through the junction depends on the value of the parameter, and that it evolves in time according to the voltage across the junction.

- When the scientists sent a current through the Josephson junction, they found that if it was small enough, the flow of paired electrons was stalled and the circuit produced no voltage.
    - **In classical physics** – This state would never change, where the electrons' flow would remain blocked.
    - **But in the quantum world** – The current has a small chance of suddenly tunnelling out of the trap and flowing freely on the other side, creating a measurable voltage.

Why was the circuit fragile?

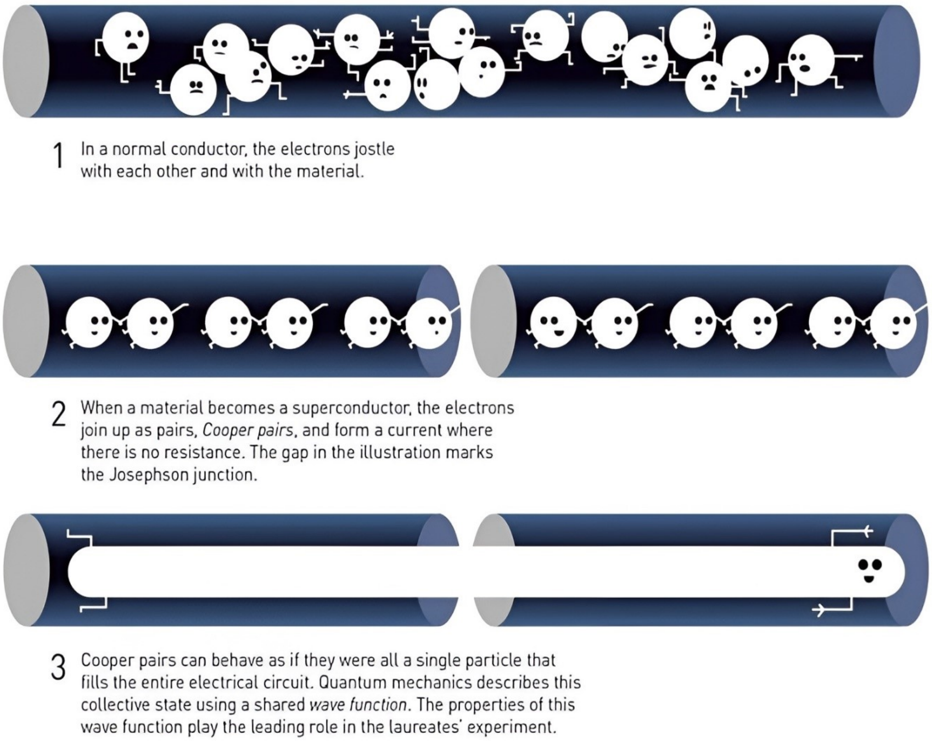
- **Investigation for tunneling** – In the early 1980s, several groups searched for this tunnelling by varying the current and recording the value at which the junction produced a voltage.
- If the electron pairs were simply escaping to the other side due to thermal fluctuations — akin to being heated enough to jump across the mountain — cooling the device ought to steadily increase the amount of current required to produce a voltage.
- On the other hand, if the electron pairs were tunnelling through, the rate of crossing over would eventually stop changing with temperature.
- **The challenge** – It was in keeping stray microwave radiation from affecting the circuit and producing data consistent with the temperature-independent behaviour.
- So the experimenters needed to reduce and characterise environmental noise with great care.
- The Berkeley team led by Clarke, working with Devoret and Martinis, solved this problem by redesigning their setup so stray signals couldn't interfere.
- **Blocking of microwaves** – They used special filters and shielding to block unwanted microwaves and kept every part of the experiment extremely cold and stable.
- **Directing the microwave pulses** – Then they sent in faint yet precisely tuned microwave pulses to gently test how the circuit responded, allowing them to measure its electrical properties accurately.
- **Matching of behavior** – When they finally cooled the system to very low temperatures, they saw that its behaviour matched the exact patterns predicted by quantum tunnelling theory.

How did the circuit show quantum effects?

- **Behaviour of a circuit** – The researchers also wanted to find out if the circuit's trapped state behaved like a quantum system with distinct energy steps which is a hallmark of a quantum state instead of a smooth range.
- They shone microwaves of different frequencies onto the junction while adjusting the current.
- **Escape of the circuit** – When the frequency exactly matched the gap between two allowed energy levels, the circuit suddenly escaped more easily from its trapped state.
- The higher the level, the faster this escape happened.
- **Conclusion** – These patterns showed that the circuit's overall state could only receive or emit fixed packets of energy, which is also how a single particle following the rules of quantum mechanics would behave.

- In short, *the circuit as a whole behaved like an atom.*
- **Facts revealed by the results** – Put together, the results revealed 2 facts.
  - A macroscopic electrical circuit — one that you could see with the naked eye, that could display quantum behaviour when sufficiently isolated from its environment.
  - The relevant macroscopic coordinate in that circuit could be understood using the standard tools of quantum mechanics.

Process Inside a Semiconductor



What are the applications of the research?

- **Applications in Quantum computing** – Quantum computers is something the scientific world is very excited about.
- **Prospects for India** – India, too, in 2023 set up a Rs 6,000 crore National Mission on Quantum Technologies and Applications.
- When fully operational, these computers will be able to solve problems conventional computers struggle with.
- The Nobel laureates' work is a big step in taking quantum computers from a great idea to actually helpful devices.
- **Quantum computers** - These are not just faster than normal computers, they are useful for a whole different kind of complex problems.
  - **For example**, quantum computers can model molecules at a quantum level, helping scientists design new drugs or materials faster, predict reactions, or optimise molecules for better performance.
- Encryption works on using a huge amount of numbers, which conventional computers struggle to get through.
- Quantum computers can break encryption faster, and thus also create more-difficult-

to-break encryption.

References

1. The Hindu| Macroscopic Quantum tunnelling

2. The Indian Express| Nobel price for physics 2025