PAVING THE WAY FOR QUANTUM COMPUTING: THE NOBEL PRIZE OF PHYSICS 2025

CREANDO EL CAMINO PARA LA COMPUTACIÓN CUÁTICA: EL PREMIO NOBEL DE FÍSICA 2025

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The foundations of quantum mechanics were laid down about 100 years ago. However, many of its non-trivial implications have taken decades to unravel.

One is the phenomenon of quantum tunneling — the ability of particles to pass straight through a barrier that should not be possible according to classical physics, given its energy. Tunneling explains radioactive decay, in which, despite being confined inside an atom, an alpha particle still has a small probability of escaping the nucleus. Another is quantum superposition, in which an object can exist simultaneously in two states. This property is crucially important for performing algorithms required for quantum computation. Both tunneling and superposition were known at the atomic scale but had not been experimentally observed in macroscopic systems. In the late 1970s, Anthony Leggett, who won the 2003 Nobel Prize in Physics for his theoretical work on superconductors, asked whether the phenomena would be observable at the macroscopic scale using superconducting circuits — loops of wire which, when chilled to a fraction of a degree above absolute zero, can conduct electricity without resistance.

The fundamental question was: would quantum mechanics be obeyed by these large systems? In the 1980s, John Clarke, Michel H. Devoret and John M. Martinis, working at the University of California (Berkeley), were among those exploring quantum effects in superconducting loops. The trio set up an experiment in which two superconductors were separated by a thin barrier, known as a Josephson junction. In this state, a supercurrent can flow with zero resistance, like a river that runs without friction — but also with zero voltage, i.e., without a downhill gradient that gives the current a push. In classical physics, the system would stay stuck like this, unless given enough energy to escape. A crude picture illustrating the electrical transport through a superconductor could be formulated like the following. Suppose that you visit a dance party. Music is playing and you are located close to a corner of the room. Starting at the corner, you cannot reach another corner without being scattered. Therefore, to stimulate conductance one should provide energy (i.e. apply finite voltage in the case of a normal conductor). The situation is different if the dancer finds a partner and dance following the music. To start, they cannot be scattered by each other. Furthermore, if all couples of dancers are synchronized to the movements of the first couple, you get a coherent system where all couples can effortlessly move around the arena –they behave similar to a superconductor!

But let us get back to actual superconducting experiments. By carefully monitoring the system, and slowly increasing the current, Clarke, Devoret and Martinis showed that the entire tiny circuit could break out into a higher energy state — by quantum tunneling, which they observed by measuring a voltage spike. This device served as a prototype of a superconducting quantum bit or 'qubit'. The fact that such large-scale objects can behave quantum mechanically is the starting point for a lot of fruitful scientific exploration in the decades since, and we are now living in an exciting era where people are starting to build quantum processors out of superconducting circuits.

Tunneling converts quantum effects into a measurable classical signal that can be used to determine a system's quantum state at the macroscopic scale. It also shows that electrical circuits, made up of trillions of electrons, could behave as single quantum object that could be manipulated by classical fields. So perhaps it is not strange that Clarke (University of California, Berkeley), Devoret (currently at Yale University in New Haven, Connecticut, and the University of California, Santa Barbara , UCSB), and Martinis (currently at UCSB) shared the Nobel Prize announced by the Royal Swedish Academy of Sciences in Stockholm on 7 October, 2025. They experimentally discovered quantum physics on a macroscopic scale, paving the way for quantum computing. Their work was a milestone for the development of superconducting quantum circuits. The research, including both the highly non-trivial phenomena of quantum tunneling and quantum superposition, has helped to underpin some of today's most advanced quantum computers.

The laureates were modest while evaluating their discovery. "I am completely stunned; it had never occurred to me in any way that this might be the basis for a Nobel Prize," said Clarke, speaking to journalists gathered for the announcement. "I think that our discovery in some ways is the basis of quantum computing" he said, adding that although he led the trio's work in the 1980s, the contributions of the other two were "overwhelming".

Today, harnessing the ability to store information in a superposition of macroscopic quantum states shows promise as a platform to create quantum computers, which could someday perform certain otherwise intractable calculations. Both Martinis and Devoret have worked at Google, the firm based in Mountain View, California, which has pioneered quantum computers using superconducting qubits. Martinis says he was very pleased by the attention the Prize has attracted. ”The real reward is to write a paper that lots of people read and refer to — and even better, that it's generated this large scientific endeavor with thousands of people working on superconducting qubits”.

The work conducting to the 2025 Nobel Prize in Physics has also a clear connection to the Nobel physics prize of 1973, where Brian Josephson, Leo Esaki and Ivar Giaever predicted and demonstrated that supercurrents can tunnel through a barrier between two superconductors. Giaever –who was directly responsible for the experimental part of the work— passed away earlier this year, and is the subject of an article later in this issue.
