From artificial atoms to quantum information machines: Inside the 2025 Nobel Prize in physics

Zhixin Wang, Postdoctoral Researcher in Physics, University of California, Santa Barbara

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This illustration shows, from left to right: John Clarke, Michel Devoret and John Martinis.

The 2025 Nobel Prize in physics honors three quantum physicists – John Clarke, Michel H. Devoret and John M. Martinis – for their study of quantum mechanics in a macroscopic electrical circuit.

Since the prize announcement, cheers and excitement have surrounded the home institutions of these laureates in Berkeley, Santa Barbara and New Haven.

The award of this prestigious prize to pioneering research in quantum physics coincides with the 100th anniversary of the birth of quantum mechanics – a revolutionary scientific theory that forms the foundation of modern physics.

Quantum mechanics was originally formulated to explain and predict the perplexing behaviors of atoms, molecules and subatomic particles. It has since paved the way for a wide range of practical applications, including precision measurement, laser technology, medical imaging and, probably the most far-reaching of all, semiconductor electronic devices and computer chips.

Yet numerous aspects of the quantum world have long remained mysterious to scientists and engineers. From an experimental point of view, the tiny scale of microscopic particles poses outstanding challenges for studying the subtle laws of quantum mechanics in laboratory settings.

The promises of quantum machines

Since the closing decades of the past century, researchers around the world have sought to precisely isolate, control and measure individual physical objects, such as single photons and atomic ions, that display quantum behaviors under very specific experimental conditions. These endeavors have given rise to the emerging field of quantum engineering, which aims to utilize the peculiarities of quantum physics for groundbreaking technological innovations.

John Clarke, an emeritus professor of physics at the University of California, Berkeley, speaks on Oct. 7, 2025, at a press conference on the campus celebrating his 2025 Nobel Prize in Physics.

Karl Mondon/AFP via Getty Images

One of the most promising directions is quantum information processing, whose goal is to design and implement machines that can encode, process, transmit and detect information in “strange” quantum manners: For instance, an object can be in a superposition of different states at the same time. Distant objects can manifest quantum entanglement – remote correlations that escape all possible classical interpretation. Compared with their conventional electronics predecessors, quantum information machines could have advantages in specific tasks of computation, simulation, cryptography and sensing.

The realization of such quantum machines would require experimenters having access to reliable physical components that can be assembled and controlled on the human scale, yet fully obey quantum mechanics. Counterintuitive as it might sound, can we break the implicit boundaries of the natural world and bring microscopic physical laws into the macroscopic reality?

Quantum mechanics in an electrical circuit

In 1985, the three Nobel laureates – then working in the same research group at the University of California, Berkeley – provided an affirmative answer to the question above. They were studying electrical circuits made of superconductors. Superconductivity is a special state of matter famous for conducting electrical currents without resistance, due to underlying quantum mechanical interactions of electrons at low temperatures. For the first time, the trio observed distinct quantum behaviors of a macroscopic physical variable.

In a superconductor, two electrons bond together to form a Cooper pair. These electron pairs condense into a macroscopic state, which can be described by a collective phase variable shared by all its microscopic constituents. In this state, trillions or more electrons effectively behave like a single entity, resembling the mass collections of atoms that form everyday objects like pendulums or billiard balls.

To observe the quantum mechanical motion of this macroscopic phase variable, the three scientists fabricated a device called the Josephson junction, which consists of two pieces of superconductors separated by an insulator layer thinner than 1/10,000 of a human hair. They discovered that, at sufficiently low temperatures (below −273 degrees Celsius, or −459 degrees Fahrenheit), the phase variable difference across the Josephson junction shows a unique quantum mechanical phenomenon known as quantum tunneling, where an object may escape a barrier without the need to climb over its summit.

Furthermore, the team exposed the Josephson junction to microwave electromagnetic radiation whose frequency is close to that of Wi-Fi signals. They measured energy levels of the circuit at discrete, or quantized, values, which are usually present only in microscopic atoms and molecules. The device used in these experiments can thus be referred to as an “artificial atom” – namely, an electrical circuit with atom-like properties, which is at once macroscopic in size, adjustable in design, and quantum mechanical in nature.

Implications and outlooks

The groundbreaking works by Clarke, Devoret and Martinis have had many profound impacts. On the fundamental level, they suggested that distinct quantum phenomena – once thought to exist only at the microscopic level – can actually manifest at much larger physical scales. In the meantime, the invention of superconducting artificial atoms has opened brand-new avenues toward building useful quantum machines with advanced engineering techniques.

Based on these discoveries, researchers – including these Nobel Prize recipients and their research groups – have made significant achievements in constructing prototype quantum computers using superconducting quantum circuits in the decades since. The elementary device unit that makes up these information processors is the superconducting quantum bit, or "qubit" for short. Each superconducting qubit is an artificial atom containing one or more Josephson junctions. Its quantum state can be precisely prepared, manipulated and measured by experimenters. The perfection and integration of superconducting qubits are among the state-of-the-art challenges in quantum information technology.

The 2025 Nobel Prize for physics recognizes original investigations in the intersection of basic and applied sciences. The prize recipients tested profound quantum mechanical hypotheses through clear and rigorous experimentation.

From those artificial atoms have emerged the audacious efforts and rapid progress in building practical quantum information machines. The combination of pure intellectual inquiries and engineering advancement has been shaping this interdisciplinary field since its creation.

This Nobel Prize is therefore a tribute to the three inventors of superconducting quantum circuits, whose inquisitive minds, broad visions and adventurous attitudes represent the true scientific spirit and will continue to inspire future generations.

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