Nobel Prize (Quantum Physics in Action)

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Several of our most transformative established technologies rely on controlling energy, electric currents, and electromagnetic waves. These physical effects are everywhere in nature, but it is when we learn to extract, control, and engineer them, and only then, that we can create technologies that shift the boundaries and what we can do. Quantum effects are also everywhere, and we do know that they govern the microscopic world for more than 100 years. However, it is only when we can extract, control, and engineer quantum effects that a whole range of possibilities will open up. Quantum technology relies on extracting the quantumness hidden everywhere in nature, enabling us once again to create a technology to push once again the boundaries of what is possible.

Quantum effects are hiding in plain sight. Quantum mechanics governs the dynamics of the world that surrounds us, and yet the most paradigmatic quantum effects including interference, tunneling and superposition do not seem to be present at our human scale. Quantum mechanics becomes unavoidably present when going to the atomic scale. And yet, at macroscopic scales, those effects are washed away, and classical physics appears. Somehow, nature has a tendency to hide quantum effects as we go to bigger scales. A crucial step to unleash quantum technologies relies on out-engineering nature, exploiting quantum materials and quantum devices in which quantum effects are not lost, but survive up to macroscopic scales.

Superconductivity is one of those examples in which a quantum effect, the coherence of the collective electron wavefunction, survives up to macroscopic scales. Superconductivity itself started as a fascinating and unexpected fundamental physical phenomena, and established a whole quantum state of matter we did not know before. Fast forward to the present, and superconductors have become a keystone of some of our most important quantum technology. Crucially, superconducting quantum materials provided a key strategy to bring quantum effects all the way up to our human scale, becoming the building blocks for controllable macroscopic qubits, and enabling the current breakthroughs in quantum detectors and quantum computers. The Nobel Prize in physics 2025 demonstrated how quantum phenomena in the microscopic world, quantum tunneling and superposition, can be brought up to our macroscopic world.

The current issue explores the path that superconducting quantum technology has taken in the last century, exploring potential future strategies to enable boundless, scalable quantum technologies. Sebastian Bergeret discusses the path that started with the discovery of superconductivty and led us to superconducting qubits, cornerstones of current quantum technology. Martin Weides explores what our current challenges in scaling quantum computers based on superconducting circuits are. Matti Silveri analyzes complementary potential strategies to create error-corrected quantum computers, scaling up quantum circuits, and improving qubits. Gianluigi Catelani and Giampiero Marchegiani discuss the role of theoretical modeling in understanding and mitigating some of the errors of conventional qubits. Finally, Antigone Marino and Paola Belardini discuss the outlook that quantum technology can provide to our future.

Unlocking quantum effects in macroscopic systems opens a door to shifting the boundaries of knowledge and technology, and what we believe to be possible and impossible. Superconducting qubits are now a central piece of quantum technology and provide a crucial building block for many strategies for quantum detection, quantum metrology, and quantum computing. Quantum materials realizing macroscopic quantum states, beyond superconductivity, can fuel the next breakthroughs in quantum technology, potentially opening subareas that we are not even aware of. Quantum technologies are in their infancy, and we yet do not understand their ultimate impact. We, however, do know one thing: its steady, rapid, and unstoppable progress will unavoidably enable us to address some of the technological and global challenges that we currently consider impossible to solve. ■