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Quantum Breakthrough awards

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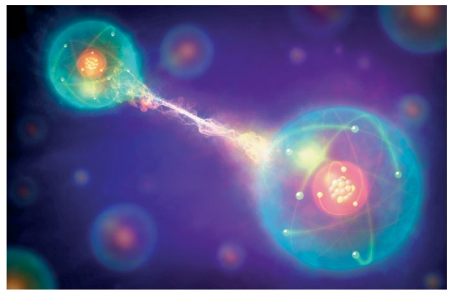
The Breakthrough Prize Foundation has awarded two prizes for pioneering theoretical and experimental research in quantum science.

Every year, the Breakthrough Prize Foundation recognizes game-changing contributions to various fields of science and technology with its highly coveted 'Oscars of Science'. One set of three prizes, the Breakthrough Prizes, are awarded in Fundamental Physics, Life Sciences and Mathematics. A second set of awards, the New Horizons prizes, typically reward early-career scientists. This year, four pioneers of theoretical quantum computation share the Breakthrough Prize in Fundamental Physics, while six early-career scientists share the New Horizons in Physics prize for the development of optical tweezer arrays to control individual atoms.

The 2023 Breakthrough Prize in Fundamental Physics has been awarded to Charles Bennett (IBM Thomas J. Watson Research Center), Gilles Brassard (Université de Montréal), David Deutsch (Oxford University) and Peter Shor (MIT) for their 'foundational work in the field of quantum information'. Long before the practical implementation of quantum protocols, the four awardees planted early theoretical seeds to make a case for quantum computation. In the 1980s, Deutsch began developing a theory of computation that would lead to the quantum generalization of a Turing machine[1], while Bennett and Brassard developed the first quantum cryptography protocol[2]. Shor's most renowned contribution is the development of quantum algorithms for prime number factorization[3]. Although these ideas were making strong cases, they were met with scepticism at the time. At a quantum computing conference in 1995 in Turin, Shor bet audiences that the first factorization of a 500-digit number would be performed by a quantum computer, rather than a classical one. Very few people shared Shor's optimism, with many attendees preferring to bet that the Sun would burn out first[4].

Now, one of the three 2023 New Horizons in Physics prize recognizes one of the most promising platforms to implement those early visions: optical tweezer arrays for the control of individual atoms and molecules. The prize has been awarded to Hannes Bernien (University of Chicago), Manuel Endres (Caltech), Adam Kaufman (JILA, National Institute of Standards and Technology and University of Colorado), Kang-Kuen Ni (Harvard University), Hannes Pichler (University of Innsbruck and Austrian Academy of Sciences) and Jeff Thompson (Princeton University).



Their contributions include a wealth of seminal experimental demonstrations of the possibilities offered by optically trapping individual atoms. Among the many contributions, some of the awardees showed the potential of optical traps for the assembly of quantum computing units by trapping, manipulating and measuring single atoms[5,6]. Optically trapped arrays of atoms are now recognized as one of the most promising platforms for the rollout of quantum computers, along with superconducting qubits and optically addressable spin centres in solids.

The importance of individual atoms and their control was articulated by Hannes Bernien, who told *Nature Photonics*: "The optical tweezer technology allows us to use individual atoms and molecules as the building blocks of large quantum systems. For instance, we use spatial light modulators to create optical tweezers for more than a thousand individual atoms." Bernien also explained: "These large quantum systems can operate as quantum simulators or processors with high fidelity control over each individual atom or molecule and the interactions between them." The possibilities offered by quantum computing were echoed by Hannes Pichler, who also emphasized the potential of such systems: "Many of the most promising applications are quantum simulations, where quantum computers will be used to understand the properties of materials, chemical compounds or models in high-energy physics."

Applications of optically trapped single atoms and molecules go beyond quantum computing, as demonstrated by the diverse pool of awardees. Their research has also contributed to a better understanding of fundamental questions about the nature of chemical reactions at ultralow temperatures[7], the role of statistical mechanics in describing quantum states[8] and quantum many-body theory. As Pichler continued to explain, the ability to control atoms with this platform is "an essential tool to build fully controlled quantum many-body systems in a 'bottom-up' approach. It enables a programmable way to engineer quantum matter with tailored properties and explore quantum many-body physics in otherwise inaccessible regimes."

Challenges remain, however. Individual atoms need to be controlled individually in large arrays. "Single atom addressing within a large array of atoms is still an outstanding challenge, especially on the fast time scales that are needed to run quantum algorithms," concluded Bernien. He also believes that nanophotonics could play an important role in addressing this need. The independent control of many individual atoms would enable scalability of the arrays, an increase in the number of qubits and, in turn, more complex computation to be performed.

All in all, although sceptics of quantum computation may have not been proven wrong (yet), recent developments would suggest that many early visions may be closer to reality than they were back in 1995. The enabling role of optics and photonics has been, and will likely continue to be, crucial in favouring the further development and deployment of quantum technologies. In a joint tribute to early thinkers and recent implementations, this year's Breakthrough prizes acknowledge pioneering contributions as well as the impact that quantum computing will have in real life.

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