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A new century of quantum physics

This month we celebrate the past and present of quantum physics and try to imagine its future.

The 1920s was a whirlpool of economic growth, emancipation and rapid social and technological change. In physics, the roaring twenties marked a break from tradition, with the birth of quantum mechanics. So far, the 2020s have been as fast-paced and turbulent. On the centennial of matter waves, we ponder where the next 100 years of quantum mechanics will take us.

In 1923, Louis de Broglie published three short contributions that would set the stage for a series of breakthroughs[1]. In the three years from 1925–1928, the foundations of quantum mechanics were laid: the exclusion principle, matrix mechanics, wave mechanics, the uncertainty principle, and Paul Dirac's relativistic wave equation. So, by 1928 the revolution seemed to be finished and the foundations of quantum mechanics laid down[1]. Not quite. It took decades to come to terms with the notion of nonlocality originally put forward as evidence for the incompleteness of quantum mechanics. In 1948, Richard Feynman came up with a third formulation of quantum mechanics (in addition to Werner Heisenberg, Max Born and Pascual Jordan's matrix mechanics and Erwin Schrödinger's wave mechanics) known as the path integral formulation.

Still, to this day quantum mechanics is not quite a finished business. Despite its extraordinary success as a workhorse theory in many areas of physics and related fields and its impact on technology (be it lasers, semiconductors or modern quantum technologies) quantum mechanics has always had a mystifying aspect. This is due to the numerous conflicting interpretations of the theory (including Copenhagen, many-worlds, QBism, and quantum Darwinism, to name a few[2]), solved and unresolved paradoxes (the EPR paradox, Schrödinger's cat or Wigner's friend), open questions such as what the nature of quantum measurement is or how it leads to the emergence of the classical world and the missing quantum theory of gravity.

Today, physicists are in a good place to start demystifying quantum mechanics. On the applied side, there are state of the art technologies that enable extraordinary experiments as discussed in two Reviews: one on single-photon applications and on one quantum teleportation. There are also more resources than ever before: government funding for national quantum technologies programmes and intense research taking place in big companies and start-ups. Delivering quantum technologies still requires fundamental research, so having more money and people should lead to advances. On the fundamental side, there are new directions to approaching the quantum measurement problem and searching for a quantum theory of gravity, as discussed in a Viewpoint in this issue. But what we think will make the difference is the new generation getting ready to join in.

> **"Today, physicists are in a good place to start demystifying quantum mechanics"**

Quantum mechanics was developed by the young. In 1923 Pauli, Heisenberg, Dirac and Jordan were in their 20s; de Broglie and Schrödinger, in their 30s, were late bloomers[1] – in the spirit of the time, they developed radically new ideas, explaining phenomena that classical physics failed to account for. Today, one starts even earlier: programmes such as Qubit by Qubit or Quantum School for Young Students (QSYS) offer summer courses on quantum information and computing to high-school and even younger students. Imagine the tweens and teens learning about superposition and entanglement and designing quantum circuits – truly quantum natives. Whether they will be inspired to pursue STEM careers, join the much-needed future quantum workforce, become the next generation of Paulis, Heisenbergs, Diracs, or do something entirely different is not that important. What matters is that the inclusion of quantum physics in high-school curricula, joining the list of traditional subjects, means it's becoming 'classical'. Then perhaps the new generation is ready – once again – to break with tradition and in answering the open questions in the foundations of quantum physics come up with a new radical theory.

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