Anton Zeilinger

Anton Zeilinger's achievements have been most succinctly described in his citation for the Isaac Newton Medal of the Institute of Physics (UK):

"For his pioneering conceptual and experimental contributions to the foundations of quantum physics, which have become the cornerstone for the rapidly-evolving field of quantum information."

Anton Zeilinger has been interested in the foundations of quantum mechanics throughout his entire scientific career. After studying physics and mathematics at the University of Vienna, he worked as a PhD student and later on as a research assistant under the supervision of Helmut Rauch at the Technical University of Vienna. As a member of his group, Zeilinger participated in a number of neutron interferometry experiments at the ILL in Grenoble. His first such experiment already confirmed a fundamental prediction of quantum mechanics, the sign change of a spinor phase upon rotation. This was followed by the first experimental realization of coherent spin superposition of matter waves. He continued his work in neutron interferometry at M.I.T. with C.G. Shull (Nobel Laureate 1995) focussing specifically on dynamical diffraction effects of neutrons in perfect crystals which are due to multi-wave coherent superposition. After his return to Europe, he built up an interferometer for very cold neutrons which preceded later similar experiments with atoms. The fundamental experiments there included a most precise test of the linearity of quantum mechanics and a beautiful double-slit diffraction experiment with only one neutron at a time in the apparatus. Actually, in that experiment, while one neutron was registered, the next neutron still resided in its Uranium nucleus waiting for fission to happen.

In the late 1980s, Anton Zeilinger became interested in quantum entanglement. This work resulted in his most significant accomplishments. Together with Greenberger and Horne, he wrote the first paper ever on entanglement beyond two particles. The resulting GHZ theorem is very fundamental for quantum physics, as it provides the most succinct contradiction between local realism and the predictions of quantum mechanics. Also, GHZ states were the first instances of multi-particle entanglement ever investigated. Such states have become essential in quantum information science. GHZ states are now even an individual entry in the PACS code.

In 1990, Zeilinger became Professor of Physics at the University of Innsbruck. He took the opportunity to start two lines of research. One concerned entangled photons, the other, because of the limited possibilities with neutrons, atom optics. He developed a number of ways to coherently manipulate atomic beams, many of which, like the coherent energy shift of an atomic De Broglie wave upon diffraction at a time-modulated light wave, have become cornerstones of today's ultracold atom experiments.

With entangled photons, his goal from the early 1990s on to demonstrate the GHZ contradiction was achieved finally in 1998. Along the road, he developed many novel tools for entangled photon physics, for example a bright source for polarization-entangled photons, ways to identify Bell states and methods for producing coherent emission of more than one entangled pair from one crystal. The resulting technology allowed him to perform a number of first quantum information experiments with entangled photons. The first ever use of entanglement in any quantum information protocol was his demonstration of hyperdense coding. His achievements also include the first entanglement-based quantum cryptography, the first quantum teleportation experiment of an independent photon, the first realization of entanglement swapping and an experiment closing the communication loophole in a test of Bell's inequality.

In 1999, Anton Zeilinger became Professor of Physics at the University of Vienna and again switched fields, abandoning atom optics for experiments with very complex and massive macro-molecules. The successful demonstration of quantum interference for C60 and C70 molecules in 1999 opened up a very active field of research. Key results include the most precise quantitative study to date of decoherence by thermal radiation and by atomic collisions and the first quantum interference of complex biological macro-molecules. This work is continued by Markus Arndt.

With entangled photons, the main focuses of Anton Zeilinger's research since 2000 were all-optical quantum computation, the development of entanglement-based quantum cryptography systems, and experiments with entangled photon pairs over very large distances.

In all-optical quantum computation, Zeilinger with his group were the first to demonstrate a number of basic procedures, like entanglement purification and certain quantum gates. This culminated in the first demonstrations of one-way quantum computation, including most recently, ultra-fast active feed-forward. The one-way quantum computation scheme was used to realize Grover's search algorithm and various quantum games, including Prisoner's dilemma.

In quantum cryptography, Zeilinger's group is developing a prototype in collaboration with industry. While most of the community was working on the much easier scheme of using weak laser pulses, Zeilinger based his approach exclusively on the more demanding scheme using entangled photons. A recent proof that entanglement is a necessary condition for the security of the quantum channel confirms that this choice is correct.

Zeilinger's experiments on the distribution of entanglement over large distances began with both free-space and fiber-based quantum communication and teleportation between laboratories located on the different sides of the river Danube. This was then extended to larger distances across the city of Vienna and most recently over 144 km between two Canary Islands, resulting in a successful demonstration that quantum communication with satellites is feasible.

An important fundamental spin-off of these experiments was the first test in 2007 of a non-local realistic theory proposed by Leggett which goes significantly beyond Bell's theorem. While Bell showed that a theory which is both local and realistic is at variance with quantum mechanics, Leggett considered nonlocal realistic theories where the individual photons are assumed to carry polarization. The resulting inequality was shown to be violated in the experiments of the Zeilinger group.

In 2005, Zeilinger with his group again started a new field, the quantum physics of mechanical cantilevers. The group was the first to demonstrate experimentally the self-cooling of a micro-mirror by radiation pressure, that is, without feedback. That phenomenon can be seen as a consequence of the coupling of a high-entropy mechanical system with a low-entropy radiation field. This work is now continued independently by Markus Aspelmeyer.

Anton Zeilinger is internationally recognized as a scientific leader in the foundations of quantum mechanics and as one of the founders of the field of quantum information science. As an example, we mention that his EU network "The Physics of Quantum Information", which started in 1996, was the first such international activity world-wide.

Anton Zeilinger's international awards include the King Faisal Prize of Science and the Newton Medal of the Institute of Physics. While still at Innsbruck University, he built its Physics Department to be a prime center of quantum optics. The Institute of Quantum Optics and Quantum Information IQOQI of the Austrian Academy of Sciences, located both in Innsbruck and Vienna, was created to provide a continuing joint platform. In the report "Controlling the Quantum World" by the National Research Council of the U.S. National Academies, this Institute is mentioned as "an example of outstanding quality".

Anton Zeilinger has continuously succeeded to inspire younger researchers towards high quality research. To date, many of his former students or post-docs have become professors at various institutions world-wide. These include Paul Kwiat (Bardeen Professor at the University of Urbana-Champaign), Jian-Wei Pan (Yangtze Scholar of Quantum Physics, University of Science and Technology of China), Dirk Bouwmeester (Professor at UC Santa Barbara and Leiden), Gregor Weihs (Canada Research Chair and Full Professor at the University of Waterloo), Jörg Schmiedmayer (TU Vienna), Harald Weinfurter (LMU Munich), Markus Oberthaler (Heidelberg University), Markus Arndt (University of Vienna) and Herman Batelaan (University of Nebraska).