Found Phys (2014) 44:449–451
DOI 10.1007/s10701-014-9799-8

Introduction to the Proceedings of "Horizons of Quantum Physics" 2012

Anton Zeilinger

The history of Quantum Physics has been one of continuous discovery and incessant wonderment. Since its inception at the beginning of the 20th century, Quantum Theory has interested and puzzled researchers across several field of Science. Not only has it brought about veritably ground shaking technological revolutions, but it also has given us an ever deeper understanding of Nature and stimulated continued investigation into the foundations of the theory itself.

When we briefly recapitulate the historic development of quantum physics we see a number of very interesting turns. After the introduction in 1899 by Max Planck of the constant today named after him and after his explanation of the black body radiation in 1900 he himself looked for a significant time for another explanation without the quantum of action. It was only Einstein who, in his famous 1905 paper took the quantum idea more serious introducing his idea of particles of light, today called photons. It is remarkable that it took a quarter of a century until in 1925/6 quantum theory was finally formulated by Heisenberg and Schrödinger.

Immediately after its discovery the new theory led to two remarkable developments. Firstly a whole cosmos of phenomena was suddenly explainable by the new theory and new ones were discovered again and again. Altogether today quantum theory is probably the most successful theory ever discovered by humanity. But secondly at

A. Zeilinger (✉)
Institute for Quantum Optics and Quantum Information – Vienna (IQOQI),
Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria
e-mail: anton.zeilinger@univie.ac.at

A. Zeilinger
Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna,
Boltzmanngasse 5, 1090 Vienna, Austria

that time immediately a discussion started about the deep conceptual consequences of the new theory. A most important work horse in these discussions was the tool of Gedanken experiment. This was essentially due to the fact that quantum physics made counterintuitive predictions for the behavior of individual systems, in general individual particles. But at that time technology was not mature enough to actually perform such experiments.

Finally, beginning in the 1970s such experiments became possible due to technological progress; witness most significantly the development of the laser. These experiments not only confirmed the quantum prediction in all cases, they also sharpened the intuition of physicist for quantum phenomena which again gave rise to the discovery of many new effects and experiments. Finally, to the surprise of everyone, all this resulted in the new field of quantum information science which is one of the most active research fields at present signified by such concepts as quantum computing, quantum cryptography and quantum teleportation-.

In quantum information science the proposal by Aaronson and Arkhipov detailing the complexity of linear optics and its use to solve classically intractable problems or the discovery by Broadbent Fitzsimmons and Kashefi of blind quantum computing are only two of the many breakthroughs that appeared in recent literature. One step further and closer to real applications we find Quantum Communication, now a well-established area of applied research with deep roots into the most counterintuitive questions of Quantum Physics. Recent results in quantum key distribution from airplanes by the Weinfurter group and long distance free-space optical quantum communication by Jian-Wei Pan in China and our group in Vienna, together with technical advancement like the multi-avalanche photodiode arrays by Edoardo Charbon in Belgium, suggest Quantum Communication as the first example of the emerging Quantum Technologies.

At the same time, and perhaps more interestingly, we have seen long standing debates on the foundations of Quantum Physics being revamped through novel techniques that have opened scenarios to experimental investigation that were before in the realm of thought experiments only. First mention goes of course to the wealth of experimental proof of the Bell Theorem, made more precise and compelling over the years by ever evolving experimental technologies. More recently, the ability to experimentally create and probed Hilbert spaces of increasingly higher dimension has opened to investigation areas so far unexplored. The question of Mutually Unbiased Bases, one example that fascinates me, and the recent work by O'Brien, Silberberg and others on quantum random walks are but examples of issues related to high dimensional Hilbert spaces that, I believe, will tell us something new about the foundations of Quantum Physics that we do not yet fully understand.

It is from this synergy between fundamental research fueling technological development and technical innovations bolstering and fostering investigation at the foundations of Physics that, I believe, we will draw the greatest benefits in the years to come. Facing problems of ever increasing complexity and handling systems with an ever increasing number of variables will surely require a very multidisciplinary approach. *"Are there limits to Quantum Physics?", "Do we already have all the Physics we need to understand complex systems, such as the human brain?", "Is it possible to formulate a deeper, more complete theory beyond Quantum Physics?"* are some of

the hard questions of the 21st century that we will need to address bringing together people from different backgrounds, different mindsets and very often talking in different "languages". It is the spirit of this volume and of the "Horizons of Quantum Physics" workshop whence it was generated to bring together a broader community of theoreticians, experimentalists and technologists and to bridge the barriers between their different approaches and interests with the goal of approaching hard but interesting question. It is often said that, in Physics, *"all easy experiments have already been carried out; all that's left are the difficult ones"*, but I am very optimistic that, with this approach, we will find new ways to look at things. After all, Isaac Newton published his *'Principia'* only 350 years ago, so when we talk about Physics we talk about a very recent human endeavor and it might well be that, though already with beautiful results, we have done no more than scratch the surface. This volume confirms that we are engaged in an exciting filed with a bright future.