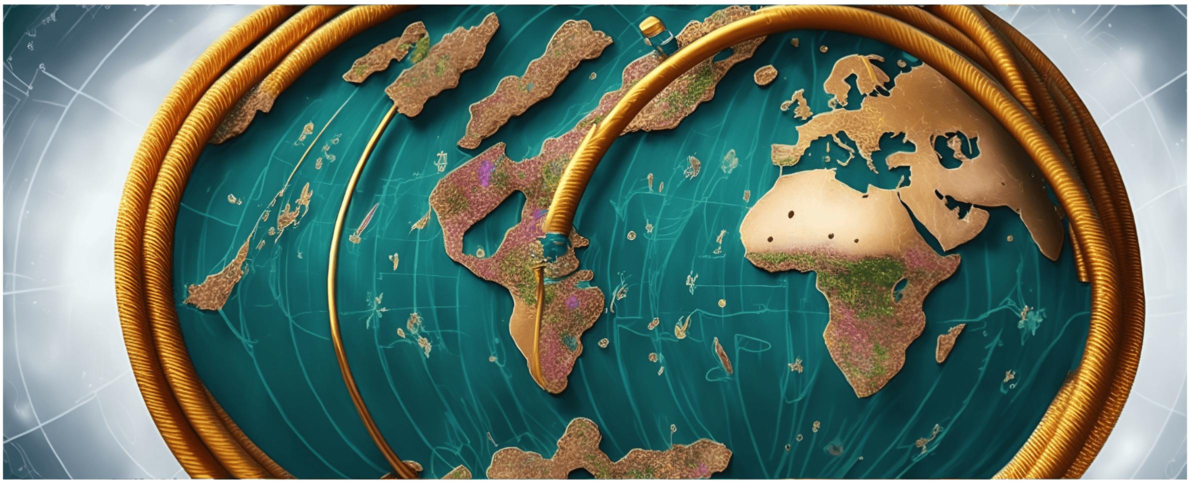
Editorial: What is the second quantum revolution?

Notes on new technologies

Lluís Torner, Anna Sanpera


Quantum world. Conceptualization: Luisa Quiroga

The world is always being confronted with new challenges and problems. The anthropocentric vision of the universe, so strongly rooted in our society for centuries, starts to fray at the seams as soon some of its consequences are seen. At the time of writing, we are well aware of some of the challenges: we observe – with horror – the effects of climate change; we are aware of the destruction of biodiversity, gender bias, the need to guarantee clean water for everyone, energy waste, the use of fake news… And we look for solutions within our reach: social, economic, philosophical, technological, etc. Technological solutions arise from our scientific discoveries and their goal is to improve everyone's quality of life.

For the first time in the history of mankind, we are capable of manipulating the atomic world, with sufficient precision, starting what we call the second quantum revolution. Quantum physics is not a new theory: it was discovered in the early decades of the 20th century and describes the components of the universe on an atomic scale. It is a physical-mathematical theory that is extremely accurate in testing and predicting new effects, but it often shows us that our world does not function in accordance with the knowledge we acquire by means of direct experience. Some of the theory's basic concepts have highly counterintuitive implications for daily life and when we seek to interpret what reality is.

This notwithstanding, the predictions made by quantum physics have always been accurate in explaining how the world behaves on an atomic scale, and its strangest effects have been tested again and again, showing an exquisite agreement with the predictions made by the theory.

And not just that: part of the behaviour of the atomic world described by quantum theory enabled immense technological progress to be made in the mid-20th century. It is what we now call the first quantum revolution. Among other things, it enabled us to understand and use semiconductor materials and, consequently, led to the appearance of the transistor and electronics as we know it today. Another product of the first quantum revolution is the laser and all its applications. The transistor and the laser, which form the core of electronics and photonics, respectively, have brought us computing and communication technologies which are now ubiquitous and define what we know as the digital society: connectivity, global internet, robotisation and artificial intelligence are, in part, defining elements of today's world. The influence of quantum theory is also found in the advanced imaging and diagnostic devices used routinely in hospitals: magnetic resonance, advanced tomography (for example, nuclear magnetic resonance (NMR) and positron emission tomography (PET) devices), surgical instruments or certain cancer therapies are also the result of using techniques derived from the first quantum revolution.

The second quantum revolution

The possibility of manipulating atoms on an individual scale for the first time gave rise to what we call the second quantum revolution. If they are well isolated, atoms can be in quantum superpositions, states that represent them here and there at the same time, as illustrated by the famous example of Schrödinger's cat. Moreover, we are able to make two atoms interact with each other and become correlated, even after they have been separated. This is the so-called quantum entanglement that Einstein found so disconcerting, and which causes such surprising effects as the teleportation of quantum effects (not of matter); completely private communication, that is, without any possibility of being spied on or tampered with, or the absolute impossibility of copying/cloning quantum states, while our phone cameras can copy any image without problem. Thus, the intrinsically quantum properties of the atom world enable us to create technologies that would otherwise be impossible. The paradigmatic example is quantum computing, which in principle – but not yet in practice – can perform calculations that are not possible with classical computers, regardless of their computing power.

> For the first time in the history of mankind, we are capable of manipulating the atomic world, with sufficient precision, starting what we call the second quantum revolution

With what we know today, we would not say that the second quantum revolution will be as transformative for our civilization as the first revolution has been during the last 50 years. Having said that, we do not know of anyone, except for the odd science-fiction writer, who during the 1960s could have predicted what that revolution has already made real today. Without wishing to seem arrogant, we can make reasonable attempts to guess how science and technology will evolve in the next 6 or 10 years, not counting the odd (welcome) surprise. But who would dare to predict what technologies will exist in 50 years' time, that is, in the 2070s?

What is absolutely certain is that the world will be very different and, given the fundamental properties of the principles that govern the functioning of nature, as we know them today, the future technologies that will have emerged from the exploration of the quantum world will play a major role in its transformation. To what degree and in what areas? What will be the social impact of the envisaged future quantum internet? What diseases will future quantum sensors be better equipped to diagnose? How many years will it take to develop a really powerful general-purpose quantum computer? These are some of the questions that we have just started to ask ourselves.

In any case, in the coming decades, mankind will have to address daunting challenges in many spheres of economic, organisational and societal activity. For example, we will need to develop new materials and use planet-friendly energies that are completely different from those we are using today. The deeper understanding described by quantum physics, which we are starting to glimpse in the field of materials, chemical processes and how the world operates on a microscopic scale, would provide some of the solutions.

A forward-looking reflection

In this monographic issue of *IDEES*, we have included articles that analyse different areas of quantum science and technologies, from practical aspects to conceptual and cultural implications, considering the present state of the art in the world, with particular emphasis on the European Union. The first articles address the deployment of cybersecurity technologies, sensors for medicine and computing, and the industrial implications of all this. The remaining texts contribute philosophical, historical, artistic and governance-related reflections. The articles' authors are international experts in their respective fields, which guarantees the factual rigour and timeliness of their contributions.

We thank the editors of *IDEES* for their vision in proposing the publication of this issue and the authors for their contributions. We invite everyone to enjoy the result: we are sure it will be of interest and will stimulate further studies.

Lluís Torner

Lluís Torner is director of the Institute of Photonic Sciences (ICFO), an international reference center that develops research in the field of photonics and its applications. He holds a degree in Physical Sciences from the Universitat Autònoma de Barcelona (1986) and a doctorate from the Universitat Politècnica de Catalunya (1989), where he has been a professor since 2000. He has been elected Fellow of several societies, including the Optical Society of America, the European Optical Society and the European Physical Society. He is an advisor to numerous public and private entities in Europe, the United States of America, Canada, Australia and the European Commission. He has received the Monturiol Medal, the global leadership award given by the Optical Society of America and the National Research Award, among other recognitions. He was president of the Catalan Association of Research Organizations (ACER) during the period 2009-2014.

Anna Sanpera

Anna Sanpera has been an ICREA research professor in the Quantum Information group of the Universitat Autònoma de Barcelona since 2005. She has been a researcher at the University of Oxford, the University of Paris-Saclay and the University of Leibniz, in Hanover, where she was an assistant professor. Her research interests range from quantum information theory to quantum gases. She is currently working on the relationship between quantum information and condensed matter. He collaborates with different national and international research groups.