Final Statement of the Workshop on Quantum Science and Technology

Recent advances and new perspectives

Quantum science is a remarkable achievement of the human mind, and it has profound implications for our understanding of nature. As we approach the centenary of its birth, we can reflect on its past, present and future challenges and opportunities.

Quantum science was developed to explain the fundamental properties of matter, following the footsteps of previous scientific revolutions. Like any other science, it started as a theoretical endeavor, subject to questions and criticism, and eventually became a source of innovation and commercial exploration.

Quantum science has contributed to the advancement of electronics, materials science, and chemistry, among other fields. More recently, quantum phenomena have been explored as potential resources for communication and computation. These possibilities are especially relevant in the age of information and technology, and they have attracted a lot of attention, popularity and investment. The benefits of these new technologies are yet to be fully realized and understood.

The topic of quantum science is still open to debate and inquiry, and it is still far from being settled or exhausted. The more than 50 presentations at this conference of the Pontifical Academy of Sciences provided us with new insights and recommendations on this fascinating topic.

1 – Lessons from the past

Quantum concepts have faced criticism and skepticism since their inception. However, the relentless efforts and interactions of scientists have led to amazing discoveries. Scientists overcame the opposition and challenges with resilience and determination, paving the way for great breakthroughs. One of the most important lessons from the history of quantum science is the value of investing in intellect and basic research, which can lead to great developments. Basic science becomes relevant science, advancing not only knowledge but also providing solutions to real world problems.

2 – The status in the present

Quantum science has led to enormous advances in various fields, such as electronics, pharmaceuticals and materials science, and – very importantly – quantum physics-based measurement. Without the foundations of quantum mechanics, we would not be witnessing the so-called quantum revolution, which is transforming communications, computation, control systems and the production of new molecules to treat specific diseases.

Quantum science has opened up a new world, where we can observe and manipulate atoms and molecules, and understand that phenomena such as superfluidity, superconductivity and other super-properties are manifestations of the same quantum principles. Quantum science has also allowed the creation of quantum simulators, which can provide experimental solutions to problems that are otherwise intractable. As the saying goes: if we can formulate the problem and we do not have its solution, nature will tell us the answer through experiments.

Quantum technology has also made possible the use of quantum properties for storing and processing information with unprecedented accuracy and speed. These properties are the basis of quantum computing, which is a rapidly developing field with many challenges and opportunities. Some researchers are focusing on demonstrating the principles of quantum computing, while others are working on scaling up the operations and processors to achieve a universal quantum computer.

Quantum technology also offers the possibility of creating quantum sensors, which can enhance the detection and measurement of various physical quantities, such as magnetic fields, gravity acceleration medicine, and detection of chemical reactions inside cells. Quantum technology is advancing fast, and many experts think that we may witness the second quantum revolution.

Many investors are seizing the opportunities and supporting companies that are dedicated to quantum science and technology. The future of quantum science and technology depends on the outcomes of the current research and development efforts.

3 – Future perspectives

Quantum science and technology is an exciting field that attracts many young researchers and challenges many technical barriers. One of the main goals is to achieve scalable quantum computing, which could offer unprecedented “quantum processing power” for solving complex problems. Quantum technologies may result even in the discovery of physics beyond established models, providing a glimpse into new laws of nature.

However, there are still many obstacles to overcome, such as the correction of natural errors that occur during quantum processing. The current progress is promising, but it is not clear whether quantum computers will become a reality or a niche tool for some problems in the near future.

Quantum communication, based on photons prepared in entangled states, offers security and privacy for data transmission through quantum cryptography. This technology can enhance digital security and prevent tampering. Quantum communication is already a reality, but it needs to become more accessible and affordable.

Quantum sensors, which can measure magnetic and gravitational fields with high precision, have many potential applications, such as exploring natural resources, oil, and carrying out pest control in crops. Quantum sensors can also help in detecting diseases at early stages, which are difficult to diagnose with conventional methods. Quantum sensors of different types can improve the detection of pests in crops and monitor pollution.

With the involvement of large companies in quantum applications, the number of startups may decrease. The large corporations may have different interests and strategies, such as providing evidence for the feasibility of quantum technologies or delaying their commercialization.

4 – Potential impact of quantum technologies on society

Quantum technologies, such as quantum sensors and quantum telecommunication, have the potential to improve the state of the art of clinical diagnosis and health care for humans, animals, and plants.

For example, precision gravitometers can help in finding and managing water resources, which are scarce in several regions of the planet, and also in detecting and preventing natural disasters such as earthquakes and emerging storms or floods.

Sensors can also enhance agriculture by combining with artificial intelligence to optimize food production, food distribution systems, and reduce environmental impact.

Quantum computing, if successfully implemented, may assist in the development of renewable energies and materials, and possibly in monitoring and mitigating climate change and its effects.

5- Concerns and recommendations to achieve quantum opportunities

1. **Support basic sciences:** Quantum physics is still at a stage of basic science and continues to generate new basic insights. It remains important to support basic research and foster public investment in international partnerships in this field.
2. **Quantum opportunities must be accessible and inclusive for all:** That is not assured. Like any new technology that arrives, its cost can be prohibitive for low-income countries. This could further increase inequalities between societies. It is necessary to take due care so that all societies are prepared to know how to deal with and use the new quantum technologies. International science partnerships and sharing knowledge are needed for that as well.
3. **Public goods focus:** Care must be taken so that narrow economic interests do not outweigh broader societal interests and that – from the outset – quantum opportunities for public goods, planetary health and people's wellbeing are to be prioritized. As developments so far are restricted to a few countries, it is necessary that open dissemination initiatives, both to explain the development of this branch of science and to facilitate the participation of many, are supported by the main participants, and endorsed by scientific associations of international scope.
4. **Secure communication:** Given that fault-tolerant quantum computers could break our current public key infrastructure essential to secure communications and much modern financial activities that are either online or the result of automated electronic transactions, it is essential to encourage the replacement of the current public key infrastructure with quantum resistant cryptography once it is standardized.
5. **Science education and media:** As quantum concepts are becoming present in several technologies, it is advisable to introduce appropriate standards and principles into basic science education such as in high schools and special colleges. Scientific dissemination in the media must be intensified too, to demonstrate that these new concepts are in accordance with nature and that they are now being mastered for the benefit of his own progress.
6. **Innovation ecosystems:** The quantum evolution needs a conducive innovation ecosystem to serve people and planet. As quantum knowledge reaches the market and society, it is necessary to think about the appropriate division of responsibilities. Who will do what, and who controls the ecosystem of quantum technologies as a whole? The main participants in this development, namely scientists, companies, and society itself, must develop concepts for access and responsibilities.
7. **Attention to solution orientation:** Quantum computing offers transformative potential to advance solutions for some of society's most pressing issues, such as climate change, health, hunger. But the existence of qubits alone will not deliver these results. Rather, industry, governments, and academia must act in concert to tackle the impact, use, and access issues this new technology presents.
8. **Cooperation rather than competition:** We have reached a point where we understand how to mitigate quantum computing's attendant security risks; we must now channel it toward societally-positive applications. Instead of a nationalistic competition of first achievers, deep

partnership and proactive collaboration will enable us to effectively harness the full power of this profound new technology. Therefore, we endorse a global, open and equitable access to quantum resources, to inclusively unleash the power of quantum technologies so that the whole world may contribute to and benefit from quantum technologies.