HEFEI DECLARATION OF QUANTUM TECHNOLOGY — WHITE PAPER FROM THE ICEQT 2019

1. Introduction

The establishment of quantum mechanics at the beginning of the last century is one of the most important intellectual revolutions in human history. It gave birth to major modern technologies such as semiconductors, lasers, and global positioning systems, which promoted an unprecedented development of human society. It has fundamentally changed our lives, the whole society, and promoted the tremendous progress of material civilization. In past decades, profound progress, made both in our understanding of exploiting quantum superposition and entanglement for new ways of information processing and in the experimental methods of coherent control and interaction of individual quantum particles, has given birth to an emerging field of quantum technologies, including but not limited to quantum communication, quantum computing, and quantum metrology. The emerging quantum technology has been driving and enabling a new generation of classically impossible tasks ranging from unconditionally secure quantum communications, breathtakingly powerful quantum simulation and quantum computation, to extremely sensitive measurements. In view of this trend, from 15th to 20th September, 2019, the International Conference on Emerging Quantum Technology (ICEQT2019) was held in Hefei, China. More than 500 experts of research institutes and universities from Austria, Australia, Canada, China, France, Germany, Russia, Switzerland, United Kingdom, United States, etc., participated the conference. The development and the future of quantum information technology were intensively discussed, and the views are summarized in the following.

2. Quantum communication

Quantum communication, an important branch of quantum information science, is the art of controlling quantum states for transferring information from one place to another. Typical tasks in quantum communication include quantum key distribution (QKD) and quantum teleportation. QKD provides an in principle unconditional security in communication, and is likely the first quantum information technology emerging from laboratories and entering real-life applications. Quantum teleportation can transfer arbitrary an unknown quantum state from one location to another, and plays an important role in quantum repeaters that are required in long-distance QKD.

After three decades of joint efforts from the global academic community, combining measurement-device-independent QKD and self-calibrated home-made sources, practical QKD systems can provide sufficient security under realistic conditions.

QKD is not intended to completely replace the classical communication infrastructures, but rather to complement existing classical cryptographic schemes. At the same time, scalable applications of quantum communication need hybrids with classical communication technologies. To build a global-scale secure QKD network, which is the ultimate goal of the field, a feasible route is to use optical fibers to connect metropolitan QKD networks, using trusted relays (currently) and/or quantum repeaters (future) to link intercity networks, and using satellites to establish long-haul QKD networks.

Practical long-distance QKD implemented by trusted relays is a viable solution adopted worldwide based on the current technology. A satellite can also be used as a relay in free-space QKD, which has been demonstrated and will be promoted further. Encouraged by China's large-scale quantum-based secure communications, especially the Beijing-Shanghai backbone network and the Micius satellite, similar efforts are being undertaken by many other countries which have started long-distance QKD projects and proposed quantum satellite initiatives. In the foreseeable future, a space-ground wide-area quantum communication network that integrates through satellite and terrestrial fiber networks is feasible.

The large-scale and commercial applications of QKD require the field to establish standards based on safety assessments under realistic conditions. The International Telecommunication Union (ITU) held its first international conference on quantum information technology in Shanghai in 2019 with emphasize on standardization of quantum communication. China's proposal to develop an international standard for quantum cryptography has been approved by the International Organization for Standardization (ISO). The European Telecommunications Standards Institute (ETSI), along with others, are also promoting QKD-related standardization.

3. Quantum computation

Quantum computing is a new computing paradigm that harnesses properties of quantum mechanics such as quantum superposition and interference for enhanced methods of computation. This can provide exponential speedups over classical computers for some problems, providing solutions for several hard large-scale problems. Both the universal quantum computer and a special-purpose quantum simulator are generally referred to as a quantum computer.

Universal quantum computers must meet five basic DiVincenzo criteria: (1) well-defined qubits, (2) long coherence time, (3) qubits can be initialized, (4) universal quantum gates can be implemented, and (5) qubits can be read out. The precision of the quantum gates is required to surpass certain thresholds for scalable fault-tolerant quantum computing with quantum error correction. In addition to the gate-based model, universal quantum computing also has other equivalent approaches: adiabatic quantum computation and topological quantum computation.

Universal quantum computing still faces stringent technical requirements, such as reaching the fault tolerance threshold and the required large number of qubits. Special-purpose quantum simulators use well-controlled quantum systems, and is expected to be easier to realize than universal quantum computers. Quantum simulators can be useful in various fields such as condensed-matter physics, materials science, and quantum chemistry, to efficiently solve the relevant many-body problems that otherwise cannot be simulated by classical computers.

Given that building a universal quantum computer still requires long-term efforts, the scientists in ICEQT agreed that in order to maintain a healthy and smooth development of the field, a feasible step-by-step roadmap could be as follows. The first stage is to demonstrate "quantum advantage", that is, showing that quantum processors can surpass the performance of classical supercomputers on certain problems. This goal is expected to soon be achieved. The second step is to realize quantum simulators with non-trivial applications such as optimization, quantum chemistry, machine learning. The final and most challenging stage is building programmable universal quantum computers, which could have high impact in cracking classical encryption systems, big-data-set searches, and artificial intelligence.

Research groups from all over the world are attempting various physical systems for quantum computing, such as ion traps, superconducting circuits, ultracold atoms, polar molecules, photons, color centers, and quantum dots.

4. Quantum metrology

With the rapid development of quantum control and quantum information technology, the metrology standards will enter the "quantum era", as marked by the 26th General Conference of Weights and Measures in 2018 (CGPM2018) on the new definition of the International System of Units by means of quantum.

By harnessing quantum effects, quantum sensing and metrology can offer higher sensitivity, accuracy and speed of use than current technologies, particularly for timing, gravity, magnetic and imaging fields. For instance, optical atomic clocks leverage advances in ultra-stable lasers and optical lattices to achieve a high-precision time standard; time-frequency transfer explores ultra-stable frequency combs to distribute accurate time and stable frequency between remote locations; atomic interferometers use quantum superpositions of atomic states to measure gravitational acceleration and rotation with extremely high precision; quantum imaging and remote sensing use high-sensitivity detection, entangled or squeezed light to provide higher resolution and sensitivity for imaging and sensing; solid-state artificial quantum sensors can perform precise measurements in quantum standards. Quantum sensing and metrology will play important roles in the next-generation time standards, precision navigation, tests of fundamental constants, particle detection, magnetic resonance imaging, long-range target recognition, satellite-based global topography, sensing of gravitational waves or dark matter and so forth.

The demands for precise quantum sensing and metrology are expanding with the developments of the “Internet of Things,” and there is a great opportunity for quantum sensors to provide enhanced capabilities over classical technologies. The scholars reached the consensus that the research community should keep developing various techniques for superior quantum sensing and metrology, including ultrastable lasers and frequency combs, ultracold atoms, entangled/single photons, nitrogen vacancy centers, superconducting devices and so forth.

5. International collaborations

The flourishing field of quantum information originated from curiosity-driven and fundamental research in quantum mechanics, which has been continuously driving and expanding the field further. Meanwhile, increasingly advanced technologies developed in quantum information, in return, have provided new tools in probing new physical frontiers in quantum mechanics. It is clear that in every stage of emerging quantum technology, the importance of fundamental research can never be over emphasized. The second quantum revolution will likely provide another huge leap in human civilization. These emerging technologies will bring benefits to the whole human society; the scientists at the ICEQT agreed that it is necessary to establish global collaborations to jointly promote the development of this field in the future. To this end, the collaboration and communication between scientists of different countries should be promoted, especially in the field of basic research and common technologies.