All physics converge into quantum information

Everyone will have a different answer to the question of what a quantum is. Some will say that something microscopic like photons or spin is a quantum, while others will say that even something macroscopic like a circuit can be a quantum. In the end, anything that exhibits the duality of particles and waves is a quantum, and the scope of its application will continue to increase and various fields will become quantum. At present, there are four major pillars of quantum computing, quantum communication, quantum measurement, and quantum life in Japan, and I believe that there will be no end to the applications of quantum authentication, quantum money, quantum games, quantum medicine, quantum astronomy, quantum meteorology, and so on. I started my career as a researcher of photophysical properties, especially exciton properties, and have since been exposed to various fields such as semiconductor optical devices, photonic crystals, quantum optics, spintronics, optical communications, quantum cryptography, quantum computation, quantum sensing, and more recently, superconductivity and optomechanical crystals. Recently, the field has been expanded to include superconductivity and optomechanical crystals. As an experimentalist, I am very happy to be involved in such a wide range of fields. Just as electric circuits have been quantized by superconducting circuits, devices that connect electricity and light, such as EOMs and AOMs, which are the main devices constituting optical circuits, are also about to be quantized, and we are experiencing the second quantum revolution. If we continue at this rate, it is not a dream that all devices will be quantum. If all the devices that make up a network become quantum, then naturally the entire network will become quantum, and I believe that this will take the form of a quantum Internet that will appear in society. However, the idea of how to use the quantum Internet is not clear yet, and it may be used for quantum authentication, quantum money, quantum games, quantum medicine, quantum astronomy, and quantum meteorology.

In Japan, a moonshot-type research and development project on quantum information was launched in December last year. The term "moonshot" means "a rocket launch to the moon" and originates from John F. Kennedy's Apollo program that started in 1961. The U.S. succeeded in landing a man on the moon, which was only a dream at the time, based on this slogan, and contributed greatly to the development of not only rockets and spacecraft, but also peripheral technologies such as communications and computers. The Moonshot as a whole has seven institutionalized goals, including AI, robotics, biotechnology, environment, quantum, and medicine, of which Goal 6 is "to realize an error-tolerant general-purpose quantum computer that will dramatically advance the economy, industry, and security by

2050" in the field of quantum information, which JST has commercialized. Goal 6 is further divided into three categories: hardware, network, and software (see figure), and I, Kosaka, have been appointed as the project manager (PM) for the network category. The name of the project is "Development of Quantum Interfaces for Quantum Computing Networks.

The development of quantum computers has been accelerating explosively in Japan, the U.S., Europe, and China, but their performance can be compared to that of a transistor, which has just shifted from a vacuum tube to a semiconductor. The fundamental problem is that current qubits have not yet achieved the same level of error tolerance that transistors have achieved through thresholding, as typified by TTL. Although various theoretical schemes have already been developed, surface codes, which are representative of such schemes, require a huge number of physical qubits to form a single logical qubit, and at this rate, the moon will appear too distant and hazy. Moonshot Goal 6 is to solve this problem by going back to various physical systems, and the Kosaka project aims to solve this problem by decentralizing quantum computers using quantum networks. The Kosaka project aims to solve this problem by decentralizing the quantum computer through a quantum network. Since a simple network connection would degrade the performance of the computer, the interface itself will have an error-tolerant quantum memory, and by networking qubits with optical qubits, we aim to not only expand the scale of the computer, but also to achieve error tolerance. This project consists of three teams: diamond quantum memory, optomechanical crystals, and piezoelectric microwave resonators, and involves universities such as Yokohama National University, the University of Tokyo, and Kyoto University, as well as national laboratories such as AIST, National Institute for Materials Science, National Institute for Materials Science, and RIKEN. Prof. Toshihiko Baba, Prof. Nobuyuki Yoshikawa, and Prof. Kosaka (concurrently) from Tohoku University will serve as the project leaders and make up each research group. Moonshot research is characterized by top-down policy decisions based on plans formulated by the government, as opposed to the bottom-up approach of KAKENHI and other programs, and requires the PM to take extremely difficult decisions that go beyond the two-sided approach of basic research and social implementation. Our university will support the activities of the Quantum Information Research Center, which was established at Yokohama National University last October.

Quantum cryptography is being developed as a completely different application from quantum computers. The most important and difficult task is to develop a quantum repeater. In Japan, the development of quantum cryptography has been underway since 2000, and last year, the Ministry of Internal Affairs and Communications launched a national project called

"Global Quantum Cryptography and Communication". One of the subjects is quantum relay technology, and I am the project leader. The three pillars of the project are quantum relaying using quantum memory by Yokohama National University, all-optical quantum relaying by Toshiba, and wavelength-multiplexed quantum relaying by Furukawa Electric. The quantum relay can be said to be a compact quantum computer with optical communication functions, and its development is as difficult as the development of a quantum computer.

Finally, the field of quantum information is similar to the fields of high energy science and space science. This is not just in a physical sense. Both require a very large intellectual workforce, and no single country can provide this workforce. It is essential to form an international forum where researchers from various fields can gather and accumulate knowledge, such as accelerator facilities in high-energy science and the International Space Station in space science. Just as the Internet was born as an indispensable tool for research in high-energy science, the quantum Internet may be born as an indispensable tool for research in quantum computing. This will further contribute to the progress of high-energy science and space science, and I believe that the intellectual capacity of humanity will increase in a spiral.

Data from the Cabinet Office (July 2020)