Jian-Wei Pan: building the quantum internet

By Philip Ball

For many decades since its inception in the early twentieth century, quantum mechanics seemed to be an exotic and peculiarly non-intuitive kind of physics that applied to matter at the smallest scales: the laws that govern atoms, photons and subatomic particles. All our engineering, meanwhile, was dominated by the familiar rules of classical physics, in which objects have definite positions, trajectories and properties.

But, in the past several decades, scientists have started to harness quantum rules in practical technologies. In 1985, the physicist Richard Feynman suggested that computers governed by quantum rules might be capable of computations beyond the means of classical ones like those in use today. At much the same time, other researchers showed that information encoded in quantum states could be transmitted between a sender and receiver using a kind of encryption that could not be intercepted and read without that being detected. Quantum computers and quantum cryptography have now become central components of a real-world quantum-information technology that may soon find scientific, industrial and social uses.

These applications could be increasingly enabled by a global information network with quantum capability: a quantum internet. China is at the forefront of that enterprise, and one of the scientific leaders in this effort is Jian-Wei Pan of the University of Science and Technology of China in Hefei. Pan studied for his PhD with quantum-information pioneer Anton Zeilinger in Vienna before returning to China to implement these nascent technologies. In 2012, he won the International Quantum Communication Award and, in 2017, he was included in Nature’s annual list of the ‘ten people who mattered in science’ over the past year. That July, he and his colleagues reported ‘quantum teleportation’ of photons from a ground-based station to a satellite 1400 km away.

NSR recently interviewed Professor Pan about the current achievements and future prospects for quantum-information technologies.

NSR: The quantum internet is becoming a popular buzzword, but what will it mean?

Pan: As we know, the internet is a global system to transfer, process and store classical information. The quantum internet is the equivalent for quantum information. The first practical task for a quantum internet may be sharing secret keys globally with unconditional security [that is, they are absolutely tamper-proof]. Quantum bits (qubits) and quantum entanglement [the interdependence of states of the qubits] will be the basic resources of the quantum internet. Various quantum-information tasks can be realized in this system, such as quantum teleportation of information between any nodes, distributed quantum computation and high-precision quantum metrology.

NSR: What are the underlying principles of quantum physics that a quantum internet would use?

Pan: The fundamental principle that quantum-information theory is built on is quantum superposition. Superposition allows a qubit to represent not just the 0 and 1 of classical bits but also any intermediate state. Classically, a bit is either in state 0 or 1. But in the quantum world, a qubit can be in a superposition of 0 + 1, or another different combination of 0 and 1, simultaneously. A basic principle is that no single measurement is sufficient to reveal all the information. This leads to the quantum non-cloning theorem, which dictates that an unknown quantum state cannot be copied precisely. When a quantum system consists of two or more qubits, superposition becomes entanglement and makes the state space grows exponentially large. The uncertainty principle and the non-cloning principle are the cornerstones of quantum communication and quantum computation, as well as of the quantum internet.

Quantum teleportation is a way to transfer an unknown quantum state from one particle to another at a distant location, without sending the original particle itself. Assume that a pair of entangled particles, denoted a and b, are exchanged between locations A and B. Then let’s say an unknown qubit c needs to be transferred from A to B. To effect teleportation, at A we perform a collective measurement on a and c, followed by a certain operation (depending on the result of that collective measurement) on b. Then the (unknown) information will be ‘destroyed’ in c and ‘teleported’ to b. But B needs the information gained that A gained in the a + c measurement in order to make any sense of the information teleported to b. And that can only be sent...
The quantum internet of the future might be completely different from what we imagine now.

—Jian-Wei Pan

The near-term target is to make telecommunication more secure.

—Jian-Wei Pan
teams all over the world. Already there is very good international cooperation on these problems.

NSR: China has been a leader in this area. Does the Chinese government see this technology as a particularly important one for future growth of the economy, finance, business and so forth?

Pan: Yes, we have received strong support from the Chinese government. As I mentioned above, we have built and put into service the Beijing-Shanghai Backbone Network, and currently real-world applications by banks, securities and insurance are being trialled. More than 150 users are now using our Backbone for secure information transfer. As I also mentioned, we have launched the first quantum science satellite, Micius.

NSR: Where do you see this technology being in, say, 20 years time?

Pan: The cost of QKD will be dramatically reduced. Devices for QKD will be miniaturized and become suitable for personal use. QKD will be a common technique for encryption and be widely used in daily life. Quantum computers or quantum simulators will be built and run as public services for certain tasks, just as supercomputers are today. I don’t think that a universal [general-purpose] quantum computer that can factorize a large number, of say 2048 bits, will be built by that stage, we will already know what such a universal quantum computer should look like and what we still need to do in order to build one.

NSR: Who or what has been your source of inspiration in this field? Would you recommend it as an area for young researchers to enter?

Pan: I believe both foundational aspects of quantum mechanics and possible practical applications are very important issues. The original motivation for me to be an experimentalist was to perform fundamental tests of the laws of quantum mechanics, to understand how and why it differs from classical physics. However, the possible practical applications of quantum mechanics also attract me deeply, since they can make a real difference to our lives.

With the invention of the internet, we have entered the information age. The quantum internet provides another rare opportunity to truly change the world. It would enable a scientific revolution. I will spare no effort to recommend that smart young researchers engage with this area.

Philip Ball writes for NSR from London.