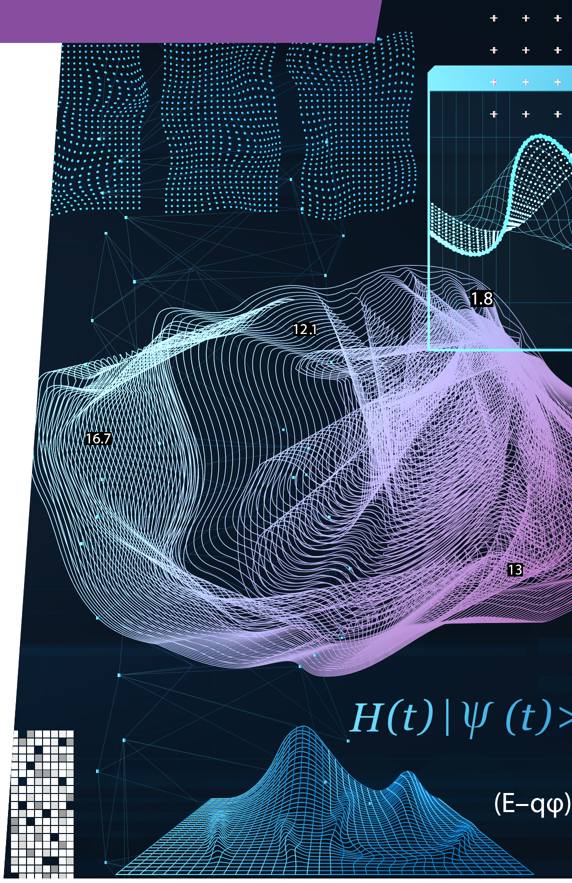


CAN QUANTUM PHYSICS MAKE THE INTERNET MORE SECURE?

Associate Professor Jacquiline (Jacq) Romero, a quantum physicist at the **University of Queensland** in Australia, is conducting experiments with photons to investigate quantum entanglement. Her research is helping to develop the quantum internet — the internet of the future will be very different from the internet today.

ASSOCIATE PROFESSOR JACQUILINE ROMERO

School of Mathematics and Physics, University of Queensland, Australia

PROFILE

Fields of research
Quantum Physics, Quantum Technology, Optics

Research project
Investigating quantum entanglement and developing the quantum internet

Funders
Australian Research Council (ARC), Westpac Bicentennial Foundation, L'Oreal-UNESCO For Women In Science Foundation

TALK LIKE A ...

QUANTUM PHYSICIST

BIT — the smallest unit of data that a computer can process and store

PHOTON — a quantum of light, the basic unit that makes up all light

QUANTUM — the smallest unit involved in an interaction

QUANTUM ENTANGLEMENT — the physical phenomenon that occurs when a group of particles interact in such a way that the quantum state of each particle cannot be described independently of the state of the others

QUBIT — stands for 'quantum bit' – the quantum equivalent of a bit

SUPERPOSITION — in quantum physics, the notion that a quantum state is a combination of many possible states, as in the possibilities are superposed until a measurement is made

Most of us use the internet every day. Whether to message our friends on social media, research a topic we want to know more about, or do some online shopping, the internet has become an integral part of our lives. The current version of the internet, however, is liable to being attacked. News reports tell stories of hackers who reveal individuals' credit card details, health records or other sensitive information. This is why Associate Professor Jacquiline (Jacq) Romero at the University of Queensland is helping to develop the quantum internet – a new version of the internet that will provide the most secure kind of communication possible within the laws of physics.

How is the quantum internet different to the regular internet?

The current internet works by using 'bits' that are always in one of two physical states, like the on/off switch of a light or TV. The state of these bits is usually represented by a single binary value, either 0 or 1. "The quantum internet differs from the regular internet because it will transmit quantum information ('qubits') instead of classical information ('bits')," says Jacq. "Quantum states are very different."

Compared to regular bits, quantum bits (known as qubits) can take on superpositions. Because the qubits are neither 0 nor 1 before measurement, qubits represent multiple combinations of 0 and 1 at the same time. By using these qubits and entangling them, Jacq and her team have been working towards developing the quantum internet.

What is entanglement?

The 2022 Nobel Prize in Physics was awarded to physicists Alain Aspect, John Clauser and Anton Zeilinger for investigating photon entanglement. They describe entanglement as a distinctly quantum phenomenon in which objects "exist in a shared state, regardless of how far apart they are". This is such a strange concept that even Albert Einstein once described entanglement as "spooky action at a distance"! Entanglement is a tricky idea to understand,

but, fortunately, Jacq has a helpful analogy to explain it: "Let's take a thought experiment with two parties: Alice and Bob," says Jacq. "Imagine there are two cards, labelled either 0 or 1, and each is placed in a closed box. The boxes could contain either number, but both boxes contain the same card. Alice takes one box to one room, and Bob takes the other to another room. The moment Alice opens her box and sees her card, she knows that Bob's card has the same number, without even communicating with him. The same is true for Bob when he opens his box."

Seems obvious so far, right? "There is nothing extraordinary about this correlation," says Jacq. "Alice and Bob know what the other person has because they know that the boxes contain cards of the same type. More importantly, the cards are ordinary objects: the 0-card is labelled 0 and the 1-card is labelled 1, regardless of whether Alice or Bob were looking in the box."

Quantum entanglement: When Alice opens her box, she knows what card is in Bob's box

However, the story is strangely different if the cards are entangled and the number on the card is a qubit. Quantum objects can be in a superposition of states, which means they can be either 0-cards or 1-cards, and this is not definite until someone looks inside the box. At that instant, the card randomly becomes either a 0 or a 1. In this version of the experiment, if Alice were to open her box and see a 0-card, then when Bob opened his box, he would see his card is also a 0-card. "Seeing a 0-card in one box depends on seeing a 0-card in another box," explains Jacq.

"Alice and Bob observe the same correlations as in the first version of the experiment, but the origin of the correlation is now superposition, not the well-defined labels on the cards that were there before they were put inside the boxes," says Jacq. The other interesting thing about qubits is that if Alice and Bob were to repeat the experiment with another pair of cards, the results will be totally random. "Whether they see 0 or 1 on their cards is totally random, but the two labels will always be the same as each other," Jacq adds. Overall, this means that when two particles are entangled, they behave as one. "The label of one card can no longer be separated from the label of the other, hence the term 'entangled', and the phenomenon we call 'entanglement'," says Jacq.

Are there different types of entanglement?

There are! The scenario above is an example of bipartite qubit entanglement. Bipartite refers to the two parties, Alice and Bob, and qubit to the two possible outcomes, 0 or 1. However, if the experiment extends to include a third person, we have multipartite entanglement. If there are more than two possible outcomes (for instance, if the cards in the box could be labelled from 0 to 5) then we have qudit, instead of qubit, entanglement.

What methods does Jacq use to conduct her research?

Jacq specifically studies the entanglement of photons. "I shoot a special crystal with ultraviolet light and, once in a while, this ultraviolet photon becomes two infrared photons that are entangled in their various properties," she says. One example of an entangled property of the photon is the shape of its cross-section intensity. "Usually, we think of light as a bright spot – intense at the centre and becoming dimmer the farther you are from the centre," says Jacq. "But light can also have other shapes."

Not only is Jacq creating entangled photons, she has also developed the technology needed to measure their shape, creating new opportunities for other quantum physicists. "I am proud that many researchers are now using the shape of photons for quantum information, thanks to the technique we introduced."

What are the applications of this research?

One application of Jacq's research is developing the quantum internet, which will be much more secure than the regular internet. If Alice sends an online message to Bob through the regular internet, a hacker might be able to read the message without either of them knowing. However, if the message is sent on the quantum internet using entangled qubits, then someone sneaking in to read the message would be detected immediately. "When quantum information is being sent from one point to another, any eavesdropper disturbs the quantum information," explains Jacq. "This means the eavesdropper can be discovered."

This new version of the internet will enable us to connect quantum computers, achieve more powerful computation and allow secure quantum communication. According to scientists, a global quantum network might be available as soon as 2030, thanks to the work of quantum physicists such as Jacq.

ABOUT *QUANTUM PHYSICS*

Quantum physics is the study of the universe at its most fundamental level. It challenges our notions of reality and often overlaps with the philosophy of science. "Quantum physics asks deep questions about how nature operates, what knowledge is, and what the role of an observer is," says Jacq. "Future quantum technologies will need the untethered imaginations of not just physicists, but also computer scientists, material scientists, engineers and people from technologies adjacent to quantum physics."

What other discoveries has Jacq made?

While it has long been known that the speed of light slows down when travelling through a different material, such as glass or water, Jacq and her team made headlines a few years ago when they discovered the speed of light can be slowed in space too.

"In one of my favourite experiments, we showed that light slows down by a tiny fraction (around 3000 km/s) if you give it a particular shape," says Jacq. This had never been shown before in single photons and was only possible because the team had so much experience working with photons.

How do gender and culture affect Jacq's work in quantum physics?

The most famous physicists tend to be white men – think of Albert Einstein, Isaac Newton, Stephen Hawking and James Clerk Maxwell. "It is really important to have cultural and gender diversity in science," explains Jacq.

"When I first left the Philippines to do a PhD in the UK, I realised I had an inferiority complex and I lacked confidence," says Jacq. "I think it is very easy to feel this way, especially for people from countries that were colonised. The Philippines was controlled by Spain for more than 300 years, and the mentality that 'white is better' is deeply ingrained."

Having grown up in the Philippines, Jacq was soft-spoken and very polite. While these are good attributes to have, she soon realised that scientists need to be forceful (you can be both forceful and polite, after all!) to make their ideas heard. "I realised I had to recalibrate to get my point across, especially when scientific discussions get intense!"

"IT IS REALLY IMPORTANT TO HAVE CULTURAL AND GENDER DIVERSITY IN SCIENCE"

Explore careers in *quantum physics*

- Jacq recommends learning about quantum computing using resources such as Qiskit (**www.qiskit.org**) and Black Opal (**try.q-ctrl.com/blackopal-app**).
- The University of Melbourne has useful information about careers in physics and advice from former university students who studied physics: **science.unimelb.edu.au/students/careers/careers-in-science/physical-sciences**
- Jacq loves the book *"Quantum Mechanics: The Theoretical Minimum"* by Leonard Susskind and recommends reading it if you are interested in learning more about quantum physics.
- According to the Economic Research Institute, the average salary for a physicist in Australia is $149,000 AUD a year.

Pathway from school to *quantum physics*

- At school and post-16, study physics and maths to learn the fundamentals of the field. Jacq recommends having a strong understanding of linear algebra, because quantum states are treated as vectors or matrices.
- At university, degrees in physics or maths could lead to a career in quantum physics. However, scientists from a range of disciplines can work in the field. "Even a chemist could find themselves working on quantum technologies, because there are many interesting materials that could be useful for quantum devices," says Jacq.

Q&A

Meet Jacq

What were your interests when you were younger?

I loved mathematics from very early on. When I was 8 years old, my uncle gave me a book on algebra which was full of word problems. I was fascinated to see mathematical equations as English sentences. When I went to high school, I was naturally drawn to physics because it was just like maths, but with the purpose of describing nature and the world around me. My interests were not all academic. I also enjoyed reading books, playing badminton, watching movies and spending time with good friends.

Who inspired you to become a quantum physicist?

When I was 15 years old, my physics teacher commented that quantum physics was the branch of physics that he liked the least. I was curious and googled what quantum physics was, and I've been hooked ever since! As I read more, I got more interested in how philosophical and yet experimentally testable, and potentially technologically revolutionary, the ideas in quantum physics were.

You have won numerous awards, including two L'Oreal-UNESCO Women in Science awards. What do these recognitions mean to you?

I am deeply honoured to have received many awards and fellowships over the years. When I left the Philippines to pursue a PhD in quantum physics, I felt a great deal of uncertainty. I even remember one professor asking me if I was sure that quantum physics was not just a fixation. I am proud to have pursued my dream, and the awards I have received are recognition of the good work and fun that I try to have every day. You can't plan to make winning an award a goal. I think the best that you can do is try to do well every day. These recognitions mean a lot to me because they inspire me to do better.

More importantly, the awards have given me space to showcase my story and show that scientist mothers can succeed. The L'Oréal-UNESCO awards were especially good for that. It has been heart-warming to receive touching emails from fellow women scientists. People are inspired by stories, and I hope my story as a member of a minority group in science (Filipino, woman and mother) can inspire others.

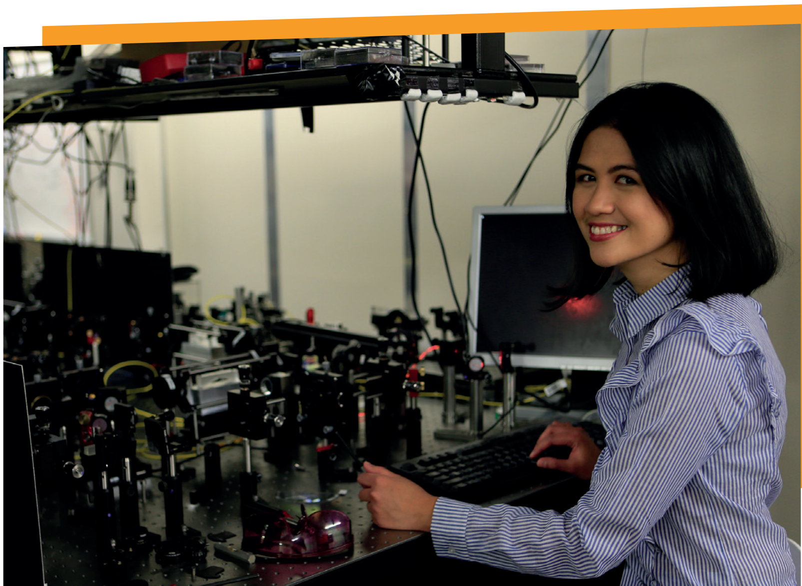
You are passionate about encouraging more women to enter STEM fields dominated by men. What message do you want to give girls and young women hoping to pursue a career in science?

I think that the first thing to do (regardless of your gender) is to be good at whatever you choose to do. Follow what drives your curiosity, build on small successes, and always ask questions. There are no dumb questions. The situation for women in STEM has improved, but unfortunately sexist environments still exist. If you find yourself in such an environment, find support (this is very important!) so that it will be easier to stand up for yourself.

> "YOU CAN'T PLAN TO MAKE WINNING AN AWARD A GOAL. I THINK THE BEST THAT YOU CAN DO IS TRY TO DO WELL EVERY DAY."

What do you enjoy doing in your free time?

I like spending time with my husband and three kids. We read books, play, go for walks and watch movies. I enjoy going on holiday with my family and having unstructured time together. I also love running and painting. When I feel stressed, I take a day off and paint.



Jacq's *top tips*

1. Your attention is your most important resource so use it well. Be present and focused on whatever it is that you are doing.

2. The best way to learn is by doing. To improve at something, you have to try it and learn from your mistakes.

3. Most importantly, have fun and enjoy yourself!