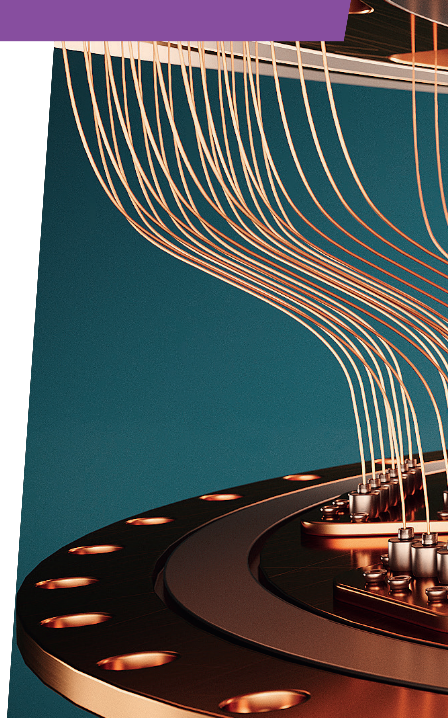


Why is it hard to build quantum computers?

Quantum computers have the potential to revolutionise technology. But at the moment, they do not work very well! **Dr Salini Karuvade**, a theoretical quantum physicist at the **University of Sydney** in Australia, is investigating how to overcome the challenges associated with creating computers based on quantum systems.

Dr Salini Karuvade

Centre for Engineered Quantum Systems (EQUS), School of Physics, University of Sydney, Australia

Field of research
Theoretical quantum physics

Research project
Exploring how to improve quantum computers by overcoming the problems caused by decoherence

Funder
Deborah Jin Fellowship, Australian Research Council (ARC) Centre of Excellence for Engineered Quantum Systems (EQUS)

Talk like a ...

quantum physicist

Bit — the smallest unit of data (0 or 1) that a computer can process

Classical computer — a machine that processes data stored in bits and that is governed by the laws of classical physics

Decoherence — when a quantum system loses its quantum behaviour

Encryption — the process of encoding data to keep information (e.g., messages and financial transactions) secure

Entanglement — the phenomenon in which distant qubits stay connected and influence each other's states

Noise — any external factor that disrupts a system

Quantum computer — a machine that processes data stored in qubits and that is governed by the laws of quantum physics

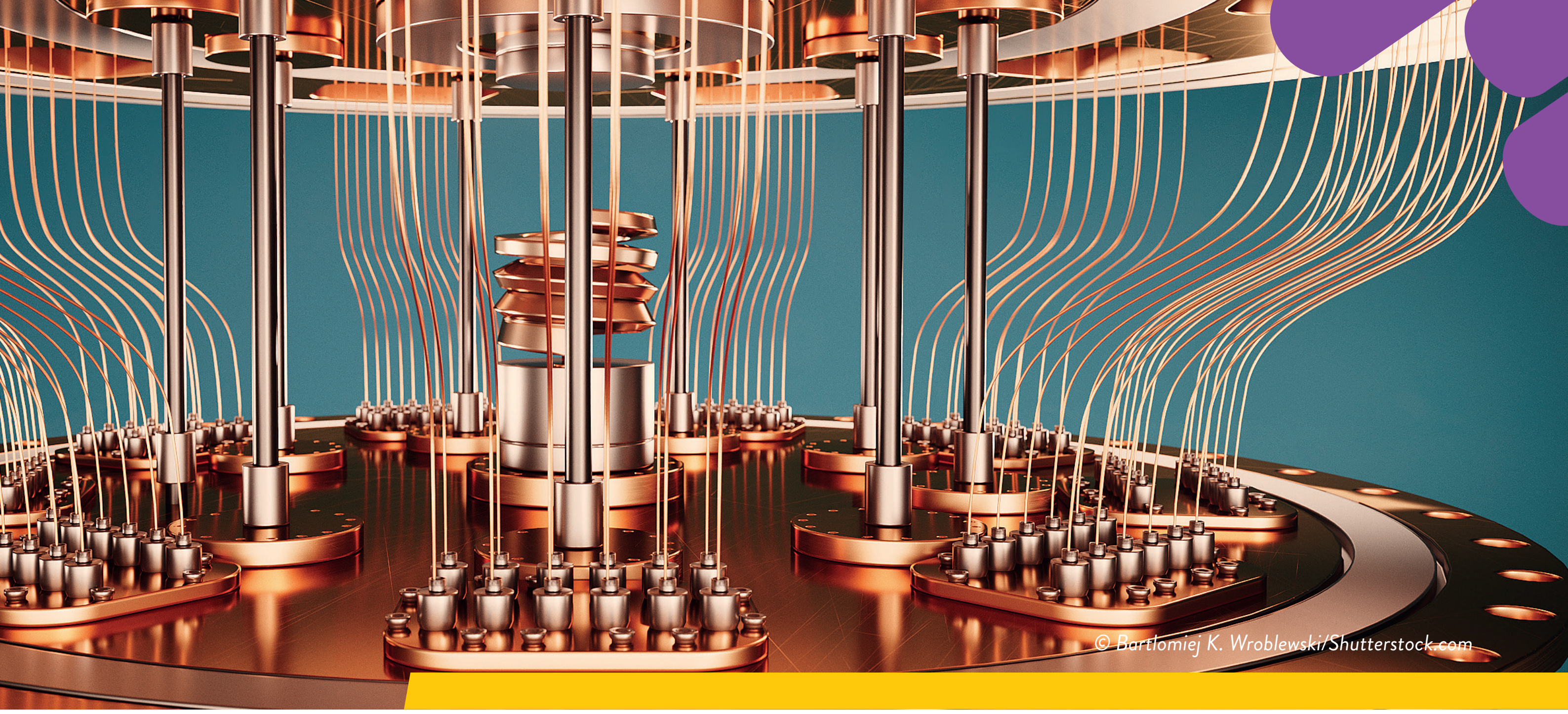
Qubit — a quantum particle (e.g., photon or electron) used as the quantum equivalent of a bit

Superposition — the phenomenon in which a qubit exists as both 0 and 1 until it is observed

Many people assume that quantum computers are simply better, faster versions of the computers we are used to. In fact, they are something completely different. While our classical computers (including smartphones) operate under the 'normal' rules of physics, quantum computers are governed by the weird and wonderful world of quantum physics.

Physicists believe that one day, quantum computers will have the ability to solve a huge range of tasks much faster than classical computers. However, achieving this dream is no easy feat. "My work is essentially about understanding how well quantum computers work," says Dr Salini Karuvade, a theoretical quantum physicist at the University of Sydney. "In other words, I study how bad they are!"

What is a quantum computer?
Classical computers store information in the form of bits, which are 0s and 1s. Whenever you scroll through Instagram or listen to music, your computer is processing long strings of these bits. In contrast, quantum computers use quantum particles, such as photons and electrons, to store information, which are known as quantum bits, or qubits. Qubits have two special quantum properties – superposition and entanglement – which scientists use to create quantum computers.



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What are superposition and entanglement?

"You can think of a bit as a light bulb – the bulb represents 0 when it's off and 1 when it's on," explains Salini. "A qubit can also be thought of as a light bulb, except this quantum light bulb can be in superposition, meaning it is both on and off at the same time!" While bits are defined as either 0 or 1, qubits exist in a superposition state in which they are both 0 and 1 until they are observed, at which point they become 0 or 1. Quantum physics gets even stranger when two qubits in superposition become entangled. Entangled qubits are connected, regardless of how far apart they are, and they could, for instance, share the same state. When a qubit is observed to be either 0 or 1, its entangled partner immediately takes the same state.

You can learn more about superposition and entanglement from Salini's colleague, Associate Professor Jacq Romero, who uses some great analogies to explain these phenomena: **www.futurumcareers.com/can-quantum-physics-make-the-internet-more-secure**

Why is it hard to develop quantum computers?

In a quantum computer, qubits in superposition can be entangled, allowing the computer to process information much faster than a classical computer. "Superposition and entanglement are the secret 'sauce' that makes quantum computers so powerful, but they are incredibly difficult to create and maintain," explains Salini.

Qubits must be completely isolated, otherwise they will fall out of superposition and become unentangled from each other. This phenomenon is known as decoherence, and it can be caused by any form of 'noise', including vibrations, temperature changes, electric or magnetic fields from the computer's circuitry, and even interactions with other qubits.

Decoherence ruins the quantum behaviour of qubits and corrupts the information they store, preventing quantum computers from functioning properly. Unfortunately, decoherence cannot be avoided as it is almost impossible to completely isolate a qubit from its surroundings. "Additionally, to process the information stored in a qubit, we need to use an external control, for example shining a laser on it," says Salini. This leaves physicists in a tricky situation – interacting with qubits is necessary for the computer to function, but at the same time it causes decoherence which prevents the computer from functioning properly. "So, the big question is how to manage and minimise the effects of decoherence that come with these interactions."

One technique that allows quantum computers to function despite decoherence is quantum error correction. "Consider the simpler example of bits," says Salini. "Instead of storing data with a single bit, we can use three bits to store one bit's worth of information." The value 0 would be stored as 000 and 1 would be 111. When a bit gets corrupted by noise, its value flips from 0 to 1 or vice versa. If the noise is weak, it is unlikely that more than one bit would flip at a time, so error correction allows physicists to determine the original value of the information, even if one of the bits has been corrupted. For example, 100 indicates a value of 0, but the first bit has been corrupted. "We use a similar idea, but in a more complex way, to encode one qubit's worth of information with multiple qubits," explains Salini.

The future of quantum computers

Large quantum computers, storing information in hundreds of qubits, have the potential to solve incredibly complex tasks very quickly. While it is unlikely that quantum computers will ever remove the need for classical computers (because a quantum computer is simply not necessary for our everyday computer needs), they will revolutionise the fields of cyber security, finance, machine learning, engineering and medicine. For example, encryption relies on the fact that classical computers are unable to find the prime factors of very large numbers quickly. Large quantum computers will change this, for better or worse, by breaking current encryption methods at alarming speeds, while also paving the way for new forms of stronger cyber security.

"However, we have not yet built a large quantum computer," says Salini. So far, only small quantum computers with a few qubits have been created. "We are still in the early stages of quantum computer technology. Each time we make progress, new challenges arise. There is still a long way to go, meaning there will be plenty of opportunities for the next generation of quantum physicists!"

About *theoretical quantum physics*

Quantum physics is the study of energy and matter at the most fundamental level. As a theoretical quantum physicist, Salini writes computer programs to help her make sense of the mathematics behind quantum computers. In turn, this helps her to understand the underlying physics. “Most of my work involves figuring out and solving the correct mathematical equations that will help answer my research questions,” she explains. “For me, mathematics is the language I use to understand physics!”

Why is theoretical work important?

“Collaboration between experimental and theoretical physicists is crucial for making ground-breaking discoveries in the complex field of quantum physics,” says Salini. As a member of the Australian Research Council’s Centre of Excellence for Engineered Quantum Systems (EQUS), Salini works closely with her experimental colleagues. Together, they uncover the secrets of quantum physics and use them to develop practical technologies. “In EQUS, experimentalists and theorists share a symbiotic relationship which is essential for advancing quantum technology,” she says. “Experimentalists build the components of quantum computers and test their performance. My work contributes to the experimental design and enhances our understanding of the fundamental physics principles.”

What is in store for the next generation of quantum physicists?

“Successfully addressing the challenges of noise and decoherence will be pivotal for the next generation of quantum physicists,” says Salini. “This will enable them to shift their focus to using quantum technologies for practical applications in fields such as healthcare, cyber security and telecommunications. Transitioning to real-world use will require continued research and development.” Quantum physicists are currently trying to build quantum computers that can surpass the abilities of classical computers. “Looking forward, our aim is to improve these quantum systems to unlock their full potential.”

Pathway from school to *quantum physics*

At school and beyond, build a strong foundation in physics, maths and computer programming. “Quantum computing combines concepts from physics, mathematics and computer science, making it intellectually stimulating,” says Salini. “If you pursue quantum physics out of a love for the underlying science, you’ll find it enjoyable!”

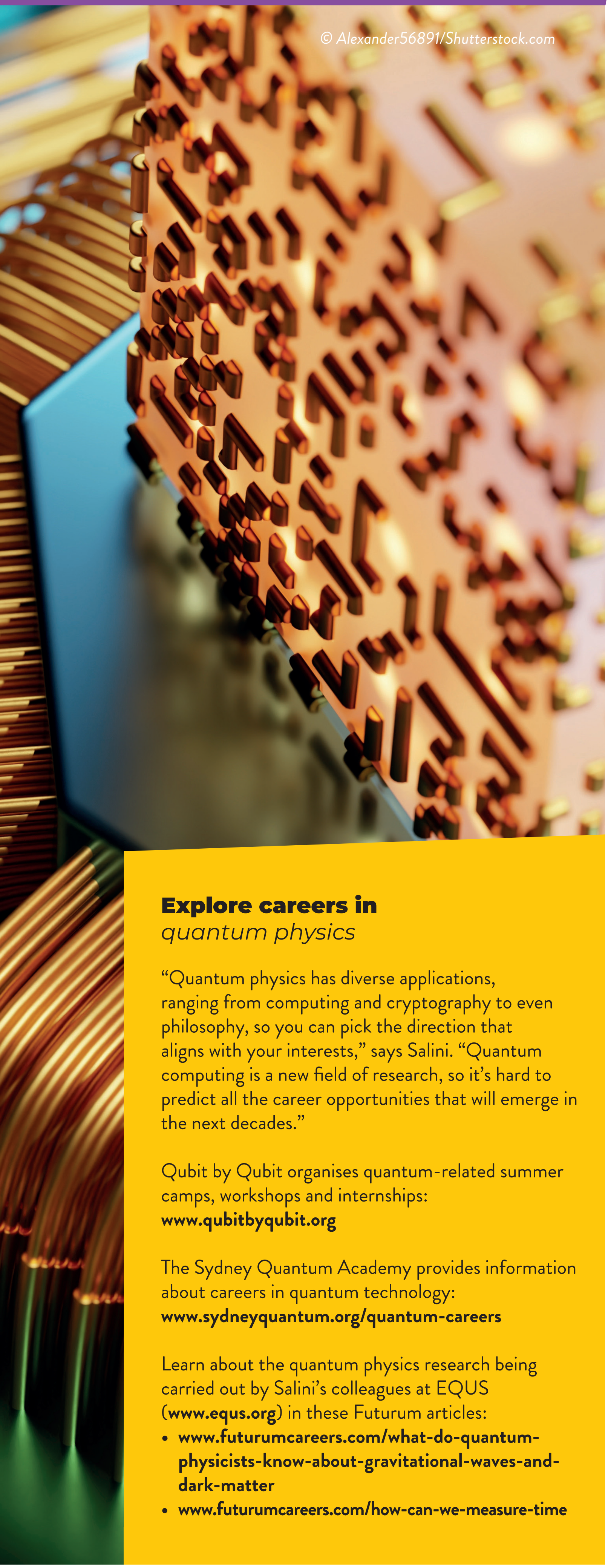
At university, a degree in physics, mathematics or computer science will prepare you for a career in quantum computing. Some universities offer specialised programmes in quantum engineering.

Salini advises taking courses in quantum mechanics, atomic physics, linear algebra, probability, data analysis and computer programming. “These will set you up for exploring the fascinating world of quantum computing,” she says.

Attend university open days to meet quantum physicists and talk to them about their work and career path. “Building these connections and understanding the experiences of others is very important,” advises Salini.

Participate in outreach activities and educational initiatives, such as EQUS’s National Quantum & Dark Matter Road Trip around Australia: **www.qdmroadtrip.org**

Explore online resources, such as IBM Quantum Learning (**learning.quantum.ibm.com**), to learn more about quantum physics.



Meet *Salini*

As a teenager, I was particularly interested in mathematics and physics. I loved conducting science experiments at home, along with reading mystery thrillers and participating in trivia competitions with my friends.

My mother is a high school maths teacher, which explains my interest in the subject. I found physics very exciting because it could explain the world around me – such as how the sun and the moon move, and why magnets stick to some metals. In college, I discovered that theoretical quantum physics combines mathematics with physics in the most exciting way, so I decided to take it up as my career.

As a high school student, I led a science project estimating fluoride levels in groundwater samples collected from two rural communities near my school. Our findings correlated with health issues prevalent in these areas, and our results led to local awareness campaigns and national recognition. That was when I realised I could do important work while also having fun.

As an undergraduate student, I had the opportunity to visit several research groups and take part in their work. These visits were not just to quantum physics groups, so gave me a wider perspective on what research entails and the questions that motivate scientists. These experiences played a crucial role in shaping my career path.

As an EQUS member, I co-founded a peer-support group for women and non-binary colleagues. Collaborating with like-minded individuals in science is crucial to me, and I'm proud to share my enthusiasm through this initiative. Looking ahead, I hope to continue tackling fascinating physics challenges while spreading the joy of scientific inquiry to others.

In my free time, I enjoy travelling, watching sitcoms, running and taking dance classes.

Explore careers in *quantum physics*

"Quantum physics has diverse applications, ranging from computing and cryptography to even philosophy, so you can pick the direction that aligns with your interests," says Salini. "Quantum computing is a new field of research, so it's hard to predict all the career opportunities that will emerge in the next decades."

Qubit by Qubit organises quantum-related summer camps, workshops and internships:
www.qubitbyqubit.org

The Sydney Quantum Academy provides information about careers in quantum technology:
www.sydneyquantum.org/quantum-careers

Learn about the quantum physics research being carried out by Salini's colleagues at EQUS (**www.equs.org**) in these Futurum articles:

- **www.futurumcareers.com/what-do-quantum-physicists-know-about-gravitational-waves-and-dark-matter**
- **www.futurumcareers.com/how-can-we-measure-time**

Salini's *top tips*

1. Enjoying your work is key to long-term success.

2. Stay curious and stay persistent.