Quantum Technology

UQ RESEARCH CAPABILITY
Quantum mechanics is considered a cornerstone of modern physics. Atomic, molecular and optical physics, as well as quantum computation and communication, are at the centre of many modern technologies. Quantum theory is central to understanding the world around us, and has opened new questions about the very foundations of physics and science, forcing us to review fundamental notions such as causality, locality, inference, and how effects of gravity combine with quantum effects. UQ is an international leader in the current quantum revolution. Researchers have expertise ranging from fundamental discovery in quantum technology through to applied research including field-based deployment in defence and the development of quantum dot solar cells.

UQ offers a Master of Quantum Technology where engineering, computer science, and mathematics graduates can gain the skills to research and develop quantum technologies capable of changing the future of sensing, communications and computation. The first of its kind in Australia, the 1.5 year program offers a unique mix of fundamental and applied physics.
Quantum computer technology
The Australian Research Council (ARC) Centre of Excellence (COE) for Quantum Computation & Communication Technology (CQC²T) delivers world-leading quantum research.

The CQC²T is developing ultra-fast quantum computing, secure communication and distributed quantum information processing.

CQC²T’s mission is to deliver quantum processors able to run error-corrected algorithms and transfer information across networks with absolute security. Systems that utilise fundamental advances in quantum information research in silicon, optical and networking platforms are also a priority.

The UQ node of CQC²T is developing optical quantum computers, secure terrestrial and satellite-based communications, and quantum repeaters. UQ research involves national and international collaborators, as well industry partners: Quintessence Labs, Xanadu and Northrop-Grumman.

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Engineered quantum systems
The mission of the ARC COE for Engineered Quantum Systems (EQUS) is to engineer the quantum future by building quantum machines that harness the quantum world for practical applications.

The Centre focuses on three research themes: quantum-enabled diagnostics and imaging; quantum engines and instruments; and designer quantum systems.

Led by UQ’s ARC Laureate Fellow Professor Andrew White, EQUS is focused on producing the material building blocks of quantum machines, including diagnostics and imaging technologies. EQUS works with a range of industry partners to ensure modern application of its fundamental discoveries.

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Quantum information
The photon is an ideal carrier of quantum information: its quantum nature survives at room temperature and optical fibre allows long-distance propagation.

Photons are used to develop photonic quantum technologies for improved communication, computation, and sensing, and to demonstrate fundamental features of quantum mechanics.

Researchers in the UQ Quantum Technology Lab are exploring and exploiting the full range of quantum behaviours – notably entanglement – with an eye to engineering new technologies and scientific applications. These include communication, computation, imaging, and sensing.

UQ also has research strength in quantum systems with more than two levels, known as qudits. Experimental quantum information is enabling researchers to explore quantum physics phenomena and develop future quantum technologies.

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Quantum computers already have the speed and agility to solve complex computing problems in a fraction of the time of conventional computing devices. There is an international race to develop a scalable, mass-produced quantum computer that is easily accessible. Such a computer could change the way we live, transform the information economy and create industries of the future. UQ researchers are collaborating with academics and industry both in Australia and abroad to maximise the accessibility of quantum super computers.
Quantum and defence

Quantum technologies are a priority theme for the Australian Defence Next Generation Technologies Fund (NGTF), recognising the potential game-changing capabilities offered by quantum science. UQ has attracted 20 per cent of the total funding for quantum technologies through the Defence Quantum Technologies Research Network, making it the leading university nationally funded through this program. UQ is committed to fundamental discovery that leads to field-based deployment, and researchers are working with the Australian Department of Defence and industry partners to integrate and package quantum sensing technologies in military environments.

Quantum sensing technologies

UQ has strong research strengths in quantum and photonic sensing technologies. The UQ Centre for Microscopy and Microanalysis and the UQ Precision Sensing Initiative house state-of-the-art facilities to fabricate nanoscale quantum devices on a silicon chip, and to package them into field deployable prototypes.

The three-year $1.17 million UQ Precision Sensing Initiative is focused on the physical technologies associated with quantum and photonic sensors, and the engineering architecture required for successful field deployment. Central to the initiative is the Optoelectronic Integration Facility (OIF), which enables researchers to take laboratory proof-of-principle nanotechnologies and integrate them into industry-ready prototypes.

The accelerometers being developed by UQ researchers will be deployed at RIMPAC 2022 (Rim of the Pacific Exercise), the world’s largest international maritime warfare exercise involving forces from Australia, Canada, New Zealand, the United Kingdom and the United States. The accelerometers will be used on maritime platforms in proof-of-principle navigation exercises.

In collaboration with the Australian Department of Defence and other key partners including NASA,

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Lockheed Martin Corporation and Orica, UQ researchers have developed on-chip acoustic sensors and magnetometers. These sensors have one hundred times better sensitivity than was previously possible and state-of-the-art magnetometers that make cryogenics redundant – they can therefore be deployed on drones and other low size-weight-and-power (SWaP) applications. UQ is also developing new forms of accelerometry based on quantum matter waves. Such accelerometers potentially allow precision a billion times superior to existing technology and provide a vital capability for precision navigation via dead-reckoning, particularly for submarines, where GPS is unavailable and in scenarios where GPS has been denied.

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Position, navigation and timing, and situational awareness

Through the Next Generation Technologies Fund, UQ is focused on next generation quantum sensing technologies for situational awareness including improved positioning, navigation and timing (PNT); improved underwater communications; and improved detection of biological and chemical threats, both man-made and natural.

A particular focus is on quantum magnetometers, accelerometers and acoustic sensors that go beyond the capabilities of conventional sensors.

These sensors are crucial tools for navigation in GPS denied environments, such as undersea, and for through-earth and through-sea communications. As well as improved positioning, navigation and communications, UQ’s magnetometers are an enabling technology for chemical analysis via nuclear magnetic resonance, offering disruptive potential in fast characterisation of small biochemical samples.

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Quantum and optical technology

The UQ Queensland Quantum Optics Laboratory researches and develops optical (and) quantum technologies. Researchers are exploiting micro- and nano-scale optical devices, with the goal to test fundamental physics and to develop applications in metrology, communication and biomedical imaging.

Much of the research is based on optical architecture integrated on silicon chips, and is compatible with present-day fibre optical systems. These architectures provide a test bed for a wide range of quantum phenomena including entanglement and non-locality, quantum enhanced measurements and microscopy, quantum optomechanics, and the physics of two-dimensional superfluids.

The robustness and scalability of UQ’s research systems offer potential for the investigation of macroscopic quantum systems and phenomena.
Superfluids

Superfluids – quantum fluids that flow without friction – can be used as matter-wave quantum technologies such as quantum inertial sensors and are an ideal medium for exploring open problems such as turbulence and quantum thermodynamics.

UQ has researchers recognised internationally for their work at the interface between nanotechnology and quantum science. UQ theoretical and experimental programs in quantum fluids include:

- Quantum non-equilibrium dynamics, hydrodynamics, and turbulence
- Bose-Einstein condensate inertial sensors, and atomtronic circuits
- Superfluid helium inertial sensors and turbulence
- Nanophotonics, nanomechanics, quantum optomechanics and photonic/quantum sensing
- Quantum engines and thermodynamics.

Quantum optomechanics

The use of light to control mechanical resonators offers many applications, from quantum-enhanced sensors to quantum computer memories and interfaces.

It further allows fundamental tests of macroscopic quantum mechanics. UQ has made substantial contributions in both the theory and experimentation of quantum optomechanical systems, with contributions in quantum sensing and superfluid optomechanics.

Quantum and energy

Scientific discoveries and new technologies are needed to ensure that the world's growing population has access to food, water, energy and information. This will require sustainable options for the use of natural resources and more efficient means to generate energy, as well as the development of materials that reduce the burden of waste. Computing must become faster and more efficient to deal with vast global data and communication networks.

At the forefront of quantum, nano and theoretical sciences, UQ's world-renowned researchers are discovering the basic principles of materials, matter and energy, and applying these findings to modern technologies.

Quantum dots

UQ researchers have harnessed the unique properties of quantum dots to develop solar cells that capture a wider range of light for energy, are more stable in their energy production and can be applied to curved surfaces.

The technology has the potential to revolutionise solar technology, with everyday objects such as car roofs and smartphones becoming portable solar cells.

Researchers have determined the technology is easy to scale-up, which could reduce the price of solar in the future. Quantum dots have a unique way of absorbing and emitting fluorescent light.

Researchers are currently working to harness power from artificial light sources including indoor lights, and the technology could enable quantum dot technology to eventually charge devices at your desk.

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Reducing energy use

The ARC COE in Future Low-Energy Electronics Technologies (FLEET) addresses a grand challenge of reducing the energy used in information technology, which now accounts for 8 per cent of the electricity use on earth and is doubling every 10 years.

FLEET meets this challenge by realising new types of electronic conduction without resistance in solid-state systems at room temperature.

These concepts will form the basis of new types of switching devices (transistors) with vastly lower energy consumption per computation than silicon complementary metal-oxide-semiconductor (CMOS). Electronic conduction without resistance will be realised in topological insulators that conduct only

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along their edges, and in semiconductors that support superflow of electrons strongly coupled to photons. These pathways are enabled by the new science of atomically thin materials.

Through FLEET, UQ researchers are investigating the methods of reservoirs and open quantum systems to drive transitions between novel non-equilibrium states of matter.

Work focuses on understanding relaxation in non-equilibrium and driven quantum systems, and how coupling to the environment can destroy the target states of interest in the laboratory.

**Superconducting quantum devices**

UQ is home to an Australian experimental lab that builds qubits with superconducting quantum devices. Researchers study quantum phenomena in systems consisting of superconducting artificial atoms, microwave resonators and mechanical oscillators.

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**Quantum biotechnology**

Quantum technologies are projected to have a major impact on biotechnology, from better microscopes to better medical diagnostics, more effective drug development, and improved catalysis and energy harvesting.

UQ has two main research efforts in quantum biotechnology:

- Diamond quantum nanosensors
- Quantum-enhanced/limited microscopes and biosensors.

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