Physics Projects 2014

Make research a part of your degree

Find a project that fits in with your degree
Welcome to Physics Market Day 2014!

Market Day is a unique opportunity for students and staff to meet and discuss the broad range of research projects that are available in the Research School of Physics and Engineering (RSPE) at the ANU. This year we have more than 180 projects on offer across our 10 Departments and Centres and they are being offered at most levels of study within the School.

- PhD/Masters Projects
- Honours Projects
- Advanced Study Course (ASC) projects
- 3rd Year Research Topics
- Vacation Scholar Projects

The projects cover all aspects of the research in RSPE and have potential appeal across the disciplines of Physics, Mathematics, Chemistry, Engineering and even Biology. Indeed, many of the projects have a clear interdisciplinary nature to them which reflects the breadth of interaction within the RSPE. All projects are current as of August 1, 2014.

We hope that you find something to appeal to your interests and curiosity amongst this mix of projects, and warmly encourage you discuss your interests with the academic staff involved.

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A special thanks to Cormac Corr, James Sullivan Jodie Bradby, Patrick Kluth, Tim Wetherell and Martin Conway for their work in putting this together.
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Extreme events happen in nature and in social life. To list a few, we can mention financial disasters, fires, hurricanes, tsunami, rogue waves, stampedes, climate catastrophes etc. Surprisingly, they happen more often than people would normally expect.

Are there common features to be seen in these apparently disparate events?

Can they be described using the tools of modern science?

No doubt, their analysis is vitally important at the present time. Students have a chance to make their own contributions to this science -- it may change the way we will deal with cataclysms in the future.


Required background
Interest in general science and knowledge of mathematics

Project suitability
- Honours project
- PhD or Masters project

Project supervisors

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Localised formations in open systems

Research fields
- Photonics, Lasers and Nonlinear Optics
- Theoretical Physics

Project details
Dissipative solitons can be considered as localized objects in open systems that appear as the result of a balance between energy supply and dissipation. In order to have stationary localized solutions, this balance has to be exact to prevent either an indefinite growth or the complete disappearance of the soliton. Dissipative solitons in these systems also require a balance between the matter supply and loss. These objects are ‘alive’: they oscillate when there isn't enough energy or matter, as if the object were breathing. When matter and energy stops flowing through the system, it ‘dies’. If these processes happen in simple formations like solitons, we can imagine how the very basic forms of life were ‘born’ in nature from non-living elements. Thus, the soliton model can help us to understand basic biological functions. This concept is also well-accepted in optics and generally in physics. It allows us to explain complicated dynamics in simple terms. Students have the chance to make their own contribution to this modern science.

Required background
Interest in general science and knowledge of mathematics

Project suitability
- Honours project
- PhD or Masters project

Project supervisors

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3  Fundamental tests of quantum mechanics with matter waves

Research fields

- Atomic and Molecular Physics
- Quantum Science and Applications

Project details

In 1935, Einstein, Podolsky and Rosen described a thought experiment - the EPR paradox. According to Einstein, the solution to the paradox was that quantum mechanics offers an incomplete picture of our world, and there exists a set of properties which are hidden from our view. In 1964, John Bell proposed a method - the Bell theorem - that would test for the existence of "hidden variables".

Here at the ANU we are in the process of experimentally testing these fundamental tenets of quantum mechanics with matter waves for the first time. We use an excited state of helium (in a metastable excited state - He*) cooled into a Bose-Einstein condensate (BEC) as our matter wave source to generate entangled matter wave pairs. Single-atom-detection of the atom pairs allows us to formulate Bell inequalities - allowing us to test non-local realism with macroscopic matter waves.

The main outcome of the project will be a new fundamental knowledge of large-scale EPR-entanglement and quantum nonlocality with massive particles. First laboratory demonstrations of EPR-entangled photon states that violated the classical bounds demanded by a Bell inequality have been heralded as among the most important experiments of 20th century quantum physics. Such demonstrations, however, have been so far realised only for massless photons and pairs of massive particles, but never for large ensembles of massive particles. Generation of large-scale entanglement is important for understanding how quantum mechanics works on mesoscopic and macroscopic scales, and to determine the ultimate size of future quantum devices.


Required background

An interest in quantum mechanics, optics, atomic physics

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Research fields

- Atomic and Molecular Physics
- Quantum Science and Applications

Project details

This project will measure for the first time the “tune-out” wavelengths for atomic helium.

Modern understanding of atomic structure is based on the theory of quantum electrodynamics (QED). In terms of the ability to predict atomic structure, non-relativistic QED (NRQED) is one of the best-tested theories in modern physics, and consequently attracts considerable interest as advances in experimental precision measurement continually challenge the latest theoretical predictions.

This project will search for the so-called tune-out wavelengths of helium, which occur near atomic transitions where the opposite sign of the respective contributions to the dynamic polarizability of the atom cancel to yield a net zero polarizability. You will use our new atom interferometer facility to accurately determine the frequency of light illuminating the helium atoms for which there is no change in the sensitive interferometric fringe position - the smoking gun for the tune-out wavelength predictions of QED.

Atom interferometry exploits the dual wave/particle nature of atoms by splitting the centre-of-mass atomic de Broglie wave into two paths, then recombining the two partial matter waves to measure the relative phase difference between the two paths. By imposing a varying phase shift on one path relative to the other, the resulting fringe pattern can be determined as a function of the external light frequency. If no change in the fringe pattern is observed the laser light intensity is varied, then the tune-out condition is achieved. The aim is to measure the tune-out wavelength to 1ppm in order to test the latest QED theory.


Required background

Honours in physics with a background in atomic physics.

Project suitability

- PhD or Masters project

Project supervisors

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5  String theory and integrable systems

Research fields
- Theoretical Physics

Project details
Integrability is a beautiful phenomenon usually confined to one- or two-dimensional systems. Recently it was established that higher-dimensional quantum field theories, such as certain supersymmetric Yang-Mills theories in four dimensions and Chern-Simons theories in three dimensions, can also be integrable, at least in their planar limit. The appearance of integrability, yet to be understood, seems to be related to the AdS/CFT mechanism, which connects these field theories to string theories embedded in generalised Anti-de Sitter spacetimes. The emerging structures, such as factorised S-matrices, Bethe equations, thermodynamic Bethe ansatz, quantum algebras, etc. bear many similarities with well-known solvable models (Heisenberg magnets, Hubbard models, Sine-Gordon models, two-dimensional sigma models), but seem to generalise and unify them in yet-to-be understood ways.

This project aims to develop and employ the full power of the theory of integrable quantum systems to new models of quantum many-body spin systems in string theory. These models have been placed at the international centre-stage of developments in string theory in a series of recent surprising and unexpected mathematical connections, which relate spectra of free strings in the AdS5/S5 curved background to the spectra of the Heisenberg type spin Hamiltonians with non-local interactions. Several student projects of various complexity are available at the honours and PhD levels.

Required background
MATH3351, PHYS3001

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Theoretical Physics

Project details
It is well known that the quasiclassical quantisation of the harmonic oscillator leads to its exact quantum mechanical spectrum. Remarkably, this result can be generalized to various anharmonic systems via mysterious connections to Conformal Field Theory. The idea is that the exact quantisation conditions take the form of the so-called Bethe Ansatz equations, which are the key transcendental equations in the theory of integrable quantum system. This phenomenon is known as the ODE/IM correspondence. (ODE stands for "ordinary differential equations" and IM for "integrable models").

At the honours level the project will consist of an advanced study of the quasiclassical approximation to the Schrödinger equation in quantum mechanics.

At the Masters and PhD levels the project will aim to construct and study new cases of the ODE/IM correspondence for systems with extended conformal symmetry, connected to W-algebras. Remarkably the problem have important applications to mesoscopic quantum systems, e.g. Kondo impurities and ultra-small Josephson junctions.

Literature.

Required background
Advanced level courses in maths and theoretical physics.

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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Research fields

- Theoretical Physics

Project details

Conformal Field Theory (CFT) in two-dimensions describes physics of the second order transitions in statistical mechanics and also plays important role in string theory, which is expected to unify the theory of strong interaction with quantum gravity. It is quite remarkable that CFT is a completely integrable quantum system leading to new fascinating mathematical structures in the theory of infinite-dimensional Lie algebras and the theory of differential equations.

At the honours level the project will consist of studying the basics of CFT and understanding its connection to the theory of quantum groups and the theory of integrable quantum systems.

At the masters and PhD levels the project aims to study the problem of diagonalization of an infinite-dimensional abelian subalgebra for various W-algebras of (extended) conformal symmetry and the problem of construction of reflection matrices of the corresponding Weyl groups.

Literature.


Required background

Advanced level maths courses.

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Theoretical Physics

Project details
It appears that the scattering amplitudes in Quantum Chromodynamics (theory of strong interactions) can be exactly calculated in certain limiting cases (e.g. in the so-called multi-Regge kinematics). This is possible due to remarkable connections of this problem to the theory of integrable systems based on the Yang-Baxter equation.

At the honours level the project will focus on the review of known results for calculation of scattering amplitudes and Wilson loop integrals in gauge theories and their string theory description in terms of minimal surfaces in the anti-de-Sitter space.

At the Masters and PhD levels the project will aim to generalise existing results to other cases by using new solutions of the Yang-Baxter equation.

Literature.

Required background
Advanced level courses in maths and theoretical physics

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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9. New connections between classical and quantum field theories

Research fields
- Theoretical Physics

Project details
The standard correspondence principle implies that quantum theory reduces to classical theory in the limit of the vanishing Planck constant. This project is devoted to a new type connection between quantum and classical systems which holds for arbitrary finite values of the Planck constant. The connection relates integrable quantum field theory (QFT) with integrable classical non-linear evolution equations in two space-time dimensions. More precisely there is a one-to-one correspondence between stationary states in the quantum theory and singular solutions of the classical evolution equations.

At the honours level the project will consist of a basic introduction into integrable quantum (classical) field theory in two dimensions (2D).

At the Masters and PhD levels the project will aim to apply this connection to study some important models of 2D QFT, in particular, the so-called non-linear sigma models. The required techniques range from the spectral theory of differential equations and theory of integrable quantum systems to numerical analysis of partial differential equations on the super-computer.

Literature.


Required background
Advanced maths and theoretical physics courses.

Project suitability
- Honours project
- PhD or Masters project

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Research fields

- Fusion and Plasma Confinement
- Clean Energy

Project details

Recent advances in databases and intelligent algorithms have enabled machine-based “trawling” of very large databases, to find both prescribed or already known phenomena, and by looking for data that does not fit known patterns, discover new behaviour. Association rules or clustering algorithms even allow machines to discern patterns without human guidance. H-1 provides a rich variety of instability phenomena, from the drift frequency range (low kHz) to higher magnetohydrodynamic (MHD) frequencies up to ~ 1MHz, from several types of sensor array sets. These include two 20 channel magnetic probe arrays (“Mirnov”), a new toroidal-helical array, two arrays of visible light detectors (miniature photomultiplier arrays), two “soft” X-ray arrays and a new 20 channel plasma density interferometers. The “Datamining” project is a combination of development of algorithms as described above, and physical understanding of the phenomena, with a weighting to best fit the student’s interest and ability. There may be opportunities to apply this technique to data from other leading international devices, either remotely, or on a short visit.

Required background

Students will need to have an interest in plasmas, fusion and data analysis. The work will involve data acquisition and analysis, so familiarity with computer programming languages such as Python, IDL or something equivalent would be an advantage, as would experience in signal processing or data mining. The scope and depth of the work can be adapted to suit the interests of the student, with more or less emphasis on computational, physics or signal processing aspects.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Frequency-time graph of and instability in hydrogen/helium plasma, overlaid with the time evolution of plasma density in green

Project supervisor

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11 Mapping magnetic field configurations in the H-1 Heliac

Research fields
- Fusion and Plasma Confinement
- Clean Energy

Project details
The unique heliac plasma shape is generated by a carefully designed, fully three dimensional magnetic field. The magnetic field lines can be directly mapped by launching electrons, and collecting them on a 64 wire grid array. The data is tomographically inverted by existing algorithms. This apparatus has been recently upgraded, and the project is to map the magnetic field for various configurations, looking at sensitivity to small changes in current, formation of magnetic islands, and the chaotic region at the plasma edge.

For example, the n=3, m=2 island in H-1 is equivalent to the recently discovered 'knotatron' configuration (Hudson, 2014). Another recent development is the multivariate optimisation of a general model of the magnetic field of H-1. By mapping unexplored configurations, the accuracy of this model can be improved.

You will get experience in
- elementary electron optics
- magnetic fields and their geometries
- image processing techniques
- chaos and related phenomena
- physics related to high vacuum

The scope and depth of the work can be adapted to suit the interests of the student. This project could be extended to a PhD level by inclusion of plasma experiments, or by more detailed studies of transition to chaos and related phenomena.


http://w3.pppl.gov/~shudson/bibliography.html

Required background
Students should have an interest in experimental work in plasmas and fusion. The work will involve both data acquisition and analysis, so familiarity with computer programming languages such as IDL, Matlab, python or something equivalent would be an advantage. Students could optionally extend the work to include calculation of 3D magnetic fields.

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
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Research fields
- Fusion and Plasma Confinement
- Clean Energy

Project details
Magnetic confinement of plasma is achieved by creating a closed magnetic geometry in the form of a torus. Improved stability and confinement can be obtained by twisting the magnetic field lines. H-1 allows flexible variation of the twist, and even the shape of the plasma by computer control. This project examines the particle (electron and ion) confinement properties by measuring the response of plasma density to a time-varying input of fuel gas. The gas, usually hydrogen, deuterium or helium, is introduced by a supersonic gas puffer controlled by a waveform generator. The plasma density is measured by a 21 channel interferometer which provides line integrals of density along the 21 paths. These can be converted into a profile of density by suitable inversion methods, such as tomography.

Particle confinement times in H-1 are ~ 5-10ms and are influenced by the magnetic geometry, plasma generation method and level of plasma fluctuations. By use of tailored injection waveforms, from short puffs to periodic waveforms, the propagation of waves of density may be observed, allowing inference of the diffusion and confinement properties, in plasma geometries ranging from well-nested surfaces to magnetic islands and chaos.

Required background
Plasma physics special topic, some atomic physics is preferable, analysis will use python, matlab or IDL and techniques of inversion, such as tomography.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisors

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- John Howard
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Research fields
- Theoretical Physics

Project details
String theory is, at present, the only candidate for a consistent unification of all four fundamental forces. Many important advances in String Theory have been made in the last couple of years. These include: String dualities, a microscopic derivation of the Bekenstein-Hawking black-hole entropy, a concrete manifestation of the holographic principle (AdS/CFT correspondence), the emergence of noncommutative geometry as a candidate for the quantum geometry of spacetime, the classification of D-brane changes in terms of K-theory and the relation to the geometric Langlands program. This project aims to investigate one of more of these advances in more detail.

Required background
PHYS3002, MATH3351, MATH3342, MATH3344, MATH2322/3104

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Theoretical Physics

Project details
The project aims to give a basic introduction to String Theory, and the mathematical techniques required, by working through (part of) the undergraduate textbook "A First Course in String Theory" by Barton Zwiebach (Cambridge University Press, 2004). The student will be required to work through a selected set of questions from the textbook.

Required background
PHYS2013, PHYS2016, MATH2406, MATH2322/3104

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisor
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15 Generalized geometry and its applications

Research fields
- Theoretical Physics

Project details
Generalized geometry, whose definition was inspired in particular by duality symmetries in String Theory, was recently put into a rigorous mathematical framework by Hitchin [Hi] and his students [Ca, Gu]. At the most basic level it amounts to replacing structures defined on the tangent bundle of a manifold by similarly defined structures of the direct sum of tangent and cotangent bundle. As such there exist generalizations of complex manifolds, Kahler manifolds, Calabi-Yau manifolds, etc. This project aims to review these developments and their applications.

References:

Required background
PHYS3002, MATH3342, MATH2322/3104

Project suitability
- Honours project
- Summer research scholarship

Project supervisor
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Research fields
- Theoretical Physics

Project details
Collective excitations in quantum many body systems (as, e.g., in the fractional quantum Hall effect) often exhibit statistics different from the usual boson or fermion statistics. A particular form of these more general exclusion statistics has been introduced by Haldane (see, e.g., [ABS]). The aim of this project is to investigate aspects of these more general exclusion statistics using techniques from algebraic geometry. See, e.g., [B,BH]

References:


Required background
PHYS3002, MATH2322/3104, MATH3351

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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Research fields

- Theoretical Physics

Project details

The classification of topological phases for non-interacting fermionic systems (such as the integer quantum Hall fluids) is by now well-understood. One of the main current challenges is to extend this to strongly interacting systems (such as the fractional quantum Hall fluids). Here very little is known in the literature, basically because generically one cannot exactly solve strongly interacting systems. One approach is to look at an effective theory of non-interacting quasi-particles.

Specifically, the aim of this honours project is to describe the topological phases of (free) parafermionic models along the lines of the phases for (free) electron models.

While in the non-interacting case the classification boils down to understanding Clifford algebras, their modules and associated K-theory, and constructing Hamiltonians out of this, the parafermionic case involves the study of all of these aspects for so-called generalised Clifford algebras.

Required background

PHYS3002, MATH2322/3104, MATH3351

Project suitability

- Honours project
- PhD or Masters project

Project supervisor

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Synthesis of new materials by extreme pressures

Research fields
- Materials Science and Engineering

Project details
High pressure transformations of group IV elements are interesting from both a fundamental and technological standpoint. Diamond-cubic Si and Ge transform to a series of metallic phases on loading in a diamond anvil cell (DAC). Upon pressure release, these transitions are reversible until the last (on unloading) metallic (β-Sn) structure is reached. Upon further unloading the original cubic phase is not regained and instead other metastable crystalline phases are formed.

In the Si system, first the rhombohedral R8 phase is formed followed by the nucleation of the body-centered BC8 structure and a mixture of the two phases (R8 and BC8) is routinely observed after point loading with an indentation system. To date it has not been possible to synthesize significant quantities of pure R8-Si at ambient pressure. The Ge system is complex on unloading with only rapid unloading yielding the same pathway of β-Sn to R8 to BC8. Slow unloading results in the formation of a tetragonal ST12 phase.

These end phases are of particular interest but very little experimental or modelling work has been done to understand their formation or properties.

A new in-house Raman system will be used to probe the evolution of phases in addition to the standard X-ray diffraction studies conducted using high-pressure beamlines at synchrotrons in both Australia and overseas.

Required background
Ideally students would have a background and strong interest in condensed matter physics.

Project suitability
- Honours project
- PhD or Masters project

Project supervisors

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19 Probing the mechanical response of plant cells

Research fields
- Biophysics
- Materials Science and Engineering

Project details
Arabidopsis thaliana is a model plant organism – i.e the ‘white-mouse’ of plant biology. It has been shown that this plant responds to local forces by reorganising certain cell components, including elements of the cell’s cytoskeleton, actin microfilaments and cortical microtubules.

Disease-causing pathogens infect plants causing irreparable damage to plant cells. The processes involved in such ‘attacks’ are both chemical and physical in nature. This project aims to investigate the physical aspects of such a process by mimicking the physical method of infection using a nanoindentation probe which can apply a force of in the µN-range to the plant’s cell wall. This is a collaboration with Prof Adrienne Hardham at the Research School of Biology.

Required background
Some knowledge of plant biology would be useful but is not essential.

Project suitability
- PhD or Masters project

Plant cell before and after probing using nanoindentation

Project supervisor
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Research fields
- Materials Science and Engineering

Project details
Diamond cubic silicon (dc-Si) is known to phase transform under pressure to many different structures. Two phases that form after applying pressure include a technologically-interesting bc8/r8 mix. The r8 phase has been theorized to be a narrow band gap semiconductor and suitable for solar cells. The interesting phases are formed by applying pressure to Si in excess of 11 GPa and inducing a transformation to the first metallic phase of silicon.

Upon unloading using a diamond-anvil cell, the β-Sn phase transforms first to r8-Si at 11-2 GPa before transforming again to bc8-Si at 2 GPa which remains stable at ambient temperature and pressure. Interestingly, upon unloading using another method of pressure application, nanoindentation, the stable end phase is a mixture of both the bc8 and r8 phases (bc8/r8 mix).

To date there has been much work on optimising and understanding the resulting nanoindentation-induced bc8/r8 mix using the parameters of tip shape, maximum load, substrate material and indenting temperature. In this project we aim to investigate a new parameter that affects the formation of bc8/r8, the introduction of a hold interval at the maximum load that has been observed to affect the nucleation of the metallic phase. Several materials techniques including Raman micro-spectroscopy, electron microscopy and focussed ion-beam milling will be used to understand and characterise the end phases.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project

Project supervisors
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The Heisenberg uncertainty principle limits the ways in which it is possible to measure the state of things. Historically, this has been seen as a bad thing. More recently, however, there has been an outbreak of proposals that suggest Heisenberg uncertainty could be used as an integral part of “quantum information systems”. Of these, quantum key distribution (QKD) is the most advanced. This technique allows the sharing of a secret key between remote parties over an open communication channel. Although QKD has been demonstrated in optical fibres over distances over 200km [1], beyond this distance it becomes very slow or even impossible to share a key.

One possible method to fix this problem is to build a quantum repeater [2]. These devices, which are yet to be demonstrated, will extend the range of quantum communication beyond the current limit. Integral to proposed repeaters is some kind of memory capable of storing, and recalling on demand, quantum states of light [3].

Our approach to building a quantum memory relies on reversible absorption in an ensemble of atoms. This is a photon-echo technique known as a “gradient echo memory” (GEM). Our scheme has a lot of interesting properties, including the ability to change the ordering, frequency and shape of the stored light pulses. [4]


Required background
The project could be experimental or involve theoretical modelling. While not essential, for experiments, any knowledge of lasers, atoms, quantum mechanics and LabVIEW will help, for theory, some experience with numerical modelling would be good.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

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Quantum opto-mechanics

Research fields
- Photonics, Lasers and Nonlinear Optics
- Quantum Devices and Technology

Project details
Ultimately, everything in the universe is thought to obey the laws of quantum physics. Yet until recently, there was little prospect of actually observing quantum behaviour in macroscopic systems. The quantum nature of macroscopic objects is usually hidden because of thermal fluctuations and interaction with the environment. One route to observing large scale quantum behaviour is through experiments with opto-mechanical systems. Generally, this refers to a system with ultra-high quality factor resonances in both mechanical and optical modes, allowing coherent exchange of information between these degrees of freedom. The exchange is mediated by radiation pressure, where the photons in the optical mode can be red- or blue-shifted by creating or destroying a phonon in the mechanical mode. In this way the motion of a mechanical oscillator can be coupled to an optical resonance that allows both control and read-out of the mechanical mode.

In this experiment we use a nano-wire made of silver-gallium and we measure its motion using a laser. Using a second laser we can apply a force that we can use for active feedback control to cool the thermal vibrations.

In the long term we hope to find ways to bring this, or similar systems into the quantum motional ground state, making it possible, in principle, to prepare entangled states of macroscopic systems.

For more information on this research field, check out this recent review: http://arxiv.org/pdf/1210.3619v1.pdf

For more information on our research group look here: http://photonics.anu.edu.au/

Required background
Experience with lasers, optics and quantum mechanics would be helpful.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Research fields

- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details

At the nanoscale dimensions, shape matters. Indeed the continuous reduction in semiconductor materials volume, which drives the improved performance of nanoelectronics, energy and optoelectronic devices lead to objects whose properties are controlled by their surface atoms rather than by their internal structure (e.g. metal nanoparticle catalysts). One of this peculiar geometries is the nanowire – with length which can be several microns long while having a diameter of as small as a few nanometers. Stemming from the results we discovered in the course of nanowire research, **we propose to investigate nanostructures with new geometries and understand their structure/properties** by using of our new metalorganic vapour phase epitaxy facility, optical spectroscopy (microphotoluminescence, Raman spectroscopy), electron microscopies (scanning and transmission electron microscopes, X-ray energy dispersive spectroscopy) and nanofabrication facility (located in the ANFF cleanrooms).

Taking the inspiration from real trees, we aim at building functional nanotrees with the potential for energy applications (solar cells) including p-n junctions and heterostructures (sandwiches of different materials stacked along the axes or around as multi-shells) and realising other complex geometries such as nanoloops, nanoribbons and nanomembranes. These new geometries will enable the realisation of a whole new class of nanoscale devices with different functionalities.

In this project you will participate in synthesizing free-standing nanocrystals with new geometries in position controlled arrays on pre-patterned substrates using our nanofabrication facilities. You will then study their structural, optical and electronic properties. In particular electron mobility and quantum efficiency are considered the key figures of merit for high quality nanomaterials and will be extracted by mathematically fitting the results gained by advanced optical spectroscopy and electrical measurements.

Required background

Physics, Material Science, Engineering

Project suitability

- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Hoe Tan
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Zn-based II-V nanocrystals: a new class of semiconductor materials

Research fields

- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details

Nanoscale semiconductor materials are at the heart of most of the advanced energy (solar, thermoelectric), nanoelectronics (beyond Moore’s Law in downscaling transistor size below 10 nm), and optoelectronics (lasers and integrated photonics) applications. However III-V semiconductors, representing a multi-billion high-tech industry, suffer from a very small relative abundance in the earth crust and are therefore extremely expensive, which is not sustainable in the long term or for use in large scale energy production units. Therefore new, high quality earth crust abundant nanomaterials must be developed with similar or even better properties. These properties stem from their electronic bandstructure, which itself is related to their atomic constituents and their relative position in the crystal unit cell. The electronic properties can be controlled with very high precision by tuning the crystal structure/composition of the II-V semiconductors and by combining different nanomaterials in multilayers (heterostructures).

We have very recently successfully initiated pioneering research on Zn-based II-V nanoscale semiconductor materials using a conventional metalorganic vapour phase epitaxy (MOVPE) system, the same growth technique used in the semiconductor industry. These novel nanomaterials are emerging as candidates to replace or at least to complement III-V nanoscale crystals in a wealth of advanced applications.

In this project, you will participate in growing these new nanocrystals in the MOVPE system. You will then study and reveal their fundamental structural and optical properties using optical spectroscopy techniques (microphotoluminescence, raman spectroscopy) and electron microscopes (scanning electron microscopy, X-ray energy dispersive spectroscopy, transmission electron microscopy). Because these nanomaterials are very little known until now, the work will be exploratory. Two possible approaches are suggested:

- Understanding the growth mechanism, e. g. which metal seed/substrate combination are most suited, can the nanostructures be alloyed or grown as heterostructures?

- Understanding the II-V nanostructures’ optical (bandgap, impurity level, band alignment) and electronic properties (type and concentration of impurities, mobility) and explore the possibility of realizing p-(i)-n junctions in a simple device geometry (2-terminal diodes).

Required background

Physics, Material Science, Engineering

Project suitability

- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

<table>
<thead>
<tr>
<th>Philippe Caroff</th>
<th>Hoe Tan</th>
<th>Lan Fu</th>
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<tbody>
<tr>
<td>Fellow &amp; ARC Future Fellow</td>
<td>Professor &amp; ARC Future Fellow</td>
<td>Senior Fellow and ARC Future Fellow</td>
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<td>02 6125 4060 <a href="mailto:lan.fu@anu.edu.au">lan.fu@anu.edu.au</a></td>
</tr>
</tbody>
</table>
Research fields
- Quantum Science and Applications

Project details
An interesting aspect of quantum mechanics is that the state of a quantum system evolves not only via the deterministic dynamics given by the Schrödinger equation but also in a stochastic way when measured. Therefore, measurements are not only a way to extract information about quantum systems but also a possible strategy to manipulate their state.

This theoretical project aims to investigate how different feedback strategies can be used to produce interesting quantum states and control their dynamics. Our major goal is to design realistic proposals that could be implemented in current experiments in microwave cavity quantum electrodynamics (CQED). Recent experiments in this field investigated fundamental aspects of quantum mechanics including the measurement of the decoherence of a Schrödinger cat state, quantum non-demolition measurement of single photons, and the observation of quantum jumps of light.

During this project the student will have the opportunity to develop analytical and numerical skills in different areas such as:

- Quantum optics
- Quantum information
- Cavity quantum electrodynamics
- Control theory

Required background
Quantum mechanics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor
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Research fields
- Quantum Science and Applications

Project details
Just as in the classical case, where transmission over large distances become impractical due to losses, long distance transfer of quantum information would require the breakdown of the channel length into shorter segments linking various nodes. The information would then be transmitted from node to node in a more efficient way until reaching the final destination. The design of quantum networks would then require an understanding of how the nodes are connected and the entangling properties of these bonds.

This project will investigate such properties in a lattice of quantum systems where the connection between nodes changes randomly due to quantum measurements. Our goal is to investigate the connectivity of this lattice and the consequences for the entangled state that is produced in this process. We will also consider how different measurement processes and imperfect connections affect the entangling properties of the network.

During this project the student will have the opportunity to develop analytical and numerical skills in different areas such as:

- Quantum optics
- Quantum information
- Stochastic dynamics

Required background
Quantum Mechanics

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Quantum Science and Applications

Project details
Over the past years quantum information science has motivated the investigation of memories that can preserve the quantum characteristics of optical states. These quantum memories are key ingredients for quantum repeaters that would allow propagation of quantum states over large distance.

Experiments involving quantum memories have been performed at the Quantum Optics group and the Laser Physics Centre at the ANU, with states of light being stored and then retrieved at a later time using gradient echo techniques. With this project we aim to explore the possibilities available in these experiments to manipulate the state of the memory and engineer the state of light at the memory output.

During this project the student will have the opportunity to develop skills in different areas such as:
- Quantum optics
- Quantum Information
- Atom-light interaction

Required background
Quantum mechanics

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor
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Research fields
- Quantum Science and Applications

Project details
Data hiding, encoding and remote state preparation are examples of tasks that can be performed using quantum random unitary operations. Although useful, these operations cannot be generated efficiently. For some problems, however, approximations to the random ensemble suffice.

This project will investigate realistic physical implementations of these pseudorandom operations arising from the intrinsically stochastic nature of quantum measurements. Our goal is to identify and characterise the pseudorandom ensemble generated by the physical process and analyse its properties.

During this project the student will have the opportunity to develop skills in different areas such as:

- Quantum optics
- Quantum Information
- Stochastic methods

Required background
Quantum mechanics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- PhD or Masters project

Project supervisor
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Research fields
- Quantum Science and Applications

Project details
A major goal in quantum control is to generate and stabilise quantum states that would be otherwise fragile to any interaction with the surrounding environment. One of the strategies to achieve this is to use measurement-based feedback, where classical information is extracted via measurements and then used to manipulate the system. Because we want to keep the quantum features of the states, one could argue that the acquisition of classical information via measurement is not only an unnecessary step but perhaps an unwanted one. A possible solution is to manipulate and feedback the full quantum channel, retaining in that way the full quantum feature of the system.

This project aims to theoretically investigate how to design coherent feedback strategies to produce and stabilise interesting states in quantum systems. Our major goal is to design realistic proposals that could be implemented in current experiments in circuit quantum electrodynamics (CQED) and in optomechanical systems. In the optomechanical regime, we would focus on the experimental systems available at the ANU Quantum Optics group.

During this project the student will have the opportunity to develop analytical and numerical skills in different areas such as:

- Quantum optics.
- Quantum information.
- Quantum control.

Required background
Quantum mechanics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details
Fibre optic sensing arrays are beginning to see deployment in the oil and gas exploration industry, smart structures, naval submarine surveillance and other defence and security systems. Each fibre optic device acts as a listening element for seismic, mechanical or acoustic signals. With appropriate signal processing, a three-dimensional seismic or acoustic image over a large area can be constructed.

This project will continue the ongoing experimental research at the ANU to develop arrays for remote sensing at distances over 100 km. We aim to improve the sensitivity and cost-effectiveness of such sensing arrays using digital interferometry (DI). We will capitalise on DI’s ability to simultaneously measure multiple elements with a single laser and a single detector to develop new array architectures and techniques.

Required background
Students will require a background in optics and signal processing.

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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31 Gas sensing of carbon dioxide

Research fields

- Photonics, Lasers and Nonlinear Optics
- Biophysics

Project details

The molecular spectroscopy of CO2 is important for testing of performance enhancing drugs such as synthetic testosterone, and forensic analysis of illicit drugs such as heroine. The monitoring of atmospheric CO2 isotopes also provides an important tool for understanding the carbon cycle dynamics of the earth’s climate system.

The ANU is collaborating with the National Measurement Institute and industry partners to develop a highly sensitive spectrometry technique for CO2, with seed funding to commercialise the technology for field deployment. We use lasers to measure spectral absorption in CO2 using high-resolution optical interferometry, where its sensitivity is enhanced using resonant optical cavities. This effort requires multi-disciplinary R&D, and there are several experimental projects to work on, involving laser optics, physical chemistry, mechanical design, and control systems.

Required background

Students will require a background in optics and signal processing.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details
Due to the unique light weight and small footprint of optical fibres, they can be attached to musical instruments without significant alteration of their acoustic behaviour. The vibrational modes of the instrument then introduces a time-varying change in the optical path length of the optical fibre. A fibre optic interferometer can detect these displacements with very high resolution, and this signal can then be recorded with very high fidelity. This project investigates various aspects of this concept, including acoustic modelling, transducer design, and signal processing and analysis.

Required background
Students will require a background in optics and signal processing.

Project suitability
- PhB (2nd or 3rd year project)
- Honours project

Project supervisors
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33 Photonic bandages

Research fields
- Photonics, Lasers and Nonlinear Optics
- Biophysics

Project details
This project develops an optical coherence tomography (OCT) system to map a 3D image of porous materials, with the aim of implanting these materials in living organisms as a photonic bandage for in vivo monitoring of tissue healing.

Optical coherence tomography (OCT) is a non-invasive method for the analysis of material properties. It uses a low coherence optical source and white light interferometry to provide a 3D mapping of material optical reflectance and index of refraction. Recently, new porous structures have been developed, where biomolecules can bind to these substrates, thereby altering its optical properties. It has been proposed that by implanting these materials in damaged tissues of living organisms, we can monitor the healing process by using OCT. There are various aspects to this project, including design and implementation of the white light interferometer, opto-mechanical design of the probe, and testing in living tissues.

Required background
First year physics, basic knowledge of electromagnetism and/or optics.

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Roland Fleddermann
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Research fields
- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details
An optical frequency comb is an ultra-short pulsed laser whose repetition rate is locked to the accuracy of an atomic clock, such as those based on the electronic transition frequencies of Rubidium and Caesium. This pulse train in the time domain is represented as a "comb" of frequencies in the Fourier domain. The stability of the wavelength and hence frequency of each "tooth" in the comb is then also referenced to the atomic clock, thus tying the three important standards of time, length and frequency.

In this project, we will use a commercial turn-key frequency comb, which spans the visible and infra-red spectrum, as an absolute frequency reference. The aim is to develop a stabilisation scheme for an auxiliary laser using this reference to make ultra-high resolution displacement measurements for instrumentation in gravitational wave physics.

In a different application, we aim to use heterodyne interferometry involving an auxiliary laser referenced to the frequency comb to facilitate ultra-precise lineshape measurements of molecular optical absorption transitions.

One exciting prospect is to distribute these frequency stabilised optical sources across a building, or between remotely separated laboratories using optical fibres. It is known that a length of fibre can introduce random Doppler shifts to the laser frequency. We aim to design and implement a system to cancel these remote delivery noise sources using digital signal processing.

Required background
Electromagnetism, knowledge of optical physics

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Contact Information</th>
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</table>
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The limits of measurement and communication technology

Research fields
- Quantum Science and Applications
- Engineering in Physics

Project details
We (the human species) are keen observers of our world and our universe. That is, we measure the world around us precisely. We use those measurements to predict future events. That is, we calculate based on our measured data. We communicate our data and our findings in sophisticated ways using sophisticated technology.

Computation, communication and measurement are three endeavours that are critical to our success as a species, and they are three key technologies that underpin our modern society. Several questions arise.

1. What is the current state of the art in computation speed, communication rates, and measurement precision?
2. What technical limits need to be overcome to advance these three areas of human endeavour?
3. What fundamental limits need to be overcome to advance these three areas of human endeavour?
4. If we could advance any or all of these areas substantially, what new technologies or fundamental investigations might be enabled by that advance?

This is a project that will involve deep investigation into the limits of state of the art and future technologies.

Required background
This project is appropriate for second and third year students who have completed or who are taking quantum mechanics and electricity and magnetism at second year level.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)

Project supervisors

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Research fields
- Materials Science and Engineering
- Engineering in Physics

Project details
In this project, we will design and print a beam splitter mount and mirror mounts to hold optics in a precision optical interferometer, and we will assess the stability of the mounts relative to traditional commercial mounts. After designing and printing the mounts, the student will construct two Michelson interferometers. One interferometer will be constructed from commercial optics mounts. The second interferometer will be constructed from printed mounts. The student will monitor the stability of the signal from the interferometers. A variety of environmental signals (temperature, vibration, acoustic drive etc) will also be monitored. We will compare the stability of the two set ups and assess their suitability for a variety of applications in precision measurement. We aim to publish the results of this work.

Required background
An enquiring mind.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisors

<table>
<thead>
<tr>
<th>John Close</th>
<th>Nicholas Robins</th>
<th>Kyle Hardman</th>
<th>John Debs</th>
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<tr>
<td>Deputy Director (Education)</td>
<td>Fellow</td>
<td>PhD</td>
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Research fields
- Engineering in Physics

Project details
The aim of this project will be to compare three technologies for measuring accelerations and rotations. Specifically, we will construct a gyroscope using mems sensors and a ring laser gyro and quantitatively compare their performance by plotting their Allen variance. This two sample variance is a standard tool used to compare different precision measurement technologies. In turn, we will compare these two technologies to gyroscopes and accelerometers based on ultra-cold atom technology. In the first instance, we will probably gain access to the mems sensors in a mobile phone to study mems technology. We will follow that by the construction of our own mems based devices and then construct a ring laser gyro to compare the technologies. The student will be introduced to our research laboratories and will operate an ultra-cold atom sensor.

Required background
This is an experimental project that will require a hands on student.

Project suitability
- Third year special research topic
- PhD (1st year project)
- PhD (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisors

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Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

Project details
Berry's phase is a geometric phase that systems may acquire when they are cycled. The aim of this project is understand the Berry's phase shift in classical and quantum systems in detail and to address questions such as:

1. Is the Berry phase additional to the quantum phase we would calculate from the system Hamiltonian or can it be regarded as a contribution to the total phase shift that is calculated from the system Hamiltonian?

2. What quantum systems display a Berry's phase and is the phenomenon useful in technology?

Required background
2nd year quantum mechanics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)

Project supervisors

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Research fields
- Engineering in Physics

Project details
In this project, we will investigate the dynamics of the motion of a drum stick as it falls and rebounds from a drum head. We will record and measure the motion of the drum stick and model the motion. The equation of motion for the drumstick is non-linear and will require numerical solution. It is interesting that the position of the fulcrum that the drum stick rotates around (the drummer’s index finger) has a very strong influence on the dynamics of the drum stick. If the drummer holds the stick too near or too far from the end of the stick, it does not rebound correctly. We will quantitatively investigate this effect among others and ask whether we can design a better drum stick by varying the mass per unit length of the stick along the length of the drum stick and by varying the mechanical properties of the drum stick.

In addition to the dynamics of the stick, we will experimentally and theoretically investigate the frequency spectrum of the sound produced by the drum for different designs of drumstick. We will study, both theoretically and experimentally, drumsticks with different weights, different tapers and different tip designs.

Required background
An enquiring mind. A desire to perform both experimental and numerical work. Drumming skills are not necessary, but the project may appeal to a student interested in physics and music.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisors

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Gordon McDonald
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Research fields
- Fusion and Plasma Confinement
- Materials Science and Engineering

Project details
The decision to construct the first reactor scale fusion machine, ITER, marks a commitment by the world to develop fusion as an alternative sustainable clean energy source. The science and technology of materials under extreme heat loads are critical to the success of plasma fusion reactors such as ITER and is an area requiring significant research and development. A major challenge for successful operation is to control thermal and particle transport at the boundary that isolates the fusion core (10^9 K) from the low temperature wall (10^3 K).

The purpose-built linear plasma device, the MAGnetized Plasma Interaction Experiment (MAGPIE), has been constructed in the Plasma Research Laboratory of the Australian National University (ANU) to develop novel diagnostics and test materials under aggressive plasma conditions. This linear plasma device employs a combination of a high-power radio-frequency plasma source, a target chamber and a set of diagnostics for plasma and material analysis.

We are combining plasma studies with advanced material characterisation methods to improve the current understanding of materials exposed to fusion relevant conditions. The non-intrusive plasma diagnostic techniques include pulsed-induced fluorescence, laser induced fluorescence and optical emission spectroscopy. These are applied to investigate erosion and fuel retention (or surface-recombination coefficient) of materials. Of particular interest to this research program is the interdependent effect of thermal and particle fluxes at the plasma-material interface.

Both experimental and modeling based projects can be undertaken.

Required background
A physics or materials background would be preferable.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
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41 Physics of pulsed negative ion plasmas

Research fields
- Plasma Applications and Technology

Project details
Radio-frequency (RF) plasmas play a critical role in advanced technologies such as fusion heating, TV-displays, mobile phones, solar-cells, nano-chip fabrication, aerospace applications, high-efficiency lighting, biomedicine and cancer treatment. Intriguing fundamental scientific issues and the enormous social impact that result from their applications drive the field of plasma science and technology. Despite the significant benefit such technologies deliver, the physics of RF plasmas remains a challenging field. It is of importance to investigate highly promising new plasma sources that can pave the way for future technologies.

Existing plasma processes, typically based on the standard continuous wave (CW) plasma production mechanism, are reaching their limits for achieving control at the atomic scale that is critical to providing perfect selectivity and dimension control for next generation devices [1]. A cost-effective solution is to develop more controls on existing plasma tools. These new “control knobs” should allow tuning of the plasma to precisely control electron, ion and photon energy distributions and fluxes at the surface of materials. Pulsed plasma sources, whereby switching the RF power on and off periodically modulates the plasma, are attracting considerable interest in device fabrication. Pulsing provides two new control knobs – the pulsing frequency and the duty cycle of the pulses – and could provide many new opportunities for optimising the plasma-processing environment [2].

Both experimental and modeling based projects can be undertaken.


Required background
A background in Physics is desirable.

Project suitability
- Third year special research topic
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
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Research fields

- Fusion and Plasma Confinement
- Materials Science and Engineering

Project details

Plasma-facing materials in fusion reactors must be capable of withstanding large heat loads (more than 10 MW/m²) due to energetic charged and neutral particle bombardment (eV to keV), as well as the high-energy neutron flux (14.1 MeV) created by the fusion reactions. Although a substantial body of knowledge on the interactions of energetic ion beams with materials has been obtained under controlled conditions using accelerators, the fundamental science at the plasma-material interface has received much less attention due to access restrictions, curved toroidal geometry, and complex programmatic priorities of fusion devices. The recent development of high-flux linear plasma devices, such as the MAGPIE device, is enabling the extreme conditions of the ITER divertor to be created so that plasma-material interactions can be investigated in a controlled manner.

Tungsten will be the dominant refractory metal in the ITER divertor and is a contender for the wall of DEMO, which will experience temperatures in excess of 1000 K. The interaction between high-flux (>10^22 m⁻² s⁻¹) helium and hydrogen-based plasmas can lead to plasma-induced surface morphology modifications, and their impact on the material thermo-mechanical properties is an important issue not well understood. To address this issue, both experimental and simulation/theoretical approaches are required, to study the interaction of tungsten and other candidate fusion-relevant materials at elevated temperatures (300 K to 1200 K) with high-flux plasmas containing both ionic and neutral species.


Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor

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Research fields
- Nanoscience and Nanotechnology
- Environmental Physics

Project details
This field is moving fast so the nature of the projects are also moving on so I'll just give an overview of the sorts of things we are doing at the moment.

We use the Atomic Force Microscope to image nanobubbles on surfaces. These nanobubbles grow or shrink over time. We are looking at the effect of the solvent on nanobubble behavior and what happens if we change the amount of gas in the solvent. With our new AFM we will be able to study the effect of changes in temperature on nanobubble behavior.

We are also working on the theory of nanobubble stability. This has implications not just for nanobubbles at surfaces but also nanobubbles in bulk as well as wider implications for important questions such as if my mate shakes my beer how long do I have to wait until it is safe to open it?

Another interesting problem is the shape of nanobubbles. They are not what we would expect from comparison to larger bubbles. This tells us that there is something missing in our understanding. We are looking at theories for describing why these nanosized objects have a different shape.

Required background
Nil courses. A curious mind. Logical and creative thinking, persistence and imagination

Project suitability
- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Photonics, Lasers and Nonlinear Optics
- Quantum Science and Applications

Project details
The hybrid matter-light nature of polariton BECs make them ideally suited to fundamental investigations. The important fundamental problems that this project will investigate include non-equilibrium dynamics, polariton BEC coherence, and quantum turbulence.

The concept that a BEC can form in a solid state material with reduced dimensionality is remarkable. It is the aim of this project is to systematically investigate polariton BEC coherence including the onset of coherence and its subsequent time evolution. Moreover, we aim to investigate how the polariton BEC coherence is influenced by non-equilibrium dynamics, trap geometry, pumping, and output coupling.

The fundamental understanding of non-equilibrium systems had been repeatedly recognised a one of the grand challenges in physics today. Due to the inherently a non-equilibrium nature of the polariton BEC system it is an excellent platform for non-equilibrium studies. The final fundamental problem that the project will investigate is turbulence. Turbulence is thought to be the last unresolved grand challenge in classical physics. Indeed, the famous physicist Richard Feynman described turbulence as "the most important unsolved problem of classical physics". Turbulence is responsible for vast amounts of wasted energy and therefore increased emissions. Resolution, or even modest gains in the understanding of turbulence, could therefore have significant benefits for our modern society.


Required background
Students interested in either theory or experiment are encouraged to apply.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

Project details
The aim of this project is to investigate the applied properties of polariton BEC and thereby accelerate the development of the next generation of quantum and optoelectronic devices. The potential impact of a BEC in a solid state material for harnessing novel collective quantum effects for future applications of optoelectronics and precision sensors is substantial. Quantum physics has had a huge impact on modern society. It has been responsible for the transistor, laser, and Magnetic Resonance Imaging (MRI) to name but a few critical technologies.

The hybrid light-matter properties of polaritons makes them particularly appealing for integration into optoelectronic devices. The merging of polaritons and optoelectronics into a single device is so promising that it has spawned the new field of polaritronics. Polaritronics has the capability to enhance existing optoelectronic devices and to enable next generation optoelectronic devices including integrated optical circuits, classical and quantum logic elements, optical switches, and spin-memory elements.

The applied properties of polariton BEC that this project will specifically investigate include non-classical photon emission, structured potentials, and spin dynamics. Finally, during the project the student will develop skills in the following areas:

- Optics and lasers
- Ultra-fast imaging and single particle detection
- Cryogenics
- Material science
- Data analysis
- Experiment automation


Required background
Students interested in either theory or experiment are encouraged to apply.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Research fields

- Physics of the Nucleus
- Quantum Science and Applications

Project details

Research with exotic radioactive (unstable) nuclei, with 2-3 times more neutrons than protons is a major motivation for current international projects to develop large radioactive isotope accelerator facilities. For example in exotic $^6$He, two neutrons are so weakly coupled to the $^4$He core that their wave-function extends to 10 times the core radius (forming a "neutron-halo"). Not only can they interact with the target nucleus at much larger distances than the core, but they also interact more strongly with, and can bind more strongly to the target nucleus than to the $^4$He. Their (many-body) interactions with the individual nucleons of the target nucleus constitute environmental interactions and can lead to decoherence. The group's research involves experimental and theoretical investigations aimed at understanding the different interactions of stable and unstable weakly bound nuclei, using the radioactive beam capability at the ANU. A new position sensitive 512 pixel Silicon detector array has been installed to detect charged break-up fragments at backward angles. This will allow unique investigations of fragmentation of stable nuclei into alpha-particles, and studies of interactions and behaviour of radioactive nuclei.

The student has the opportunity to do hands-on developmental work and/or experiments and analysis of break-up and fusion reactions, as well involvement in theoretical modelling and simulations.

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Nanoscience and Nanotechnology
- Quantum Devices and Technology

Project details
The nitrogen-vacancy (NV) centre in diamond is a remarkable optical defect that has enabled the realisation of new frontiers in quantum technology, including quantum computing, quantum communication and quantum metrology. Individual NV centres have been used as qubits to demonstrate precise quantum measurements of electric and magnetic fields at the nanoscale. Such measurements can be applied to perform unprecedented imaging of biological systems or nanoscopic devices. Pairs of NV centres have been used as entangled qubits to demonstrate simple quantum gates, which are the building blocks for quantum computation. Problems currently exist in using the NV centre to realise more sophisticated quantum computing devices.

The aim of this project is to engineer nano-mechanical devices for two different purposes:
1. To use NV centre to perform nanoscale quantum measurements of mechanical motion and forces
2. To aid in the control of quantum computing devices built using NV qubits.

These are challenging aims and there are many aspects of the project were students of different levels can become involved, including:
1. The design and modelling of nano-mechanical devices
2. The development of techniques for quantum mechanical sensing and control
3. Experimental testing of devices and the performance of quantum mechanical sensing and control

Consequently, there are opportunities for both theoretical and experimental work and students are free to choose to their desired mix of theory and experiment.

Required background
Below is an indication of the minimum knowledge that is required to contribute to the different aspects of this project:

1. The design and modelling of nano-mechanical devices
   - First year Physics, an interest in learning solid mechanics and an interest in using advanced modelling software

2. The development of techniques for quantum mechanical sensing and control
   - 2nd year Quantum Physics and an interest in modelling of quantum systems and algorithms

3. Experimental testing of devices and the performance of quantum mechanical sensing and control
   - 2nd year Quantum Physics and an interest in experimental techniques and methods

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

Project details
Quantum defects in diamond have enabled the realisation of new frontiers in quantum technology, including quantum computing, quantum communication and quantum metrology. However, only two such defects are known: the nitrogen-vacancy (NV) centre and the ST1 centre. The NV centre has been studied for nearly 50 years, whilst the ST1 centre was only discovered in 2012.

The aim of this project is to first understand why the NV and ST1 centres are unique and to then apply this understanding to engineer or efficiently search for new defects with superior properties to the NV and ST1 centres. The ultimate objective is to develop a catalogue of quantum defects for the creation of quantum devices.

This project involves both theoretical and experimental research and students are free to choose their desired mix.

Required background
Students require a minimum of 2nd year Quantum Physics.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Neil Manson
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Design of a diamond spintronics device.

Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

Project details
Conventional electronics relies upon the displacement of electron charge to represent and compute information. As a consequence, conventional electronics are fundamentally limited by scale and thermodynamical constraints. An alternate approach is spintronics, which exploits both electron charge and spin to store and compute information. The additional resource of electron spin frees spintronics from the constraints of conventional electronics. The ultimate limit of spintronics is the representation of information by individual electron spins. A scale at which the quantum nature of the spins can be utilised to realise quantum computation.

Diamond is an ideal spintronics material: it has exceptional electronic and thermal properties, it has low spin-orbit interaction, and it hosts a number of spin defects to support spintronics. Yet, few spin transport experiments have been performed in diamond.

This project aims to engineer spintronics devices in diamond. This ambitious aim will involve both the theoretical and experimental study of spin polarization, transport, manipulation and readout in diamond. There are diverse opportunities for students of different levels to become involved. Students are free to choose their mix of experiment and theory.

Required background
Students require a minimum of 2nd year Quantum Physics.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Neil Manson
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Resistive switching in transition-metal oxides and its use in nonvolatile memory devices

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
In thin film form, transition metal oxides can be subjected to intense electric fields and thermal gradients and are known to exhibit characteristic resistance changes, including resistive-, threshold- and complementary-switching behaviour that is well suited to applications such as nonvolatile memory, low power oxide electronics, bio- and environmental-sensing and neuromorphic computing.

Resistive switching is of particular interest for non-volatile memory applications as it involves a resistance change that can be reversibly switched between stable high- and low-resistance states by the application of suitable voltage pulses. It is now generally agreed that these resistance changes are the result of thermally enhanced, electric-stress driven structural changes resulting from defect generation/migration and associated chemical (Redox) processes. Moreover, the resistance change is believed to be confined to a filamentary conduction path just a few nanometres in diameter and is therefore largely independent of the film/device area. As a result, it has the potential to provide non-volatile memory devices with improved scalability, lower power consumption, faster switching, longer retention times, and simpler device structure.

This project will combine experimental work, computer simulation and modelling to investigate the physical processes underpinning resistive switching in transition metal oxides (e.g. Ta₂O₅, HfO₂, Nb₂O₅ and NbO₂) and to explore its application in future non-volatile memory (i.e. ReRAM) devices.

Through the project, the student will develop skills in the area(s) of:
- Nanotechnology, including nanoscale fabrication and nanoscale characterisation
- Advanced materials processing and characterisation
- Semiconductor clean-room technology
- Multiphysics modelling of complex physical phenomena
- Data acquisition, analysis and interpretation
- Critical thinking
- Scientific communication (oral and written)

Further information http://en.wikipedia.org/wiki/Nanoionics

Required background
Physics, Engineering or Materials Science

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

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Graphene synthesis by ion-implantation

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
Graphene has unique structural and physical properties and is of great theoretical and technological interest but the properties of graphene depend sensitively on film thickness and quality. For many applications it is also highly desirable to fabricate patterned layers of graphene on different substrate materials. As a consequence there is considerable interest in new, more flexible methods of graphene synthesis.

Recently reports suggest that one approach to this problem is to form graphene on the surface of carbon-implanted metals. Specifically, graphene synthesis by ion-implantation involves ion-implanting a metal film with high concentrations of carbon and thermally treating the film to cause carbon out-diffusion and graphene growth on the metal surface. In this approach the thickness of the graphene film can be accurately determined by controlling the number of implanted carbon atoms and the film can be transferred to other substrates by a transfer and etch procedure. Preliminary results have been demonstrated for carbon-implanted nickel films but much remains to be investigated and understood.

This project will investigate ion-beam synthesis of graphene, including the possibility of growth on technologically important substrates, such as dielectrics and semiconductors. Through the project, the student will develop skills in the area(s) of:

- Advanced materials processing and characterisation
- Semiconductor clean-room technology
- Multiphysics modelling of complex physical phenomena
- Data acquisition, analysis and interpretation
- Critical thinking

Required background
Physics, Engineering or Materials Science

Project suitability
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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Dinesh Venkatachalam
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The metal-insulator transition (MIT) and its application in functional oxide electronics

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
The physical properties of transition-metal oxides depend strongly on their exact composition, with small departure from stoichiometry giving rise to large changes in properties such as electrical conductivity. Specific oxides are also known to undergo reversible metal-insulator transitions (MIT) during heating and cooling. The best known of these is VO₂ which undergoes a MIT at a temperature of 68 °C. In this case the MIT is associated with a thermally-induced lattice distortion in which the VO₂ crystal structure switches between monoclinic (insulating/semiconducting) and rutile (conducting) structures during heating and cooling. This transition causes a dramatic change in the electrical conductivity and infra-red reflectivity of VO₂ and occurs on a time scale as short as 100 fs. As a consequence it has found a broad range of applications in areas such as: fast optical shutters, optical modulators, optical coatings for smart window technology, high-speed cameras, data storage, and other applications.

The MIT is also of interest in solid state memory technology as a potential threshold switch, a self-regulated switch that is insulating below and conducting above a critical switching voltage. In this case the thermally-induced MIT occurs along a nanoscale filamentary path due to an electric current (Joule heating). Such devices are required to enable unambiguous addressing of memory elements in 3D arrays. However, the transition-temperature of VO₂ is too low for this application. To address this limitation attention has now turned to NbO₂ which undergoes a similar MIT at ~800-810°C, also as a result of thermally induced structural changes. However, much less is known about this material and more work is required to understand the MIT in NbO₂ and to assess its suitability for threshold switching applications.

This project aims to address these challenges by undertaking fundamental studies of the structure and properties of niobium oxide and by developing new materials-science strategies for improving memory-related threshold switching behaviour. This will include extensive experimental work using state-of-the art facilities at the ANU and available through national infrastructure such as the Australian Synchrotron and ab-initio computer simulation and modelling using in-house and national computing facilities (e.g. the ANU Supercomputer facilities).

Through the project, the student will develop skills in the area(s) of:
- Advanced materials processing and characterisation
- Semiconductor clean-room technology
- Modelling of complex physical phenomena
- Data acquisition, analysis and interpretation
- Critical thinking
- Scientific communication (oral and written)

Required background
Physics, Engineering or Materials Science

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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Nanowire THz detector

Research fields
- Photonics, Lasers and Nonlinear Optics
- Nanoscience and Nanotechnology

Project details
Nanowires are one-dimensional nanostructures with many unique properties such as large surface area-to-volume ratio, very high aspect ratio, and carrier and photon confinement in two dimensions. Nanowire research is a new and emerging field growing at a fast pace. The excitement in this field is due to the unique electronic and optical properties of the nanowires, which could lead to novel devices with superior performance over existing devices to revolutionise our technological world. These include transistors, sensors, light sources/emitters, solar cells, and photodetectors that are used in our everyday life such as mobile phones, large-area displays, solar panels, as well as telecommunication systems. Nanowire devices have all the potentials to make these smaller, faster, cheaper and more energy efficient.

In this project, we will focus on the development of nanowire photodetectors made from III-V compound semiconductors such as GaAs or InP, with numerous potential applications ranging from light sensing, single photon counting, telecommunication to THz imaging. Specific aims of the project include design, fabrication and characterisation of the nanowire photodetectors. The underlying physics of the nanowire photodetector devices will be investigated and understood through a suite of state-of-the-art nanoscale simulation and experimental tools.

Through this project, the students will develop expertise in:
- Nanowire device design, simulation and characterisation
- Material processing and device fabrication technologies within a cleanroom environment
- State-of-the-art nanofabrication techniques such as electron beam lithography and focussed ion beam processing
- Nanoscale material and device characterisation (structural, optical and electrical).

Required background
For PhD students 3rd year Condensed matter Physics or Engineering Materials Science/Semiconductor courses are recommended but for undergraduate projects no special requirements.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Nanowire array solar cell

Nanowire array solar cell

Research fields
- Nanoscience and Nanotechnology
- Clean Energy

Project details
Photovoltaics (PVs) is no doubt one of the leading technologies undergoing enormous growth in recent years to address the growing issues of global warming, climate change and energy shortage. Current solar cell technologies are dominated by Si, which only has 10-15% sunlight conversion efficiency. This limitation is primarily due to the inherent properties of Si. Cells made from III-V compound semiconductors, on the other hand, have much higher efficiencies and can be extended to cover a broader range of the solar spectrum by using multi-junction or hetero-structures. In these devices, efficiencies of over 40% have been demonstrated under concentrated light conditions. In addition, the fast emerging nanotechnology has opened up great opportunities to produce solar cells with lower cost and/or improved performance by employing the unique properties of nanostructures, such as nanowires (NWs).

Nanowires are of great interest in photovoltaics because of (i) the large surface area, (ii) high aspect ratio (iii) intrinsic antireflection effect that increases light absorption and (iv) the ability to form well aligned arrays. More importantly, they provide a paradigm shift in photovoltaics by decoupling light absorption from carrier collection paths, which lead to more efficient charge extraction. In addition, material usage in nanowires is much less than in planar devices that will ultimately lead to significant cost reduction.

This project involves the design, fabrication and characterisation of III-V nanowire solar cell arrays. A simulation platform for combined optical and electrical simulation of nanowire solar cells is developed to investigate the fundamental properties of light interaction with nanowire arrays and carrier transport within each individual nanowire and thus the design of more efficient nanowire solar cell structures.

Through the project, the student will develop skills in the area(s) of:
- 3-D coupled optical and electrical simulation on nanowire array solar cells
- Material processing and device fabrication technologies within a cleanroom environment
- State-of-the-art nanofabrication techniques such as electron beam lithography and focussed ion beam processing
- Nanoscale material and solar cell characterisation (structural, optical and electrical).

Required background
For PhD students 3rd year Condensed Matter Physics or Engineering Materials Science/Semiconductor courses are recommended but for undergraduate projects no special requirements.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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**Research fields**
- Nanoscience and Nanotechnology
- Materials Science and Engineering

**Project details**
Semic conductors constitute the backbone of the electronics and photonics industries. Development of microelectronic technologies has led to revolutionary changes in our everyday lives, in particular, in the areas of information and communication. Though clock-speeds are exceeding 3-4 Gb/s in current computers, bus speeds are still slow which requires a new solution for faster communication on board. Currently, optical inter-converts hold the key for this solution and in consequence, how small we can make such optical sources is one of the keys factors to determines its success. Nowadays, novel nanowire-based electronic and photonic devices with new properties or superior performance over existing devices are expected to revolutionise this technological world in the way of new devices and components.

In this project, our aim is to grow such semiconductor nanowires using metalorganic chemical vapour deposition (MOCVD) in a well-controlled manner in terms of orientation, composition, crystal structure and conductivity etc. The growth control is sought to be with precision down to the monolayer level. This 1D anisotropic growths are initiated by via vapour-liquid-solid (VLS) mechanism using nm-sized gold or other metal particles. Different material systems can be then grown at either vertical or radial directions as designed to achieve different functionalities such as quantum confinement and bandgap engineering. This project can be divided into different modules for students to take depending on their interests or the length of available time:

- Investigate the nanowire nucleation process with different metal particles such as Au, Ni, Pd and Pt.
- Control the growth aspects of nanowires such as growth rate, growth orientation etc.
- Engineer the multiple-layer semiconductor heterostructures to achieve solid-state quantum confinement
- Control the conductivity of nanowires via impurity doping
- Structural, electrical and optical characterisation of nanowires using electron microscopy, X-ray diffraction, photoluminescence

**Project suitability**
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

**Project supervisors**

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Schematic of selected area epitaxy (SAE) of semiconductor nanowires

Research fields

- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details

Semiconductors nanowires have attracted intensive research interest in last decades because they have great potential as nano-building blocks for future electronic and photonic devices, which will revolutionise the current technological world. Additional to widely used metal-catalysed vapour-liquid-solid (VLS) growth mechanism, an alternative way to grow the nanowires is by a technique known as selective area epitaxy (SAE) which combines bottom-up and top-down nanofabrication technology. In this approach, a thin layer of dielectric material, typically SiO$_2$ or SiN, is deposited on selected parts of the semiconductor wafer, then nano-sized holes can be opened on this layer by using electron-beam lithography and etching methods. Finally, nanowires will be grown vertically on this patterned substrate. By designing the mask pattern, the nanowires can be grown on a predetermined position of the substrates, or it's easy to realize a periodic array of nanowires. This method fully utilizes the nature of epitaxial growth, it is expected to exhibit superior crystalline quality as well as good controllability of the growth with an atomic precision to form abrupt doping profiles and heterojunctions, including vertical and lateral heterostructures.

Specifically, the aims of project are to (i) develop and understand the SAE mechanism of III-V semiconductor nanowires; (ii) control the growth of axial and radial nanowire heterostructures and superlattices to engineer the band structure and quantum confinement effect; (iii) grow nanowires on Si substrates; and (iv) demonstrate the prototype nanowire optoelectronic devices based on these nanowires (such as light emitting devices and solar cells).

This project can be further divided into different modules for students to take depending on their interests or the length of available time:

- Study of growth parameters, namely the growth temperature, the ratio of group V precursors to group III precursors (V/III ratio), the flow rate of group III precursors.
- Effect of mask dimensions on nanowire growth such as nanowire diameter, nanowire length.
- Light trapping study dependent on nanowire density and dimensions.
- Controlled growth of axial and radial nanowire.
- Growth on Si substrate.

Project suitability

- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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The nature of aerosol and cloud formation has been identified by the Intergovernmental Panel on Climate Change as one of the most important uncertainties in determining Earth’s climate sensitivity to radiative perturbations. Despite a great deal of research, fundamental questions remain about the mechanisms responsible for the formation of aerosols.

This project will investigate mechanisms of aerosol cloud formation, and the essential role of hydrated species in the formation of sulfuric acid clouds, that in turn limit global warming. It starts at the single molecule level, examining through some novel spectroscopy the chemical properties of ozone, its negative-ion, and how these properties are modified by the proximity of water molecules.

The measurements together with the atmospheric modelling, provides key information on the chemistry of aerosol formation, essential for the understanding of the aerosol forcings for climate change.


**Required background**

Some basic quantum mechanics (e.g. PHYS2013), thermodynamics (e.g. PHYS2020), spectroscopy (e.g. PHYS3031), or chemistry recommended (not required).

**Project suitability**

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

**Project supervisors**

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Research fields
- Atomic and Molecular Physics

Project details
Isomerization reactions that involve migrating hydrogen atoms often play a critical role in more complex chemical reactions, including dehydration of alcohols, hydration of alkenes, and the gas-phase combustion of hydrocarbons. The ultrafast time scales, small barriers to rearrangement, breaking/forming of bonds, make these processes challenging to investigate.

The simplest example is vinylidene (\(\text{:C}=\text{CH}_2\)) which is a transient, reaction intermediate. It is more commonly recognised by its stable isomer form, acetylene (H-C≡C-H). The transition from vinylidene to acetylene requires one H-atom to move to the other side of the molecule, yet it occurs on the order of a few pico-seconds. The physics picture is a bound system interacting with a system of much higher density of states, a situation that appears in many different fields of physics. However, it now seems likely that the vinylidene structure corresponds to 2 – 3 exact eigen-states, each is given by a coherent superposition of both vinylidene and acetylene amplitudes. This form may exist for several microseconds.

This project will use a state-of-the-art electron imaging spectrometer, with world-leading energy resolution, to examine the vinylidene transition state, to provide a definitive identification of large amplitude signature states proximal to the isomerization barrier. These signatures will provide a rational basis for future control of unimolecular chemical reactions.

Further information [http://pubs.rsc.org/en/content/articlepdf/2013/fd/c3fd20160k](http://pubs.rsc.org/en/content/articlepdf/2013/fd/c3fd20160k)

Required background
Recommended, not required, some basic quantum mechanics (e.g. PHYS2013), thermodynamics (PHYS2020), spectroscopy (PHY3031).

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor

Stephen Gibson
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Research fields
- Atomic and Molecular Physics

Project details
AMPL is home to a unique and versatile spectrometer that interrogates negative-ions using laser light, imaging the resultant detached electrons. Its performance exceeds any other spectrometer of its type in the world.

Each measured electron image yields a photoelectron spectrum (PES), that provides the energy level structure of the anion and neutral, and the photoelectron angular distribution (PAD), that provides the dynamics of the photodetachment process. This project will involve computational analysis of previously measured atomic and molecular photoelectron images, to extract spectra for publication, and to investigate the intricacies of each spectra.

Required background
Some familiarity with programming languages e.g. Python or equivalent, or C, and Unix operating systems. Basic spectroscopic/quantum mechanics knowledge.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisor
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Images acquired by electron microscopes showing the dimension, morphology and atomic structure of typical III-V nanowires with purposely modulated crystal structure.

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
All III-V compound semiconductors excluding nitrides naturally adopt a zinc blende (ZB) structure, which is essentially a cubic close packing lattice (the same as Si crystals and diamond). This includes GaAs, InAs, GaP, InP, GaSb and InSb. However, when their nanoscaled counterparts, namely the III-V nanowires, are synthesised, they can also adopt a combination of the wurtzite (WZ) structure, which has the alternative close packing order, i.e. the hexagonal close packing, and the ZB structure. Such phenomenon of mixed ZB-WZ phase is also referred to as structural polytypism. Many properties of semiconductors are determined by their crystal structures, which will in turn determine how they will be used in devices. The ZB-WZ polytypism in III-V nanowires brings both challenges and exciting opportunities for next-generation devices. On one hand, the mixed phase can become structural defects and degrade device performance, and thus has to be eliminated. On the other hand, if well controlled, the polytypic nature can provide extra degree of freedom to manipulate the energy band structure at atomic level for a range of applications.

This project will involve the use of metal-organic chemical vapour deposition (MOCVD) and electron microscopy to synthesise and characterise the nanowires in order to understand the fundamental mechanism of polytypism in nanowires and how to control the formation. Students will have the opportunity to learn and master crystallography and electron microscopy.

Required background
Condensed matter physics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project

Project supervisor
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Research fields
- Physics of the Nucleus
- Theoretical Physics

Project details
The discovery or synthesis of new elements has always fascinated scientists, and currently the search is on to find new "superheavy" elements (elements with atomic number around 120). These elements are synthesised in the laboratory by fusing two heavy nuclei. Fusion leads to superheavy element formation only when the combined many-body quantum system survives the competing processes of fission and quasi-fission, which cause the system to break apart. This depends sensitively on many variables, such as the shape of the interacting nuclei, their mass difference, shell structure, and possibly the number of excess neutrons. The group is currently working on the challenging tasks of isolating the factors that influence the formation of heavy elements, and of theoretically predicting their yields.

Using the 15 Million Volt electrostatic accelerator, and the highly efficient CUBE fission detectors, this research project will involve making measurements of fission cross-sections, and mass and angle distribution of the outgoing fragments. From these data, reaction timescales of less than $10^{-20}$ seconds can be measured. This will allow us to obtain a picture of the dynamics of the fusion reaction. The project can also involve working on theoretical developments of a stochastic model aimed at simulating the process of fusion and quasi-fission, working with our Japanese theoretical collaborator. The relative weights of the experimental and theoretical components can be tailored to suit the interests of the student.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Research fields
- Photonics, Lasers and Nonlinear Optics

Project details
There is a whole range of micromachining, medical and biological applications in which only ultrashort laser pulses can be used due to their ability to process any substance with accuracies and resolutions going below the range of the laser wavelength. The key role of light polarization in the ultrashort pulse-matter interaction is now widely recognized and various polarization-related effects are being actively studied.

This PhD project is aimed at developing a new method for ultra-precision laser micromachining and dissection of biological tissues using sub-picosecond laser pulses with inhomogeneous distribution of polarization (so called vector pulses). The capability of these unconventional laser pulses to process different materials with unsurpassed precision and efficiency offers significant economic and clinical benefits. The project will involve i) investigation of underlying mechanisms responsible for laser-induced material modification/ablation as a function of the laser wavelength, polarization and pulse duration, ii) laser-assisted fabrication of microphotonic and microfluidic devices and iii) pioneering experiments on dissection of biological tissues using ultrashort inhomogeneously polarized pulses.

The project provides an excellent opportunity to work in the innovative, internationally competitive areas of research. The PhD candidate will acquire a valuable set of experimental skills including operation of different picosecond and femtosecond laser systems, optical and electron microscopes, optical profilers, micro-Raman spectrometers, and other optical and electronic diagnostic tools (e.g., digital oscilloscopes, signal generators, spectrum analyzers, tunable lasers, power meters etc) typical of a modern photonics laboratory.

Required background
- A first class honors or equivalent in electrical engineering, physics, optics, or materials science.
- Prior laboratory research experience is a must for the project. The preferred fields are Electro-Optics and Electronics.
- Experience in data acquisition and motion control using LabVIEW is highly desirable.
- Australian/NZ citizenship or Australian permanent residency is a must (due to the funding regulations of the University).

Project suitability
- PhD or Masters project

Project supervisors
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- Wieslaw Krolikowski
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Research fields
- Fusion and Plasma Confinement
- Clean Energy

Project details
Controlled magnetic confinement fusion offers the possibility of an inexhaustible supply of energy with zero greenhouse gas emissions. At the very high temperatures needed to initiate a fusion reaction, the fuel (a mixture of deuterium and tritium) exists in the plasma state.

Magnetohydrodynamics (MHD) is an electromagnetic fluid model of magnetized plasmas, with applications ranging from solar flares through to fusion experiments in the laboratory. In an ANU/international collaboration, a new MHD model is being developed: multi-region relaxed MHD (MRXMHD). This is based on the use of a topological invariant called the helicity, which is used in conventional plasma relaxation theory to constrain the evolution of a relaxing plasma towards a minimum energy state. In MRXMHD the plasma is divided into multiple regions, each with its own helicity invariant, thus allowing the description of a richer variety of phenomena.

It is already known that reconnection ("tearing") of magnetic field lines is compatible with helicity conservation, thus allowing the spontaneous formation of helical states, called "tearing modes", during relaxation. The project is to relate the onset of tearing mode instability in MRXMHD to the multi-tearing Delta’ formalism of Dewar and Pletzer (developed in an earlier ANU PhD project) and to use this to model recent experimental results in Reversed Field Pinches (RFPs), a class of toroidal fusion devices.

During the project the student can expect to develop skills in:
- Plasma equilibrium and fluid dynamics theory
- Applied mathematics, in particular using differential geometry and dynamical systems theory
- Computation and visualization

Required background

Project suitability
- Honours project
- PhD or Masters project

Project supervisors
Matthew Hole
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Research fields

- Fusion and Plasma Confinement
- Clean Energy

Project details

Controlled magnetic confinement fusion offers the possibility of an inexhaustible supply of energy with zero greenhouse gas emissions. At the very high temperatures needed to initiate a fusion reaction, the fuel exists in the plasma state.

Magnetohydrodynamics (MHD) is the study of magnetised plasmas, with application ranging from solar flares through to laboratory confinement. MHD has been very successful in the description of axisymmetric (2D) toroidal plasmas, such as tokomaks, where the field lies everywhere in toroidal surfaces. The description of the magnetic field in asymmetric (3D) plasmas is less developed, and indeed the existence of solutions where the field is confined to toroidal surfaces is not guaranteed.

Driven by the 3D existence problem, an ANU / Princeton collaboration recently proposed a stepped pressure profile model, MRXMHD. In their model, nonzero pressure gradients are restricted to toroidal surfaces, on which a sheet current balances a step function change in pressure. In general, the magnetic field only lies in toroidal surfaces at the interfaces. The model, which is mathematically well-posed, addresses the existence problem explicitly, by inferring restrictions on the field and pressure at the interfaces.

The model has had recent success in describing the formation of helical states in the reverse field pinch. An important but missing ingredient is the inclusion of toroidal flow into MRXMHD. Indeed, flow-shear is thought to be important in the diffusion of 3D fields into the plasma from the edge during resonant magnetic perturbation experiments. In this project extensions to MRXMHD with flow will be formulated.

Required background

Background in vector calculus and variational methods is necessary, and experience using Mathematica desirable.

Project suitability

- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Astrophysics
- Fusion and Plasma Confinement

Project details
The structure and dynamics of the solar corona is dominated by the magnetic field. In most areas in the corona magnetic forces are so dominant that all non-magnetic forces like plasma pressure gradient and gravity can be neglected in the lowest order. This model assumption is called the force-free field assumption, as the Lorentz force vanishes.

A common assumption in modelling coronal solar flares is to assume the field is force-free, and adjust the field pitch to match local measurements of the photosphere field footprint. Such fields are called nonlinear force free fields.

In this project, we apply multiple-region relaxed MHD model, designed to describe the fractal fix of chaotic field lines, magnetic islands, and flux surfaces in toroidal magnetic confinement, to describe a solar flare.

Required background
Electrodynamics. A knowledge of plasma physics is desirable, but not essential.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisor
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Research fields
- Astrophysics
- Fusion and Plasma Confinement

Project details
An accretion disc is a structure formed by plasma in orbital motion around a massive central body - normally a star or black hole. Such structures are often modelled by the Grad-Shafranov equation, which describes the balance of forced perpendicular to flow lines.

In toroidal magnetic confinement, the assumption of toroidal-axis symmetry also leads to the Grad-Shafranov equation, which in this case represents force balance perpendicular to magnetic field surfaces. Both treatments normally use polynomial representations for the constraints, and solve for the configuration using current-field iteration.

In this project we would compare the construction of accretion disc and magnetic configuration Grad-Shafranov problems, and apply a recently developed toroidal magnetic confinement equilibrium code to model an accretion disc. A focus of the project will be constraining free functions to observational data.

Required background
- electrodynamics, plasma physics

Project suitability
- Third year special research topic
- Honours project
- Summer research scholarship

Project supervisors
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Michael Fitzgerald
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Research fields
- Plasma Applications and Technology

Project details
Particle accelerators so far have relied on electric fields generated by radio waves to accelerate electrons and other particles close to the speed of light. Such machines however have an upper limit of tens of MeV per meter of beam line.

A developing technology is the generation of a wakefield in a plasma through either a laser or a beam of charged particles. The subsequent electric field can resonantly accelerates the particles to tens of thousands of MeV per meter of beam line, offering potentially staggering performance gains over existing technology.

In this project the principles and design of a plasma wakefield accelerator will be reviewed, and the opportunities for a low-cost wakefield accelerator explored.

Required background
- electrodynamics, plasma physics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisor
Matthew Hole
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Research fields
- Fusion and Plasma Confinement
- Clean Energy

Project details
High performance toroidal magnetic confinement plasma experiments such as the next step fusion experiment ITER will have up to 16MA of current in the plasma (roughly equivalent to 300 lightning bolts). Such devices also have strong magnetic fields: in ITER the toroidal field strength is 5T. This ensuing Lorenz force during a plasma disruption can be immense.

In this project we will examine the forces generated in superconducting magnetics, and scope the forces generated during a disruption.

Required background
electrodynamics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisor
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Research fields
- Fusion and Plasma Confinement
- Clean Energy

Project details
Controlled magnetic confinement fusion offers the possibility of an inexhaustible supply of energy with zero greenhouse gas emissions. At the very high temperatures needed to initiate a fusion reaction, the fuel exists in the plasma state. Fusion energy research is now poised to advance rapidly due to a large international investment (~$20 billion) in the International Thermonuclear Experimental Reactor, ITER, with a power gain of over five, will explore the uncharted physics of burning plasmas, in which the energy liberated from the confined fusion products of reaction exceeds the energy invested in heating the plasma. As fusion products slow by collisions with the bulk, they can drive a range of wave-modes, some of which are deleterious to confinement. A full understanding of these wave-modes requires fluid modelling of the plasma (e.g. MHD) to compute wave modes, a kinetic treatment of ion motion, to compute wave-particle resonance, and comparison to experimental observations in a well-determined magnetic configuration.

In this project the wave-particle resonance condition will be computed for a range of precomputed particle orbits (and orbit populations), which initially were computed for transport studies. An estimate of wave-drive due to spatial gradients will be afforded using wave functions from an ideal MHD stability analysis and orbit population information. Predictions of wave amplitude will be compared measured wave activity from magnetic pick-up coil and spectroscopic fluctuation diagnostics.

The project complements active research on burning plasma physics, and builds on collaborations with the Culham Centre for Fusion Energy and Max Planck Institute for Plasma Physics.

Required background
Interest in sustainable energy technology solutions, a sound understanding of electromagnetic theory, and good analytic and numeric skills.

Skills and understanding developed in the project offer the student an entry to the field of fusion energy research and laboratory plasma physics, and are portable to space and solar physics, and astrophysics.

Project suitability
- Honours project
- PhD or Masters project

Project supervisors
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Michael Fitzgerald  
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Nonlinear evolution of energetic particle modes to saturated helical structure

Research fields
- Fusion and Plasma Confinement
- Clean Energy

Project details
Controlled magnetic confinement fusion offers the possibility of an inexhaustible supply of energy with zero greenhouse gas emissions. Fusion energy research is now poised to advance rapidly due to a large international investment ($16 billion) in ITER (the International Thermonuclear Experimental Reactor). ITER, with a power gain of over five, will explore the uncharted physics of burning plasmas, in which the energy liberated from the confined products of reaction exceeds the energy invested in heating the plasma. Burning plasmas are energetically complex nonthermal systems, in which a significant fraction of the stored energy resides in beam-heating-driven fast ions (~1 MeV) and fusion-reaction-product helium ions (3.5 MeV alpha particles). Neutral beams inject momentum into the plasma, driving rotation, and currents associated with these beams can change the magnetic configuration.

As both beam and alpha particles undergo collisions with the background plasma they lose energy and can drive electromagnetic modes of the plasma. At large amplitude these modes have been observed to evolve into long-lived "helical" structures in several machines, notably the Mega Ampere Spherical Tokamak of the Culham Centre for Fusion Energy. In this project we investigate the role of energetic particles during the transition from bursting fishbone to a long-living mode.

The project builds on an existing collaboration between the ANU and the Culham Centre for Fusion Energy.

Required background
electrodynamics, plasma physics (desirable), vector calculus

Project suitability
- PhD or Masters project

Project supervisors
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**Research fields**
- Fusion and Plasma Confinement
- Plasma Applications and Technology

**Project details**
The purpose-built linear plasma device, the MAGnetized Plasma Interaction Experiment (MAGPIE), has been constructed in the Plasma Research Laboratory of the Australian National University (ANU) to develop novel diagnostics and test materials under aggressive plasma conditions. This linear plasma device employs a combination of a high-power radio-frequency plasma source, a target chamber and a set of diagnostics for plasma and material analysis.

Recent evidence from convergent field MAGPIE plasmas suggests the plasma experiences both azimuthal and axial flows.

In this project, an existing two fluid model designed to describe a plasma centrifuge, and successfully used to model helicon discharge plasmas, would be modified to account for the field compression and non-uniform temperature profile. The project is well defined, and suitable as an Honours project for students with an interest and skills in theoretical modelling, and interpretation of data.

**Required background**
An understanding of electrodynamics and fluid theory.

**Project suitability**
- Honours project
- PhD or Masters project

**Project supervisors**

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<thead>
<tr>
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</tr>
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Research fields

- Physics of the Nucleus

Project details

Neutron-rich isotopes can be studied by the use of deep-inelastic and transfer reactions on already neutron-rich targets close to the line of β-stability, with the observation of gamma rays on high-efficiency multi-detector arrays, such as Gammasphere at Argonne National Laboratory in USA. The choice of the beam energy at ~15-20% above Coulomb barrier enhances the multi-nucleon transfer processes substantially. As a result, in addition to the inelastic channel, a large number of nuclei are populated around the target mass region. This can be clearly seen from the calculation shown above for an 840 MeV $^{138}$Xe ($Z = 54$) beam on enriched $^{186}$W ($Z = 74$) target, where the colour indicates the yield.

This project aims to understand the population distribution in these reactions by comparing the calculations with experiment. As the data were collected both in-beam and out-off-beam time ranges, these reactions are most suitable for yields distribution measurements for prompt structures as well as isomeric decays. Data from three different targets ($^{186}$W, $^{187}$Re, and $^{192}$Os) are available, all bombarded with a $^{138}$Xe beam. Primarily the yield of long-lived isomeric states will be examined to identify reaction products and determine their yield for comparison with calculations. Latter, data from other targets can be used for consistency check.

Required background

No specific background knowledge. But should be enthusiastic about gamma ray spectroscopy.

Project suitability

- Third year special research topic
- Summer research scholarship

Project supervisors

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Effect on fission in deep-inelastic and transfer reactions for actinide targets

Research fields
- Physics of the Nucleus

Project details
Fission of heavy elements produces neutron-rich fission fragments which cannot be produced by other means. However, as most spontaneous fissioning nuclei have been investigated thoroughly, new techniques such as neutron-induced fission or fusion-fission are explored with some success to study more neutron-rich nuclei. One fission mechanism which has not been investigated properly is sequential fission following deep-inelastic and transfer reactions. Now, with the availability of deep-inelastic and transfer reaction data for neutron-rich actinide targets an investigation can be carried out for sequential fission. In this project, the products of spontaneous fissioning of $^{248}$Cm and $^{249}$Cf will be compared to the fission products in these nuclei following heavy-ion deep-inelastic and transfer reactions. Isotopic yields will be measured to see whether the population of neutron-rich side of the fission products is enhanced. In addition, we will evaluate the population of higher-spin states compared to spontaneous fission. The results will improve our understanding on sequential fission following heavy-ion deep-inelastic and transfer reactions.

A figure with a rough sketch of deep-inelastic and transfer reactions mechanism is shown above. A sequential fission is when the target like residues goes fissioning just after the reaction.

Required background
No specific background knowledge. But should be enthusiastic about gamma ray spectroscopy

Project suitability
- Third year special research topic
- Summer research scholarship

Project supervisors

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Selective gating on sum-energy – multiplicity spectra to eliminate backgrounds in Gammasphere data.

Research fields
- Physics of the Nucleus

Project details
Gammasphere (GS) has been extensively used for high-spin spectroscopy of nuclei using deep-inelastic and transfer reactions. Due to the reaction mechanism, these reactions always populate a plethora of unwanted nuclei. This results in the decrease of peak-to-background ratio, creating difficulties to find weak gamma ray sequences or links. In case of radioactive, fissioning actinide targets the background further increases, leaving little scope for finding weak γ-rays.

However, multi-detector, multi-parameter Gammasphere data can be used for selective gating on the sum energy (H) and total multiplicity (K) spectrum to obtain better peak-to-background ratio. The mechanism relies on the simple fact that when an event occurs, many fold gamma rays are detected simultaneously which is generally represented by K (numbers of detector that fired in GS), whereas H is the summed gamma ray energy. High-spin structures are often associated with very high folds and large summed energy. By selectively choosing and optimizing the H-K spectrum, a much cleaner spectrum can be obtained for the nuclei of interest. This is shown (above) for the $^{251}$Cf target ($t_{1/2} = 898$ y) experiment where the radioactive target was supported by a thick $^{197}$Au backing, which is typical for such targets.

In this project H-K gating technique will be used for data with $^{244}$Pu, $^{248}$Cm, and $^{249}$Cf targets with better overall statistics than $^{251}$Cf data.

Required background
No specific background knowledge. But should be enthusiastic about gamma ray spectroscopy.

Project suitability
- Third year special research topic
- Summer research scholarship

Project supervisors

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**Research fields**
- Fusion and Plasma Confinement
- Plasma Applications and Technology

**Project details**
Coherence imaging is a new interferometric technique for measuring the spectral and polarimetric properties of spectral emission lines from both low and high temperature plasmas. For the hydrogen Balmer series, the upper state is broadened by electron impact, the broadening being related to the electron number density. There are also competing effects due to Doppler broadening and Zeeman splitting.

The project will first entail assessing the relative importance of the various broadening mechanisms followed by the design of an imaging system that allows the Stark contribution to be extracted without ambiguity. This will allow 2D imaging and Abel inversion of the plasma density profile in MAGPIE for comparison with single channel microwave interferometer measurements.

Once the system has been properly benchmarked, you will undertake a series of systematic experiments to study the plasma profile as a function of magnetic field strength and configuration. In particular, you will explore the possibility of directly imaging the density perturbations produced by the helicon wave that produces and heats the plasma. This would allow, for the first time, direct imaging of the wave propagation, its dispersion and energy deposition properties for comparison with simple models.

**Required background**
A basic knowledge of optics and interferometry is required. Some plasma physics would be useful, as would familiarity with scientific computing languages such as IDL, Matlab and/or labview.

See the following papers about coherence imaging:


**Project suitability**
- PhD (2nd or 3rd year project)
- Honours project

**Project supervisors**

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Research fields
- Atomic and Molecular Physics
- Theoretical Physics

Project details
Quantum control strategies, that make use of tailored ultrashort laser pulses, can manipulate a great variety of physical and chemical properties of matter. One can try, for example, to alter function of bio-molecules, form new molecular structures, or optimize charge transfer in molecules that more efficient solar cells can be created. Speed of information processing in computers can be increased if we understand how electric current in nanometer-scale circuitry can be manipulated. Applications range from basic research, non-linear optics, materials processing, quantum computing, control of chemical reactions. From the computational point of view, the problem consists in finding the laser pulse parameters such that quantum evolution of the system in the presence of this pulse, which is described by the time-dependent Schrödinger equation, guides the system from an initial quantum state to a desired final quantum state with high efficiency. This problem can be quite computationally challenging even for simple quantum-mechanical systems. To implement it in practice, one has to develop efficient methods of the solution of the quantum mechanical evolutionary equations, and advanced numerical algorithms.

The student can expect to perfect and develop skills in:
- Quantum mechanics, in particular, theory of laser light-matter interaction
- Theory and practice of numerical calculations
- High level Fortran programming
- Use of advanced numerical algorithms
- Working in a team environment

Required background
Interest in quantum physics, atomic and molecular physics, theory and practice of numerical calculations.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Atomic and Molecular Physics
- Theoretical Physics

Project details
Multi-photon atomic ionization, resulting in ejection of a single atomic electron in intense laser fields, is relatively well understood by now. In contrast, strong field ionization with several active electron involved is a much more challenging problem in which the laser field-atom interaction is entangled with the few-body correlated dynamics. The double-electron ionization of helium is the archetypal reaction of this kind. The most interesting phenomena in this process are nonlinear. One may mention the possible existence of the Rabi oscillations in the double ionization probabilities, which can be expected to exist on general theoretical grounds. These phenomena are, at the same time, the most difficult to describe theoretically. This problem becomes tractable (though by no means trivial), if we use a simplified one-dimensional model of the helium atom, which captures essential features of the process.

The student can expect to perfect and develop skills in:
- Quantum mechanics, in particular such subjects as theory of laser light-matter interaction and scattering theory
- Theory and practice of numerical calculations, use of advanced numerical algorithms
- High level Fortran programming
- Working in a team environment

Required background
Interest in atomic and molecular physics, theory and practice of numerical calculations, computer programming

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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UV nano-LEDs

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
Nitride-based semiconductors, such as GaN, InGaN and AlGaN, are materials that are used in ubiquitous white, blue and green LEDs, and laser diodes (for Blu-ray players) which is a huge industry with a multi-billion dollar market. The technologies of these semiconductors have progressed and matured enormously over the last two decades and has resulted in very low cost production for these devices.

Nanowires are quasi-1-D structures having diameters of a few tens to hundreds on nm but with lengths of um’s. These structures have many unique and desirable properties such as large surface area-to-volume ratio, which has great potential for applications such as high efficiency solar cells and the next generation of ultrasensitive sensors for the detection of biological and chemical species on an unprecedented atomic scale level. The synthesis of nanowires also result in the spontaneous formation of energetically preferred facets, such as the non-polar m-plane. These facets can be utilised to circumvent the effect of internal piezoelectric polarisation field, which causes the electron and hole wavefunctions to separate spatially and hence reduce quantum efficiency.

There are many applications that utilise the UV region of the electromagnetic spectrum such as water sterilisation, air purification, surface disinfection, free-space non-line-of-sight covert communication, epoxy curing, counterfeit detection, light therapy and fluorescence identification of biological/chemical agents. Currently nearly all UV lamps generate radiation by means of a gas discharge. They are fragile, bulky, expensive, and contain toxic substances such as mercury or deuterium. Hence there are lots of interests in realizing small, robust and highly portable UV sources. AlGaN is a good candidate as it has a large bandgap that corresponds to the UV range and also the maturity of LED technology.

This project can be divided into two main modules in which students choose both or either modules or any aspects of each module depending on interests of the students and duration of the program:

- The first is to synthesise the AlGaN nanowires using our new MOCVD system and understand, through various structural, electrical, and optical characterisation techniques, how to (i) improve the material quality, (ii) efficiently dope this semiconductor layer, (iii) control the composition and material, and (iv) to engineer the bandstructure of multilayer structures

- The second part of the project involves (i) the design of the LED structures, (ii) the use of state-of-the-art device fabrication facilities to transform these nanostructures into LEDs with electrical contacts and (iii) characterising the performance and properties of these LEDs to understand the underlying physics of the devices.

 Required background
Physics, Material Science, Engineering

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Hoe Tan
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Visible wavelength nanowire lasers

Research fields
- Photonics, Lasers and Nonlinear Optics
- Nanoscience and Nanotechnology

Project details
Nitride-based semiconductors, such as GaN, InGaN and AlGaN, are materials that are used in ubiquitous white, blue and green LEDs, and laser diodes.

Nanowires are quasi-1D structures having diameters of a few tens to hundreds of nm but with lengths of μm's. They act as excellent optical waveguides and confine light along their axis. The ends of the nanowire act as tiny mirrors and form a cavity, eliminating the need for specialised processing steps to form a cavity or coupling to an external cavity. This reduces the footprint of the devices allowing for high density integration. The shape of the nanowires also allows for easy out-coupling of laser light into optical fibres. Nitride-based semiconductors have bandgaps covering the entire visible wavelength, however the efficiency of the laser drops dramatically in the green region and beyond. In this project we will focus on nanowire lasers operation in the yellow-green wavelength region, which has applications in the biotechnology and medical science areas such as flow cytometry, photocoagulation of blood vessels and phototherapies for skin treatment.

This project can be divided into three main modules in which students may choose any combination of modules or any aspects of each module depending on interests of the students and duration of the program:

- The first module is to develop an analytical and/or numerical modelling technique to understand the gain and cavity properties of semiconductor nanowires. This will then allow the exact geometry and dimension of the nanowires to be designed to achieve lasing. The introduction of quantum confined structures such as quantum well tubes will also be investigated.

- The second part is to synthesise the nitride nanowires using our new MOCVD system and understand, through various structural, electrical, and optical characterisation techniques, how to (i) improve the material quality, (ii) efficiently dope this semiconductor, (iii) control the composition and material, and (iv) engineer the bandstructure of multilayer structures.

- The third part of the project involves (i) the design of the laser structures, (ii) the use of our device fabrication facilities to transform these nanostructures into lasers and (iii) characterising the performance and properties of these lasers to understand the underlying physics of the devices.

Required background
Physics, Material Science, Engineering

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Research fields

- Photonics, Lasers and Nonlinear Optics

Project details

The fast pace of technological development in many scientific fields, such as time measurement, single particle detection, surface, temperature or pressure sensing, requires increasingly sensitive sensors. Amongst the different types of existing metrological devices, optical sensors are particularly interesting due to their versatility and high sensitivity. For example, gravitational wave sensors, arguably amongst the most sensitive sensors in the world, capable of detecting changes in distance of the order of $10^{-18}\text{m}$ in arms typically several kilometres long, are based on optical interferometric techniques.

Most optical sensors work by coupling the physical quantity of interest (temperature, length, magnetism, …) to a change in the phase of a laser beam, that can be subsequently detected using interferometric techniques. Typical interferometers are able to detect phase changes of the order of a fraction of the optical wavelength (typically a few tens of nm). Their sensitivity can be further improved using optical cavities, which can enhance the phase sensitivity by orders of magnitude. Amongst the most promising cavity geometries are the family of Whispering Gallery Mode (WGM) resonators.

WGMs are a family of eigen-modes supported by monolithic circular resonators. These modes are confined inside the cavity through total internal reflection, potentially leading to very high Q factors, as long as the surface roughness is controlled to minimize loss through scattering. Q factors as high as $10^9$ have been reported in the literature. Moreover, in part due to the small dimensions of WGM resonators - from a few microns to a few millimetres -, WGM resonators enable much higher power densities than the Gaussian modes carried by more traditional cavities.

Several groups have started using WGM resonators to design sensitive metrological devices. For example, WGM based mechanical sensors have been developed to measure forces and pressure as well as temperature and magnetic fields.

This project will focus on the development and characterization of a magnetometer based on WGM. An optical resonator will be combined with a magnetostrictive material such as Terfenol-D that will enable ultra-precision sensing of magnetic fields using fully optical techniques.

Student will develop skills in:

- Mechanical and optical design of laser cavities
- Quantum control of laser cavities
- Characterization of laser cavities
- Machining of WGM resonators
- Data analysis and interpretation

Project suitability

- Honours project

Project supervisors

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InP-based nanophotonics bonded on Si

Research fields
- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details
The project will consist of performing mechanical adhesive bonding of InP-based epitaxial structure containing InGaAsP layers. The adhesive bonding makes use of benzo-cyclo-butene (BCB) and the epi-structure is bonded using BCB onto Si wafer that act as hosting material. After bonding the InP substrate is removed using wet selective etching. Afterwards, the remaining InP and/or InGaAsP thin layer will undergo optical characterisation (photoluminescence) to validate the technology. Fabrication of photonic devices, like waveguides, S-bends and photonic crystal cavities, can take place either before the bonding process or after. This also opens the door to double side processing.

The project can be split into small sub-projects depending on the desired study duration.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project

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Research fields

- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details

In this project we intend to explore the technology of bonding GaN-based epitaxial structures on external substrate like silicon or glass. The epi-structures are suitable for the fabrication of light emitting diodes and they will be bonded to high reflectivity mirrors deposited on silicon or glass followed by the removal of the used substrate during the epitaxy. The dielectric mirrors will be fabricated using a sputtering technique to deposit a distributed Bragg reflector (DBR) based on a quarter wavelength engineered stack of dielectric layers such TiO₂ and SiO₂. Photoluminescence and reflection measurements will be used to characterise the epi-structures, the DBR mirrors and the bonded GaN structures in order to validate the transfer technology before an electrical characterisation takes place by processing LEDs as a first step towards green VCSELs (vertical cavity surface emitting lasers).

The project can be split into small sub-projects depending on the desired study duration.

Project suitability

- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor

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Solar Hydrogen Generation from Rust using 3-D Nanostructured Photoelectrodes

Research fields
- Nanoscience and Nanotechnology
- Clean Energy

Project details
The quest for abundant, renewable energy is currently one of the world’s greatest technological challenges. One solution to this problem is the conversion of solar energy to storable chemical fuels, such as H₂. Hydrogen generated from solar-driven electrolysis of water has the potential to provide clean, sustainable, abundant and transportable energy. Towards realizing this goal, artificial photosynthetic approaches such as photoelectrochemical (PEC) cells are being extensively investigated. A PEC cell requires a semiconductor electrode that fulfills several essential prerequisites: a small semiconductor bandgap for efficiently harvesting a large proportion of the solar spectrum, appropriate band edges for water oxidation and reduction, high conversion efficiency of photogenerated carriers to hydrogen, durability in aqueous environments, and low cost.

Hematite (α-Fe₂O₃), often referred to as “rust”, is a promising electrode material for photoelectrochemical hydrogen generation from water – it has low cost, good long-term stability and absorbs light efficiently. However, its use is limited by its poor electrical conductivity. In this project, a novel host-guest nanostructure will be developed that exploits the beneficial light-absorption properties of hematite (the guest) but shifts the charge transport function to a nanostructured transparent conductive oxide (TCO) host. The specific objectives of this project are:

• Develop a novel hematite electrode based on a porous 3D nanostructured TCO film as a host for an extremely thin hematite layer
• Understand the mechanism of charge separation and transport in these photoanodes based on the host-guest nanostructure approach through systematic investigations employing time-resolved absorption spectroscopy and electrochemical impedance measurements.

Depending on the interests of the student and the length of the course, various aspects of the project can be tailored to suit the student.

Project suitability
- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisors

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Research fields

- Atomic and Molecular Physics
- Theoretical Physics

Project details

The idea of using femtosecond (1 fs = 10^{-15}s) laser pulses as a strobe for studying nuclear dynamics in molecules brought a Nobel Prize in Chemistry and laid the foundation of a rapidly developing field of femtochemistry. The electronic motion in atoms and molecules, which typically occurs within tens to hundreds of attoseconds (1 as = 10^{-18}s), remained unexplored by this technique due to the fundamental limit in time resolution. This limit fell with the invention of the so-called “attosecond streak camera”. The camera makes use of the high harmonic generation process which converts a driving nearinfrared (NIR) femtosecond pulse into coherent extreme ultraviolet (XUV) bursts, at least one order of magnitude shorter than can be produced by conventional laser systems. An attosecond XUV burst sets an atomic electron in motion while the same driving NIR pulse, after a carefully monitored time delay, is used as a strobe. The key ingredient of attosecond streaking is phase stabilization of the driving NIR pulse with a shot-to-shot stability of a few attoseconds. This stability constitutes a built-in temporal ruler of incredible precision. Such a ruler can be applied to a variety of atomic processes to resolve them in time. However, the utility of time-resolved techniques such as attosecond streaking can only be fully realized if one is able to model reliably the electron response to the intense laser field immediately upon ionization, which can only be done with realistic quantum-mechanical calculations.

Required background

Advanced quantum mechanics course and competence in scientific programming/numerical computations

Project suitability

- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Atomic ionization in super-strong laser fields

Research fields

- Atomic and Molecular Physics
- Theoretical Physics

Project details

Recent years have witnessed a remarkable progress in high-power short-pulse laser techniques. Modern laser systems provide peak light intensities of the order of $10^{20}$ W cm$^{-2}$ or above in pulses shorter than 100 fs. The field strength at these intensities is a hundred times the Coulomb field binding the ground state electron in the hydrogen atom. These extreme photon densities allow highly nonlinear multi-photon processes such as above-threshold ionization, high harmonic generation, laser-induced tunneling, Coulomb explosion, multiple ionization and others, where up to a few hundred photons can be absorbed from the laser field.

In parallel with these experimental developments, massive efforts have been undertaken to unveil the precise physical mechanisms behind multi-photon ionization (MPI) and other strong-field ionization phenomena. It was shown convincingly that multiple ionization of atoms by an ultra-short intense laser pulse is a process in which the highly nonlinear interaction between the electrons and the external field is closely interrelated with the few-body correlated dynamics. A theoretical description of such processes requires development of new theoretical methods to simultaneously account for the field nonlinearity and the long-ranged Coulomb interaction between the particles.

In our group, we developed explicitly time-dependent, non-perturbative methods to treat MPI processes in many-electron atoms. These methods are based on numerical solution of the time-dependent Schrödinger equation for a target atom or molecule in the presence of an electromagnetic and/or static electric field. Projecting this solution onto final field-free target states gives us probabilities and cross-sections for various ionization channels.

Further information [http://dx.doi.org/10.1103/PhysRevA.80.063418](http://dx.doi.org/10.1103/PhysRevA.80.063418)

Required background

Advanced quantum mechanics course and competence in scientific programming/numerical computations

Project suitability

- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Research fields

- Astrophysics
- Physics of the Nucleus

Project details

Carbon, the fourth most abundant element in our universe, is produced in the triple-alpha process in helium-burning red-giant stars. In 1953 Fred Hoyle realized that the fact that there is carbon in the universe requires a resonant state in $^{12}\text{C}$ very near 7.7 MeV energy. The subsequent observation of the state in 1953 is often cited as the beginning of experimental nuclear astrophysics. In the so-called triple-$\alpha$ process, the unstable $^{8}\text{Be}$ nucleus, which decays back to two $\alpha$ particles with a half-life of $T_{1/2}=6.7 \times 10^{17}$ s, is combined with a third $\alpha$-particle to form the 7.654 MeV resonant state in the stable nucleus $^{12}\text{C}$. However 99.96% of the time the resonant state decays back to $^{8}\text{Be}$ by alpha emission, producing no stable carbon nuclei. A small fraction of the time, the resonant state decays to lower states in the carbon nucleus, which remain stable against $\alpha$-emission. These decay paths, the only source of carbon in the universe, proceed by the emission of a 3.215 MeV electric quadrupole (E2) and a 7.654 MeV electric monopole (E0) transition.

The sum of absolute E2 and E0 decay rates is known to only 12% accuracy, which has been identified as a major obstacle to improve current stellar models. We are planning to measure the relative E0 and E2 decay rates by observing the electron-positron pairs emitted in these high-energy nuclear transitions.

The Hoyle state can be excited in the laboratory by 10.5 MeV protons incident onto a $^{12}\text{C}$ target. The main goal of the student project is to develop a magnetic pair spectrometer, based on a superconducting solenoid transporter combined with an array of semiconductor detectors. The project will involve instrumental developments and extensive Monte Carlo simulations to understand the spectrometer response to the high energy electron-positron pairs, as well as photons and other background radiations. The understanding of the energy and angular correlations of the pairs plays a crucial role in reaching the desired accuracy in the E0/E2 branching ratio.

Project suitability

- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Theoretical Physics
- Materials Science and Engineering

Project details
X-ray micro-tomography is a non-destructive technique for high-resolution 3D imaging of specimens of interest in research fields such as material science, (e.g. foams, granular packings), medicine, biology, paleontology, and geology. It is not a direct imaging technique but rather the 3D image is "computed" from a set of 2D X-ray images of the specimen taken from various directions.

The micro-tomography facility at ANU uses a broad spectrum of X-ray energies for imaging (a.k.a. polychromatic radiation). The attenuation properties of materials are a function of X-ray energy; low energy (or soft) X-rays are preferentially attenuated causing the x-ray beam to contain a greater proportion of high energy (or hard) X-rays as it passes through the specimen. This process is termed "beam hardening" and causes the set of 2D X-ray images to be inconsistent and leads to a computed 3D image with cupping, streaking, and halo artifacts that degrade image quality. It is the high-density objects in specimens in particular, (e.g., minerals in rocks, metal-pins in biological specimens), that cause significant streaking and halo artifacts (and in some cases make the final 3D image unusable).

A hardware solution is to "pre-harden" the X-ray beam, i.e., filter the X-ray source. This can mitigate the effect, however, there is a loss of sensitivity to components of lower attenuation. Several software techniques also exists to cope with high-density objects; this project will explore the performance of these methods as well as investigate alternatives with the aim to improve on the image quality resulting from "pre-filtering."

Required background
Willingness to engage with mathematical, physical, and computational disciplines. Familiarity with one or more of python/c/c++ is preferable.

Project suitability
- Honours project

Project supervisors
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Multi-spectral x-ray micro-tomography

Research fields
- Theoretical Physics
- Materials Science and Engineering

Project details
The ANU micro-CT facility houses several X-ray micro-tomography systems that have been designed and built in-house. The systems use a broad spectrum of X-ray energies for imaging (a.k.a. polychromatic radiation). We have the ability to coarsely tune this spectrum by varying the accelerating voltage of the electron beam in the X-ray source [this determines the maximum X-ray energy] and by filtering the beam with various materials [this removes more or less of the low energy X-rays].

When imaging a (biological, geological, paleontological,...) specimen of interest, the variation in X-ray attenuation over different energy ranges can tell us a lot about its composition. To date the ANU facility makes no use of this fact and simply works with the “average” attenuation data over the spectrum used for imaging.

This project involves firstly determining the spectral "bands" over which we can image at our facility and how to achieve them. Specific applications suited to these bands produced must be identified. Secondly, the existing techniques to extract information gained from multi-spectral data must be developed, explored, and adapted to be suitable methods for the ANU facility.

Required background
Willingness to engage with mathematical, physical, and computational disciplines. Familiarity with python/c/c++ is a bonus.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project

Project supervisors

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3D phantoms for X-ray micro-tomography

Research fields
- Topological and Structural Science
- Materials Science and Engineering

Project details
The Applied Maths department has designed and built several computed tomography (CT) systems that image at the micron scale, i.e., a micro-CT facility. The group has also purchased a 3D printer. The idea here is to design and 3D print some phantoms to be imaged at the facility.

"Phantoms" are objects used for performance testing and/or calibration of 3D X-ray computed tomography (CT) systems. There are several standard calibration phantoms used for medical CT, however, there seem to be no universally used standards for micro-CT. The first part of this project involves the design of a phantom that could serve for calibration of micro-CT.

Typically the 3D colour printer prints on a kind of plaster; a printed object would appear as a black/white object in X-ray tomography. By modifying the inks used we should be able to get varying degrees of X-ray attenuation throughout the plaster and effectively see "greyscale" printing in the X-ray images. The second part of the project involves testing/proving this concept.

Thirdly, if we can have "greyscale" printing: we can start investigate the printing of "ghost" objects. Ghosts are objects that essentially disappear at certain projection angles. This part of the project would be done in collaboration with Dr. Imants Svalbe from Monash Uni. (An expert on ghost functions).

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisors
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Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
GaSb and InSb are semiconductors suitable for fabricating high-frequency electronic and optoelectronic devices. Ion implantation, commonly used for introduction of electrically-active impurities ("doping") in semiconductor materials, can lead to the damage/amorphization of such materials. In addition appropriate implant conditions will render GaSb and InSb porous leading to fascinating network structures (see image). Porous structures can be observed after irradiation with ions in a wide energy range, between keV and GeV, however, the porous morphology depends on the ion energy. In particular the effect of high energy (>50 MeV) irradiation has not yet been studied in detail for GaSb and InSb but offers high potential to create novel nanostructures for application in electronic and optoelectronic devices.

The project seeks to investigate the structure and morphology of the fascinating porous networks that evolve in the antimonides upon high energy ion irradiation and study its stability under a variety of application relevant conditions. It offers the ability for the student to become acquainted with a range of state of the art analytical and processing techniques including synchrotron x-ray techniques at the state-of-the-art Australian Synchrotron in Melbourne and Positron Annihilation Lifetime Spectroscopy at the ANU.

Depending on the extent of the project the student can develop skills in:
- High energy ion beam processing
- Synchrotron based small angle x-ray scattering and x-ray absorption spectroscopy
- Positron Annihilation Lifetime Spectroscopy
- Microscopy techniques such as transmission electron microscopy and scanning electron microscopy
- Laboratory based analytical techniques such as x-ray diffraction and raman spectroscopy
- Semiconductor processing techniques and device fabrication
- Working in a team on a multidisciplinary project

Required background
Interest in solid state physics, nanotechnology, materials science, synchrotron techniques

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
Minerals such as apatite and zircon can incorporate and retain trace amounts of uranium and thorium. The spontaneous fission of uranium leads to energetic nuclear fragments, which induce narrow cylindrical trails of damage in the material just a few nm in diameter and several micrometers in length, so called ‘fission tracks’. Fission tracks are used for dating (geochronology) and constraining the thermal history (thermochronology) of geological samples with a commercial interest for oil exploration and to infer rates of tectonic uplift. The current dating technology utilizes chemical etching, which preferentially attacks the radiation-damaged volume in the undamaged bulk, to enlarge the nm-sized latent tracks such that they can be observed by optical microscopy. The currently lacking detailed understanding of the primary track damage and its dependence on relevant geological parameters can provide key information for geo- and thermochronology and interpretation of etched track distributions. We have demonstrated that synchrotron small angle x-ray scattering is well suited to study the primary track damage (for example see B. Afra et al. Phys Rev B (2011) 064116).

The project will study fission track formation and stability in a natural and synthetic apatites and zircon under a variety of geologically relevant conditions such as high pressure and temperature. Characterisation will be performed using synchrotron based small angle x-ray scattering (SAXS), transmission electron microscopy, x-ray diffraction and Rutherford backscattering spectroscopy. The emphasis will be on synchrotron SAXS at the Australian Synchrotron which enables in situ studies in high pressure and temperature environments.

Required background
Interest in interdisciplinary physics, materials science, synchrotron techniques

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Monte-Carlo simulation of x-ray scattering from nano-objects

Research fields
- Nanoscience and Nanotechnology
- Topological and Structural Science

Project details
Our group extensively utilises synchrotron small angle x-ray scattering (SAXS) to study nanometer sized objects such as high energy ion tracks, nanoparticles and voids in porous materials. The complex structures of these objects often require numerical methods to model the observed scattering patterns. This project aims to develop a computer code that simulates scattering from nano objects based on Monte Carlo methods. Development of the code will be accompanied by measurement and analysis of appropriate nano-objects, in particular ion tracks and nano pores.

While this project is predominately computational, the student will be involved in all experimental aspects of the sample preparation and analysis, in particular with the SAXS measurements at the state-of-the-art Australian Synchrotron.

Required background
condensed matter physics, computational skills

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Ion track nanotechnology

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
Ion tracks are long columnar defect structures that evolve in many materials when they interact with high energetic heavy ions. These ion tracks possess high aspect ratios, as they are generally only few nanometers in diameter but up to tens of micrometers long. Often the damaged zones in the ion tracks show enhanced chemical etching rates compared to undamaged material and/or changes in the physical properties such as electrical conductivity. These characteristics make ion tracks very interesting for a variety of applications in nano- and micro-technology, including templates for nanowire growth, biological sensors and filter membranes.

The project will investigate fundamental properties of ion tracks and exploit their utilization for application in nano- and micro-technology. It will include the study of the damage structure as a function of ion irradiation parameters in a variety of materials, adaptation of suitable etching protocols and development of functional nano-materials/devices based on ion track technology. The project encompasses a variety of semiconductor processing and fabrication techniques as well as state-of-the-art analytical techniques including synchrotron based small angle x-ray scattering.

Required background
Interest in nanotechnology, materials science, synchrotron techniques

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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Research fields

- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details

Metal and semiconductor nanoparticles embedded in dielectric materials such as SiO₂ and Si₃N₄ are interesting for advanced optical applications. Such nanoparticles can be synthesised by ion implantation or thin film deposition and subsequent thermal annealing.

This project will study the growth kinetics of nanoparticles using in situ annealing combined with synchrotron small angle x-ray scattering (SAXS) experiments as a function of nanoparticle material, matrix material and annealing conditions. Together with laboratory based analytical techniques such as transmission electron microscopy, Rutherford backscattering spectroscopy and x-ray diffraction this systematic study will yield vital information for the fabrication of application specific nanoparticle composite materials.

The student will acquire experience with a variety of semiconductor processing techniques, such as ion implantation and thin film deposition and will make use of the Australian Synchrotron for the SAXS measurements.

Required background

Interest in nanotechnology, materials science and engineering, and synchrotron techniques

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

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### Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

### Project details
Levitation, derived from the Latin word “levitas” meaning “lightness”, is the process of suspending a physical object by applying a force to counteract gravity. Levitation of macroscopic objects has been demonstrated using superconducting magnetism, electrostatic field, thermal drafts, and other physical effects. In 2000, an Ig Nobel Prize in Physics was even awarded to two physicists for the magnetic levitation of a frog. Perhaps the most well known application of levitation is the Maglev high-speed train where levitation is used to eliminate track friction, enabling speed of more than 500 km/h for passenger carrying transport.

While levitation is not new, it was never thought of as a technology that could be used for probing quantum theory or as a tool that could be used for precision sensing. In recent years, however, it has gained considerable attention in the physics community for these new purposes. Levitation of nanoparticles, glass beads, and other microscopic objects have been attempted for the purpose of studying the quantum opto-mechanical interactions between optical fields and mechanical objects.

These new generation of experiments transform levitation from a process that simply counteract gravity to one that is cleaner and more precisely controlled. The aim of this project is towards the realisation of the world’s first laser levitation of a macroscopic mirror. The student is asked to join a team of scientists and PhD students to theoretically model and/or develop components for the laser levitation experiment.


### Required background
Second year physics

### Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

### Project supervisors

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Research fields
- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details
In the last few decades, fibre optics has revolutionised telecommunications. At the same time, they have also been used for sensing in a broad range of applications, from measuring chemical concentration to nanoparticle detection. One of the most exciting areas of fibre optics research and development is their use as distributed acoustic sensors. Distributed sensors allow signals to be detected throughout the entire length of fibre. Combined with low optical signal attenuation in telecommunications grade fibre, this allows continuous sensing over hundreds of kilometers.

Experiments in this project will investigate sensing techniques with extremely high precision. The student will gain a variety of hands on experience involving lasers, optical fibres, optical components, and digital signal processing.

Required background
Students will require a background in optics and signal processing.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Jong Chow
Convenor for Photonics Program
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The primary tool for investigating the structure of exotic nuclei is time-correlated gamma-coincidence spectroscopy, where the cascades of gamma-rays that de-excite highly-excited states in atomic nuclei are resolved and identified with high-resolution gamma-ray detectors. Typically, these detectors are high-purity germanium (HPGe) detectors surrounded by Compton-suppression shields (typically bismuth germanate scintillator) used to ensure that only full-energy events are collected for each detected gamma-ray.

The CAESAR array in the Dept of Nuclear Physics consists of 11 HPGe detectors, 9 of which are Compton suppressed, and two of which are unsuppressed low-energy photon spectrometer (LEPS) detectors that are optimised for high-resolution measurements of low energy gamma-rays and x-rays.

CAESAR is optimised for isomer spectroscopy, commonly using the pulsed-beam from the 14UD accelerator to probe long-lived states in atomic nuclei with lifetimes of tens of nanoseconds or longer. It is then possible to employ the time-correlations between the gamma-rays observed above and below isomeric states to build up complicated level schemes that are then interpreted in terms of different models of nuclear behaviour. There are a number of ongoing programs of research investigating different regions of nuclei and probing particular aspects of nuclear behaviour, for example, shell model structure of nuclei near $^{208}$Pb and the transition from spherical to collective behaviour, and the nature of the K quantum number and related high-K isomers in well-deformed nuclei.

Required background

No specific background knowledge is required. This project will suit students who like to solve puzzles and are comfortable with computer-based data analysis.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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<thead>
<tr>
<th>Name</th>
<th>Title/Contact Information</th>
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<tr>
<td>Gregory Lane</td>
<td>Senior Fellow and ARC Future Fellow 02 6125 0375</td>
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<tr>
<td>Andrew Stuchbery</td>
<td>Head of Department 02 6125 2097 <a href="mailto:Andrew.Stuchbery@anu.edu.au">Andrew.Stuchbery@anu.edu.au</a></td>
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<tr>
<td>Matthew Reed</td>
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<td>Sankha Hota</td>
<td>Postdoctoral Fellow 02 6125 0609 <a href="mailto:sankha.hota@anu.edu.au">sankha.hota@anu.edu.au</a></td>
</tr>
</tbody>
</table>
Research fields
- Physics of the Nucleus

Project details
SOLENOGAM is an electron and gamma-ray spectrometer funded by the ARC Discovery and ANU Major Equipment programs. It is presently being installed on a new beam line at the focal plane of an 8T superconducting solenoid that is used to separate the weakly-populated fusion products of interest from the wealth of background produced from scattered beam and fission. In this background-free environment it is possible to perform sensitive gamma-ray and electron spectroscopy of the states populated in either the decay of long-lived isomer states or the beta or alpha-decay from nuclear ground states.

SOLENOGAM has advantages over competing devices in terms of the way it is optimised for high-efficiency, high-resolution electron spectroscopy, the fact that it has a very high transmission efficiency for fusion products, and that the compact nature of the solenoid provides a sensitivity to short-lived isomeric states.

The initial research program of SOLENOGAM is being developed and is expected to focus on shape coexistence in neutron-deficient mercury/thallium/lead nuclei, as well as studies of high-spin isomeric states in the N=82 region. There are a number of projects available, from short-term testing and calibration measurements, through to long-term investigations of exotic nuclear phenomena in nuclei far from stability.

Required background
No specific background knowledge. As a new device, this project will suit students who are willing to work hands-on with experimental equipment, while also being comfortable with computer-based data analysis.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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</tr>
</tbody>
</table>
Research fields
- Topological and Structural Science
- Materials Science and Engineering

Project details
Image segmentation is the task of labeling every voxel in an image such that voxels with the same label share similar characteristics (similar grey value, similar texture, ...). Challenges specific to dealing with micro-CT images include: (a) the size of the datasets (tens of gigabytes), (b) presence of noise and (c) blurring (or point spread). The predominant supervised segmentation algorithms typically require some form of user input (either by selecting threshold-values associated with each label, or by selecting image regions associated with a label). For quantitative segmented image analysis, the deficiency of this approach lies in user subjectivity; different users may select different thresholds/features resulting in different segmented images, which ultimately leads to different quantitative analyses. Unsupervised segmentation methods are dominated by "machine learning" where a training set of (image, segmented-image) pairs are used to optimise algorithm parameters. Subsequent images (i.e. non-training images) are segmented using the optimised parameters. The deficiencies of these methods are having a large enough and high quality training set and reduction in segmentation accuracy when "unseen" image features are encountered.

This project will evaluate performance (computational performance and segmentation accuracy) of segmentation methods for synthetic and micro-CT images with particular emphasis on recent graph partitioning methods. The project will take advantage of existing segmentation software such as ilastik (http://www.ilastik.org) and the graph optimization and inference library OpenGM (https://github.com/opengm/opengm). The higher level research goal is to develop an unsupervised segmentation method for micro-CT images.

Required background
This course is suitable for students from physics and engineering. Some programming experience is essential. Python and C++ will be used in the project; skills in these particular languages can be learnt as part of the project.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

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Example segmentation of sandstone (black pore, green clays, red quartz, blue high-density minerals)
Research fields
- Atomic and Molecular Physics
- Physics of the Nucleus

Project details
Emission of Auger electrons and X-rays can be triggered by creation of vacancies through nuclear decays such as internal conversion of electron capture. Non-energetic Auger electrons are usually neglected in handling of Auger-electron-emitting radioisotopes. Recent experiments show that Auger electrons exhibit high linear energy transfer (LET) behaviour, and are effective in killing targeted cells when emitting radioisotopes are very close to the nuclear DNA (~10 nm). Auger emitters are now of great interest in internal radiotherapy of malignancies. Biological effectiveness of Auger emitters depends on their Auger yields per nuclear decay. The databases of Auger yields for medical radioisotopes are highly inconsistent and computed using outdated nuclear and atomic data. Initiated by the International Nuclear Data Committee (INDC) of IAEA, efforts are underway to develop a comprehensive calculational route to determine Auger yields to a higher degree of detail and consistency than is available at present.

The project will involve theoretical calculations of atomic properties and modelling of emission of Auger electrons and X-rays using Fortran programming language. Sophisticated atomic structure packages GRASP2K and RATIP will be used to compute energies and emission probabilities of Auger electrons and X-ray. GRASP2K and RATIP have been proven to be highly reliable in calculating atomic energies and emission probabilities. Accurate atomic properties are extremely important in determining Auger yields as the calculation of Auger yields is highly sensitive to atomic emission probabilities. The student will be able to calculate Auger yields for radioisotopes of great interest using current emission model developed at the department. The student will have the opportunity to participate in developments of new emission model using GRASP2K and RATIP.

Project suitability
- Third year special research topic
- Honours project
- PhD or Masters project

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Research fields

- Photonics, Lasers and Nonlinear Optics

Project details

Third order nonlinear optical processes in optical waveguides supports a wide range of phenomena that can be used to process data streams at unprecedented speed. In addition nonlinear optics is used in supercontinuum generation and the creation of optical frequency combs, both phenomena leading to new opportunities for spectroscopy and optical sensing. In our research we focus on the use of so-called chalcogenide glasses for waveguide nonlinear optics since these materials offer the combination of high nonlinearity and unrivalled transparency well into the mid infrared. Mid infrared transparency means that chalcogenides can be used to make devices that operate across the important molecular fingerprint region of the optical spectrum where virtually any molecule can be identified from its characteristic spectral signature. The aim of our program is to develop new devices which can integrated lasers with supercontinuum or comb sources onto optical integrated circuits.

Required background

Physics or appropriate engineering degree

Project suitability

- PhD or Masters project

Project supervisors

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Research fields
- Photonics, Lasers and Nonlinear Optics

Project details
We recently demonstrated an integrated planar waveguide nonlinear optical supercontinuum source generating broadband MIR light >100x brighter than a synchrotron. Whilst offering ground breaking functionality, this source used an external mainframe laser for pumping, and these are bulky and expensive. To fully planar integrate such sources requires an on chip mode locked laser as a pump source. A fully integrated mode locked laser has never been demonstrated. To attain such a device requires a planar waveguide with high gain, passive waveguides which can be dispersion tailored and where pump couplers and mirrors can be built, and a waveguide saturable absorber. We have already demonstrated a high optical gain waveguide platform and suitable passive waveguides in Tellurium dioxide, and so are offering the opportunity to take this platform and make an on-chip mode locked laser. The project will require both theoretical and experimental work, the former to design the individual components comprising the laser as well as the total nonlinear cavity, and the latter involving the planar fabrication of the designed components and laser, and characterisation thereof. This project is being partly funded by Agilent through the support of the Stevens Creek Research Laboratories in California and Agilent Australia.

Project suitability
- PhD or Masters project

Project supervisors
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Research fields
- Photonics, Lasers and Nonlinear Optics

Project details
Conventional wideband MIR detectors are based on narrow band gap semiconductors requiring exotic processing and are not easily integrated with conventional waveguide technology. In recent times it has become apparent that Graphene possesses photodetection capabilities, and very recently it has been found that this extends deep into the MIR in some circumstances. Additionally it has also been established that certain superconductor materials also enable MIR detection at the single photon level. Both of these technologies are well suited to integration onto chalcogenide glass waveguides (now established as an excellent MIR waveguide platform). This project seeks to examine the MIR photodetection in graphene and find the optimum waveguide & detector architectures for this as well as to characterise and optimise the MIR performance of waveguide superconducting nanowire detectors. The project also includes collaboration with the UNSW and ANU LPC nodes of the Centre for Quantum Computing and Communication Technologies, and the world’s leading experts on Superconducting nanowire materials at NIST and Graphene detectors at TU Wein and Monash University.

Project suitability
- PhD or Masters project

Project supervisors
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Research fields
- Photonics, Lasers and Nonlinear Optics

Project details
Analysis of MIR supercontinuum generation has clarified that to get the very broadband spectral coverage required for next generation sensing systems, a MIR pump at >3.5um is essential. Currently this requires the use of an optical parametric device, but interestingly chalcogenide glass hosts uniquely offer the properties required to enable rare earth lasing in glass hosts at wavelengths beyond 3.5um and perhaps as far as 10 um. To reduce the cost to an acceptable level the lasers also need to be planar integrated. However until recently there had been no demonstrations of rare earth doped amplifiers or lasers in such hosts in any form beyond 1.3um. Very recently we achieved the first gain at 1.55um in a chalcogenide host using Erbium and also the first demonstration of a planar waveguide amplifier in a chalcogenide glass. Erbium also has lasing transitions at 2.8 and 3.5um and other rare earths offer longer lasing wavelengths. This project then aims to explore the materials and excitation challenges in making the world’s first chalcogenide MIR waveguide laser. The project will be heavily focussed on materials fabrication and excitation characterisation to determine the pump energy loss pathways with the goal of making a waveguide amplifier/laser using the simplest possible structure. The project is partly supported by CUDOS ARC Centre of Excellence.

Project suitability
- PhD or Masters project

Project supervisors

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Research fields
- Photonics, Lasers and Nonlinear Optics

Project details
The prime goal of MIR sensing devices is to enable ultrasensitive detection of chemical species for applications in health (breath diagnosis is a key target here), the environment, national security, agriculture and industry, and so this requires appropriate device architectures. Planar waveguide devices by their nature have a small cross section and confine most of their light in the waveguide and so the interesting question of how to increase sensitivity arises. This project seeks to investigate waveguide designs that maximise the overlap of the guided light with the material to be sensed and also resonant structures that increase sensitivity effectively by using multipass methods. Work will involve detailed optical modelling and optimisation of devices and architectures, fabrication and characterisation of planar waveguide integrated sensing structures, and ultimately demonstrations in real life settings such as breath analysis potentially in a healthcare setting.

Project suitability
- PhD or Masters project

Project supervisor
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Research fields

- Photonics, Lasers and Nonlinear Optics

Project details

Whilst the work we have undertaken at the Laser Physics Centre over the last 10 years has laid an excellent foundation for highly integrated nonlinear optical devices on a chip, much remains to be done. Our current focus is on building nanophotonic devices to increase nonlinearity, loss compensation, non-linear processing in the presence of gain, and heterogenous integration of multiple optical waveguide platforms on a single chip. Work spans basic materials science through to device architectures and full heterogeneously integrated device fabrication. We collaborate with a number of the world’s leading institutions in planar optics and nonlinear processing, (e.g. IMEC, Ghent, DTU, etc) and can offer a number of projects in the nonlinear planar devices arena. This project area forms a core part of the CUDOS ARC centre of excellence program and is fully supported by CUDOS.

Project suitability

- PhD or Masters project

Project supervisors

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Research fields
- Theoretical Physics

Project details
Quantum integrable systems play a very important role in many fields of theoretical physics like quantum field theory, statistical mechanics, string theory, etc. This project aims to study their basic properties. One-dimensional Heisenberg model of interacting spins is one of the basic nontrivial examples of such systems. Despite the seeming simplicity it reveals a highly nontrivial mathematical structure which eventually led to a discovery of quantum groups. This mathematical structure reveals itself in terms of a special master equation for structural constants of the theory, the Yang-Baxter equation. A study of solutions of this equation led to major breakthroughs in many areas of physics and mathematics including knot theory, string theory, condensed matter physics, etc.

Required background
PHYS2013, PHYS3001, MATH3351

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor
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Research fields

- Theoretical Physics

Project details

It is well known that certain systems in classical mechanics are completely integrable in a sense that they possess a sufficient number of integrals of motion which allow us to integrate equations of motion explicitly. In Hamiltonian formulation the number of integrals of motion should be no less than the number of canonical coordinates (or canonical momenta). Then there exist special canonical variables called action-angle variables such that the dynamics of the system in these coordinates reduces to a set of one-dimensional problems.

These ideas can be extended to quantum integrable systems. In quantum case we are looking for a complete set of eigenfunctions which simultaneously diagonalize "quantum integrals of motion". Quantum separation of variables allows us to express these multi-variable eigenfunctions in terms of functions of one variable only. In principle this helps to solve the equations of motions for the original system. Surprisingly such (integral) transformations are linked to some well known (or sometimes new) formulas in the theory of classical special functions.

Required background

PHYS3001, MATH2406, MATH3351

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor

Vladimir Mangazeev

Vladimir Mangazeev

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Research fields
- Theoretical Physics

Project details
During last decades integrable systems helped to answer a number of difficult outstanding questions in mathematics. They led to advances in knot theory, string theory, theory of differential equations, etc. This project consider connections of integrable systems to combinatorial problems and special functions. It is natural to consider quantum spins systems with discrete fluctuating variables as an efficient tool to count "something" in its configuration space of the system. For example, we can talk about the total number of configurations with 11 spins up, etc. Recently it was found that one can count some special types of matrices using such techniques. It led to a large boost of interest which helped to prove many conjectures in the theory of alternating sign matrices. This project aims to look at different generalizations of such connections.

Required background
PHYS2020, MATH2406, MATH3351

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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Research fields

- Theoretical Physics

Project details

This project aims to develop advanced analytic and numerical methods to analyze the behavior of quantum spin systems near its critical point. It is well known that when the system reaches its critical region, small correlations between individual components of the system turn into macroscopic correlations of a large number of particles. As a result, most of existing methods of analysis fail in this regime. The system becomes scale invariant (or conformally invariant) in a sense that the whole system behavior is very similar to the behavior of its smaller part. This can be used to formulate a fast converging iterative algorithm which can predict thermodynamic properties of the system with unprecedented accuracy. This algorithm uses a special technique which is called corner transfer matrices method (CTM) originally invented by Prof. R. Baxter. The student will study the method and its modifications and develop a set of analytic and numerical programs suitable for studies of particular interacting quantum systems in 1 or 2 dimensions.

Required background

PHYS3001, MATH3351, working knowledge of Mathematica or other programming language and basics of linear algebra

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor

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Research fields

- Photonics, Lasers and Nonlinear Optics
- Quantum Science and Applications

Project details

Laser-interferometric gravitational wave detectors, such as those of the Laser Interferometer Gravitational Wave Observatory (LIGO), are the most sensitive position meters yet made, able to measure length variations of order $10^{-19}$ m (or 1/10000th of the diameter of a hydrogen nucleus).

However, the LIGO interferometers are limited by quantum noise of the light itself, and the next-generation Advanced LIGO detectors are expected to be limited by quantum light noise across their entire measurement band. In the last decade, the injection of squeezed states of light has been established as a promising technique to reduce quantum noise, providing an opportunity to improve the detector sensitivity even further. The implementation of squeezed states creates technical challenges that need to be addressed.

The ANU Centre for Gravitational Physics is a key member of the LIGO Scientific Collaboration and continues to develop hardware and techniques for use at the LIGO observatories. We are a lead group in the Collaboration on the generation and implementation of squeezed light. We currently seek students at the Honours or Graduate level to join our dynamic group. Each project is tailored to the goals and abilities of the applicant. Interested individuals are encouraged to contact us to discuss potential research topics.

Find out more by following the Further Information link below, or by visiting the Centre for Gravitational Physics website

Further information http://cgp.anu.edu.au/research/lowfsqueezing/

Required background

Experience with optics and lasers is a must, knowledge of quantum optics and computational skills (e.g. MATLAB) would be beneficial

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

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Electronic band structure of semiconductor nanowires

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
Nanowires, with their unique properties, are expected to revolutionise the semiconductor industry. They have a wide range of electronics, photonics, photovoltaic, and thermoelectric applications. Many of these intriguing properties result from the high surface area to volume ratio or high aspect ratio which results in carrier confinement in two dimensions.

Initially, the project will entail calculating the electronic band structure of nanowires with varying diameters (3-50 nm) and methods of surface passivation. This theoretical modelling to calculate band structures will be performed from first principal calculations using density functional theory. These calculations require a large cell, so these calculations will employ the NCI supercomputer (raijin) using the program VASP. The electronic band structure of nanowire radial heterostructures for photovoltaic or thermoelectric device applications will then be calculated using the same techniques.

PhD students can then build upon the theoretical calculations using an experimental technique called Angle Resolved Photoemission Spectroscopy (ARPES) which utilizes synchrotron X-rays to measure the correlation between nanowire diameter or passivation and the surface electronic band structure.

Required background

Familiarity with Linux helpful but not required.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Fusion and Plasma Confinement

Project details
The ANU's H-1 Heliac is a fusion research facility aimed at investigating how the 'twist' of magnetic field lines is important through the use of a helical coil and features flexibility that larger fusion devices do not possess. The complicated topology of ion and electron orbits in this magnetic field effectively determine how well the plasma can be confined and how the plasma flows as a reaction. Whilst flow measurements have carried on on H-1 for some time, in both the toroidal direction and poloidal (normal) direction, measurements have not been precise enough to relate the plasma flow direction to the magnetic field direction. Theory says that the plasma flow tends to be in the direction with lowest ripples in the magnetic field. The project involves Doppler spectroscopy techniques, including the use of tomography, and/or Mach probes to measure plasma flow in both toroidal and normal directions and basic comparison with theory. Additionally, a biased limiter may soon also be available to induce flows by externally charging up the plasma magnetic surfaces and the transient reaction will enable evaluation of the so-called neoclassical viscosity. Such topics are of strong relevance in the field as rotation is a key parameter to avoid instabilities and turbulence in fusion reactors.

Required background
Plasma course under 'research topics' will be vital. The project will be fairly analytical requiring the use of computers for evaluation of results and the mathematical concepts involved include topology, geometry, linear algebra and optimisation techniques. The project is also experimental and so courses with a lot of labwork will be helpful.

Project suitability
- Honours project
- Summer research scholarship

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Neutral light image from the H-1 Heliac (used to derive particle ionization)

Research fields
- Fusion and Plasma Confinement

Project details
The ANU's H-1 Heliac is a fusion research facility where a confining 3D twisted magnetic field is produced by entirely by external coils. The complicated topology of ion and electron orbits in this magnetic field effectively determine how well the plasma can be confined. These manifest in three basic channels: particles, momentum and heat. Balancing of the sources and sinks in each of these three channels will lead to a quantitative 'transport' analysis to be compared with theory.

For evaluating the particle flux, a detailed quantitative analysis on the ionization rate can be done by analysing the neutral hydrogen light available from filtered imaging (as in the figure). The turbulent particle flux can be obtained directly from Langmuir probes inserted into the plasma. Furthermore, to obtain diffusion and convection coefficients, relevant for comparing with collisional transport theory, the transient response to a perturbation can be analysed. A new multi-channel interferometer will be used for density measurements. The background gas can be modulated periodically or the density risen abruptly using a supersonic gas injector.

This project will involve both experimental design and analysis, as well as the utilization of advanced codes for modelling plasma geometry and transport due to collisions. These results are relevant to the question of whether fuel would be effectively transported to the core of the plasma in a Stellarator reactor.

Required background
Plasma course, experimental lab based physics courses, analytical and computation mathematical skills.

Project suitability
- Honours project
- Summer research scholarship

Project supervisors
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Research fields

- Astrophysics
- Atomic and Molecular Physics

Project details

Venus in many ways is the planet most similar to the Earth but some differences have defied explanation for decades. One outstanding issue is the chemical (and dynamical?) processes that maintain the long-term chemical stability of the atmosphere's primary constituent, carbon dioxide. Others relate to the chemistry and dynamics that produce the observed distribution of sulfur oxides on Venus, including the global, 30-km thick sulfuric acid clouds. Similar processes did, are, or will shape the evolution of the Earth's atmosphere.

Atmospheric chemistry on Venus typically is organised into three primary cycles: the carbon dioxide, sulfur oxidation, and polysulfur cycles. Below this top level, however, a number of conundrums exist. For example,

- What process(es) maintain the chemical stability of CO2, the primary constituent of the atmosphere?
- What causes the observed factor of ~10 variations with time in hemispherical average abundance of SO2 and SO?

Numerical models and observations are key tools for understanding atmospheric chemistry on Venus (and the Earth). Observations by collaborators based in the USA and Europe, eg. using HST, require analysis and interpretation with numerical models. In addition, new technology is creating opportunities for observations that can detect and characterise key species. Finally, advanced numerical models are required to simulate the complex interaction between dynamics and chemistry on Venus.

The ultimate objectives for this research are to understand the dominant chemical processes on Venus, what role(s) they've played in the evolution of Venus' atmosphere, and what implications they have for the Earth.


Required background

A range of projects are available that can be tailored to student experience and interests. Students should have a good quantitative science or engineering background appropriate to their level of studies. At minimum, students should have completed first year physics, calculus, and linear algebra. Desired background includes advanced physics, mathematics, chemistry, earth science, computer science, engineering, and/or astronomy. Postgraduate students should have a relevant honours or Masters degree or Bachelors degree with relevant research and/or work experience.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
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</tbody>
</table>
Research fields
- Environmental Physics
- Clean Energy

Project details
Multiple related projects are underway to quantify the effects of clouds on surface solar radiation and to develop techniques for forecasting the production of solar energy. Opportunities available for students include:

- Design remote data collection, archive, and distribution system
- Design remote data logging system for retrieving data from geographically dispersed photovoltaic and camera arrays
- Deploy, operate, calibrate, and analyse data from a nascent on-campus solar measurement network
- Analyse data from distributed photovoltaic arrays and other sensors
- Analyse sky images to derive cloud characteristics and motion

One objective for ongoing projects is to forecast production from a collection of photovoltaic (PV) systems distributed across a suburb at 5-60 minute in advance timescales. Another is to quantify the benefits of geographic dispersion for reducing the inherent variability of solar energy production. These projects are using data collected in Canberra, Alice Springs, Singapore, San Diego, and Florida.

Related efforts focus on the requirements for integrating much larger amounts of renewable energy into Australia’s electricity grid and the possibility of exporting solar-generated electricity from the Northern Territory to SE Asia.

Further information https://researchers.anu.edu.au/researchers/mills-fp

Required background
A range of projects are available that can be tailored to student experience and interests. Students should have a good quantitative science or engineering background that is appropriate to their level of studies. Desired background includes advanced physics, mathematics, earth science, computer science, engineering, and/or astronomy.

Project suitability
- Third year special research topic
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
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Research fields

- Atomic and Molecular Physics
- Environmental Physics

Project details

Australia's climate is influenced by multiple global- and regional-scale phenomena, each of which has a different timescale. Understanding the factors affecting Australia's climate and how they are likely to change in the future requires analysis, interpretation, and intercomparison of observations and model simulations.

Aerosols, small liquid and solid particles suspended in the atmosphere, directly affect incident sunlight and the altitudes at which it is absorbed. Indirectly, they can change cloud properties and the amount and type of cloudcover. Aerosol abundances over Australia are generally small, but some Australian aerosols have unique radiative properties, and the importance of Australian aerosols in future Australian climate scenarios is poorly constrained.

The interaction between atmospheric chemistry and climate is an important emerging research area. Stratospheric distributions of ozone, for example, play a major role in controlling circulation in the stratosphere, which, in turn, has been found in some model simulations to have significant effects on surface climate, particularly in the Southern Hemisphere.

Precipitation is one of the most difficult climatic variables to simulate, yet it is one of the most important for assessing climate change impacts. Opportunities exist for research on precipitation from the local to national scales, including statistical analyses of observations, process studies using atmospheric general circulation models (AGCMs), and characterisation of local weather patterns (eg via neural networks).

Clouds form, evolve, and dissipate on spatial scales smaller than can be observed from satellites. A major ANU project is creating a unique solar radiation and cloud measurement network based on the campus.


Required background

Honours: Require first year physics, calculus, and linear algebra or equivalent plus second or third year applied mathematics, quantitative earth/environmental science, or physics. Require basic computer and Web skills. Desire programming experience (any language or type). Postgraduate: Relevant honours or Masters degree or Bachelors degree with relevant research and/or work experience.

Projects can include laboratory components through joint projects with photon physics, observational studies using traditional - eg, Bureau of Meteorology - or nontraditional - eg, PV array - data, modelling and simulation analyses, or model development. Independently-developed project ideas are encouraged.

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

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Stephen Gibson
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Optical nanoantennas

Research fields
- Photonics, Lasers and Nonlinear Optics
- Theoretical Physics

Project details
Antennas are all around in our modern wireless society: they are the front-ends in satellites, cell-phones, laptops, that establish the communication by sending and receiving signals, typically MHz-GHz. But, according to Maxwell's equations the same principles of directing and receiving an excitation should be working at various scales. Thus, one may ask “Can a TV-antenna send a beam of light?” And the answer is “Yes, optical nanoantennas can!”

Optical nanoantennas are one of the most promising areas of activity of the current research in nanophotonics due to their ability to bridge the size and impedance mismatch between subwavelength emitters and free space radiation. They are of tremendous use for the development of novel optical sensors, solar cells, quantum communication systems, and for the emission enhancement and directionality control over a broad wavelength range.

The starting point for design of an optical nanoantenna begins from scaling down their radio-frequency counterparts. One of the most versatile of antenna designs are arrayed antenna systems. In most cases, the elements of an array are identical, but this is not necessary, which provides with wide opportunities for control of radiation pattern.

This project is focused on developing novel designs of optical antennas for molecular sensing, optical information transfer, and electromagnetic field localization beyond the diffraction limit. Optical antennas should not be made necessarily from metal, which opens new opportunities for other materials, like dielectric materials allow to effectively manipulate magnetic component of the light.

Required background
A background in electromagnetic wave propagation will be required to understand basic principle of how nanoantennas operate. The ability to process data using computer packages such as Matlab and/or Mathematica is also desireable.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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119 Nanowire DFB lasers

Research fields
- Photonics, Lasers and Nonlinear Optics
- Nanoscience and Nanotechnology

Project details
Information processing speed is currently limited by the speed of electronic components on a chip. High density photonic chips are promising for surpassing this limitation and further enhancing information processing speed. Light generation and manipulation at the nanoscale are critical components of any photonic chip. Ultra-small, low threshold, fast and stable semiconductor lasers are the key to high density integration of devices/components on a photonic chip.

Semiconductor nanowires are promising for developing nanoscale lasers. Nanowires are cylindrical semiconductor structures with diameters of few 10s of nm and height/length of few microns. These nanowires thus reduce the footprint of semiconductor devices and also enable 3D device architectures (Figure 1).

This project involves design and demonstration of semiconductor nanowire lasers (Figure 2). Control on the direction of light emission from the nanowire laser gives additional degree of freedom for design of high density photonic chips. This can be achieved by controlling the shape of the nanowires to introduce periodic variations in the refractive index along the length of the nanowire. The periodic variation in the refractive index of the nanowire provides distributed feedback (DFB) and the direction of light emission can be controlled by controlling the periodicity of the index variation.

This project will ultimately lead to faster and more economical/environmentally friendly/low energy consumption information processing systems.

This project can be divided into the following smaller modules, and students may take up one or more of the following tasks to suit their interests:

1. Development of analytical and numerical modelling for understanding the photonic behaviour of semiconductor nanowires: This step identifies the exact dimensions of the nanowire to achieve lasing and control the emission direction with respect to the nanowire axis. This step is most suitable for students with aptitude for analytical modelling techniques.

2. Fabrication of nanowires with periodic index variations along the length: This step involves working with nano-fabrication equipment like FIB (focused ion beam) and EBL (electron beam lithography) to manipulate the nanowires. This step is most suitable for students aiming to get hands-on experience with state-of-the-art experimental equipment.

3. Optical characterisation of nanowire emission and nanowire lasers: This step involves handling optical set-ups for gaining an insight into the characteristics of nanowire lasers and is most suitable for students interested in spectroscopic techniques.

Required background
Physics, Materials Science, Engineering

Project suitability
Third year special research topic
PhD first year project

Project supervisors

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**Research fields**

- Nanoscience and Nanotechnology
- Materials Science and Engineering

**Project details**

One of the technologies with the greatest scope for reducing greenhouse gas emissions is photovoltaics. The most important step in promoting photovoltaics is to bring down the cost of solar electricity to a level lower than electricity from fossil fuels. This can be achieved by simultaneously increasing the device efficiencies and reducing the volume of semiconductor material used for absorbing the solar radiation. III-V semiconductor nanowires maximise absorption of sunlight per unit volume of material. In fact, modelling suggests that III-V semiconductor nanowire solar cells require only a small fraction of semiconductor material used in conventional solar cells to achieve similar or higher efficiencies.

Achieving high efficiencies in solar cells also requires efficient separation of photogenerated electron-hole pairs to prevent recombination and generate current in an external circuit. The most widely used approach for electron-hole separation is to create electric fields at a junction formed between p- and n-type materials, in what is known as a p-n junction, to force electrons and holes into different regions of the device (Figure). Fabricating good quality p-n junctions at the nanoscale is very challenging. Moreover, eliminating the need for p-n junctions will reduce the number of process optimization steps. Thus, photovoltaic device structures that do not rely on p-n junctions for separation of photogenerated electrons and holes, are a promising alternative to fulfil the potential of the nanowire array device geometry.

This project will develop alternative approaches to separate photogenerated electron-hole pairs to exploit the full potential of nanowire solar cells. This involves the search for materials that have a type-II bandgap alignment with III-V semiconductors (Figure). For heterostructures with type-II bandgap alignment the minimum in conduction band and the maximum in valence band occur in different materials. Hence electrons and holes diffuse to different sides of the heterostructure and are spatially separated. Such structures are ideally suited for photovoltaic applications.

This project involves aspects of materials development, nano-scale fabrication and device characterisation and will result in products that will have a direct impact on the solar cell commercial market. The materials development aspect involves identifying correct material combinations that will maximise electron-hole separation; nano-scale fabrication is required to fabricate these materials in the correct geometry/configuration and the device characterisation steps are necessary to evaluate the performance of the final device. Students may choose to work on any aspect of this project that interests them.

**Required background**

Physics, Materials Science, Engineering

**Project suitability**

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

**Project supervisors**

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</tr>
</tbody>
</table>
Research fields

- Theoretical Physics
- Materials Science and Engineering

Project details

The ANU micro-CT lab is host to several 3D X-ray imaging systems (a.k.a. X-ray micro-tomography scanners) that can produce up to ~240GB of data per machine, per day. These scanners provide valuable information on geological, paleontological, and biological specimens. Further increases in the data rate and number of machines will necessitate the use of some sort of compression algorithm to store the recorded data.

The student will initially assess the practicality of various lossy and lossless compression algorithms. Any lossy compression will introduce defects into the recorded X-ray data; the student will conduct a mathematical and empirical evaluation of the effect that these defects have on: (i) the synthesis of 3D images from the recorded X-ray data; and (ii) the subsequent computational analysis of these 3D images. This investigation may lead to new algorithms to perform either or both of these steps.

Finally, research into *compressed sensing* methods shows that a successful data compression method can actually be used to improve the synthesis of 3D images from the recorded X-ray data; this will be explored if the student has time.

Required background

Willingness to engage with mathematical, physical, and computational disciplines. Familiarity with python/c/c++ is a bonus.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project

Project supervisors

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<tr>
<td>Glenn Myers</td>
<td>Andrew Kingston</td>
<td>Benoit Recur</td>
<td>Adrian Sheppard</td>
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Intelligent 3D X-ray imaging, for improved analysis of complex 3D images.

Research fields
- Theoretical Physics
- Materials Science and Engineering

Project details
X-ray computed tomography (CT) is a technique for non-destructive 3D imaging, that is used at the ANU to collect information about geological, biological, and paleontological samples. Elsewhere, the technique is used throughout medicine (CAT scans) and the material sciences.

The technique generates incredibly detailed images of complex 3D structures: a single 3D image may be up to 100GB. Analyzing this massive amount of data requires algorithms for the automated interpretation of 3D images, called "segmentation" algorithms. These algorithms make use of available a priori information to extract useful data from a 3D image.

Recent work suggests that it is possible to combine the generation and segmentation of the 3D image, allowing both parts of the process to benefit from a priori information, and improving overall accuracy. The student will attempt to develop and test such a method, improving the ability of the ANU micro-CT imaging facility to analyse samples of scientific interest. The project also has broader implications for the low-dose imaging of medical and biological samples.


Required background
Willingness to engage with mathematical, physical, and computational disciplines. Familiarity with python/c/c++ is a bonus.

Project suitability
- PhD or Masters project

Project supervisors
- Glenn Myers, Postdoctoral Fellow, 02 6125 4690, glenn.myers@anu.edu.au
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- Adrian Sheppard, Senior Fellow, 02 6125 8516, adrian.sheppard@anu.edu.au
Understanding carrier transport and doping in semiconductor nanowires through electrical characterization

Research fields
- Quantum Devices and Technology
- Materials Science and Engineering

Project details
The current trends in science and technology are increasingly towards reduced device feature sizes and/or using nanostructures taking special advantage of their sizes and consequently their unique size-dependent properties giving rise to new generation of optoelectronic and photonics nanodevices. Over the past decade, semiconductor nanowires have emerged as a potential candidate for the continued miniaturization of microelectronics. However, it is necessary to precisely quantify and control fundamental material properties such as doping and carrier mobility of nanowires for scalable production of practical devices. Nanowire geometry, which makes them interesting for various applications, on the other hand, poses a major problem in characterizing the basic electronic properties of nanowires. This project concentrates on developing nanowire contacts and electrical measurements on single nanowires to quantify doping concentration and carrier mobility of the nanowires. The results obtained from these measurements will allow us to gain further understanding of carrier transport mechanism in nanowires. Furthermore, it will provide a valuable feedback to improve the quality and doping of nanowires that will facilitate their implementation in advanced practical optoelectronic devices.

Student will develop following skills through this project:
- State of the art electron beam lithography technique to form contacts on nanowires
- Electrical characterization of nanowires
- Understanding of the properties of various semiconductor nanowires

Required background
- Semiconductor Physics
- Electronics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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<td>Chennupati Jagadish</td>
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The four-probe geometry of contacts on GaAs nanowire to reduce the effect of contact resistance onelectrical measurement.
Photoluminescence spectra of Inp nanowire before and after surface passivation with controlled wet etching process

Research fields
- Photonics, Lasers and Nonlinear Optics
- Materials Science and Engineering

Project details
Surface states and crystallographic defects are detrimental for the quantum efficiency of semiconductors. This problem is further exacerbated in nanowires due to the large surface area-to-volume ratio. Achieving high electrical and optical quality of nanowires is crucial for them to be used as optoelectronic components. Passivation of surface states is an effective and important processing step for nanowire-based optoelectronic devices to minimize non-radiative surface recombinations to fulfill the demand of high efficiency devices. Surface passivation of nanowires of different III-V compound semiconductor will be studied in this project. Different wet chemical processes will be investigated to remove surface defects while maintaining precise control on the diameter and geometry of the nanowires to enhance their quantum efficiencies. Passivation by atomic layer deposition of various oxide- and nitride-based materials will also be compared to wet chemical passivation to achieve best possible material quality. The passivation effect will be quantified by comparing PL intensities, line-widths, carrier life times and electrical measurements of the nanowires.

Student will develop skills to understand the properties of semiconductor nanowires and gain semiconductor device processing skills within a clean room environment. Student will have opportunity to characterize optical properties of nanowires using a suit of structural, electrical and optical techniques.

Required background
- Semiconductor Physics
- Photonics

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Metamaterials can bend the light in an unusual way

Research fields

- Photonics, Lasers and Nonlinear Optics
- Nanoscience and Nanotechnology

Project details

In recent years, metamaterials have attracted significant attention from the scientific community. These artificial materials exhibit exotic properties not normally found in nature. Examples include negative refraction (i.e. light bending in the ‘wrong’ direction), cloaking (as demonstrated by different research groups worldwide) and creation of perfect lenses. In conjunction with plasmonics, metamaterials also offer the possibility of creating sub-wavelength devices that may lead to the sought-after integration of electronic and optical devices on the same chip.

Importantly, in recent years, the research agenda in metamaterial research is shifting from fundamental studies to practical applications. In particular the research in metamaterials is focusing on the development of novel metadevices, which incorporate widely tunable functional metamaterials for dynamic light control, sensing and imaging.

Being a design concept that is highly scalable with frequency, metamaterials provide a unique platform for the development of novel materials with desired electromagnetic properties. This opens up the possibility of novel applications using visible and infra-red sources and detectors. However, there are several important challenges that need to be overcome for the development of such enabling technologies. The most urgent challenge is to address the narrow spectral range of operation of metamaterial devices. Most metamaterial devices work in a limited range of frequencies, due to their


Required background

Optical Physics (PHYS3057)

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor

Dragomir Neshev

QE II Fellow

02 6125 3792

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Research fields

- Photonics, Lasers and Nonlinear Optics
- Quantum Science and Applications

Project details

Polaritons are bosonic composite particles that are part light and part matter. They are composed of photons and excitons (electron/hole pairs) forming in semiconductor microcavities in the strong light-matter interaction regime. Akin to ultracold neutral bosonic atoms, polaritons can undergo Bose-Einstein condensation. In a Bose-Einstein condensate (BEC), millions of bosons occupy a single quantum mechanical state and display collective quantum behaviour, thus bringing the quantum physics onto the macroscopic scale.

A BEC is one of the most sensitive and controllable quantum systems. It has applications ranging from precision measurement sensors and metrology standards, through to tests of the fundamentals of quantum mechanics. The polariton BEC bears many similarities to the acclaimed BEC of neutral atoms which forms at temperatures within a millionth of a degree of absolute zero. However, and most remarkably, a polariton BEC can be obtained at both cryogenic and room temperatures in a solid state. This transfers the amazingly rich and technologically promising physics of condensates from a fragile gaseous state in an ultra-cold and ultra-high vacuum environment, typically only found in state-of-the-art experimental laboratories, to a very accessible level. Moreover, due to their semiconductor nature, polaritonic devices could be readily integrated into conventional electronic circuits.

Observation of the first polariton BEC in 2006 has prompted the emergence of polaritonics – a new field of optoelectronics that employs collective quantum effects in solid state, cost-effective devices.

This project will investigate collective behaviour of polariton condensates and their manipulation by structured pumping and external potentials.


Required background

Students interested in either theory or experiment are encouraged to apply.

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

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Robert Dall  
Research Fellow  
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An example of a magneto-elastic metamaterial which achieves strong nonlinearity through coupled electromagnetic and mechanical degrees of freedom.

Project details

The electromagnetic properties of most ordinary material is described by their refractive index, which greatly simplifies the calculation of wave propagation. In recent years, this concept has been extended so that artificially created micro and nano structures can be made small enough that they can also be described in the same way. The advantage of these structures is that they can achieve exotic behaviour not found in the optical properties of natural materials, including negative refraction, perfect lensing, backward waves, optical rotation, strongly nonlinear properties, highly tunable structures and many more.

Depending on the length of your project (honours, masters or phd), you could include one or more of the following elements in your project:

- **Theoretical modelling**: The exotic properties of metamaterials mean that waves propagating in them can exhibit a range of interesting new properties. Examples include creating materials which combine strong nonlinearity with unusual dispersion characteristics, or “transformation optics”, which make the wave behave as though space has been transformed.

- **Numerical simulation**: The design of metamaterials for experiments usually requires CAD modelling with advanced electromagnetic simulation software. This also shows how many exotic properties emerge in these systems.

- **Microwave experiments**: We have a well equipped laboratory for creating and measuring microwave structures. Due to the larger size of these waves, it makes many experiments feasible which are much harder to do at shorter wavelengths.

- **Terahertz experiments**: The terahertz wavelength range is a relatively unexplored part of the spectrum between microwave and near-infrared. There are many potential applications such as imaging, drug and explosive detection, which are expected to benefit from devices fabricated using metamaterial technology. We have a THz spectroscopy system which enables the measurement of metamaterials in this range.

- **Micron/nano fabrication**: Since metamaterials must be small compared to the wavelength at which they operate, this means that THz structures must have dimensions in the tens of microns. We have access to state of the art facilities at ANU which enable these structures to be created.

Required background

A basic background in electromagnetic waves will be required to understand metamaterial concepts. Some experience working in a laboratory environment is desirable for experimental projects. The ability to process data using computer packages such as matlab is also important.

Project suitability

- Honours project
- PhD or Masters project

Project supervisors

- **David Powell**
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- **Ilya Shadrivov**
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- **Dragomir Neshev**
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  - 02 6125 3792
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Research fields

- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

Project details

Metamaterials are artificially structured materials with subwavelength inclusions or features that result in a variety of unusual and exciting response to electromagnetic (EM) waves. These properties are not observed in naturally occurring materials. The electric permittivity and magnetic permeability, which characterise the response of metamaterials to the EM radiation, can be engineered to be both negative, resulting in these unique and unusual properties. The operating EM wave in metamaterials has a wavelength much larger than these inclusions/features but they can be treated as macroscopically homogeneous media.

The THz spectral regime lies between the microwave and infrared frequencies, loosely extending from frequencies of 0.1 THz (a wavelength of 3 mm) to 10 THz (30 μm), bridging the worlds of electronics and optics. THz technology can offer an unprecedented broad range of applications in the area of astronomy, security, public health, biomedicine, defence, communications, and quality control in manufacturing. However, research into the control and manipulation of THz waves is still lagging. Metamaterials are geometrically scalable and the design flexibility provides a promising approach towards filling the THz gap. This project will explore an electrically controllable high speed THz metamaterial switches based on III-V compound semiconductors and transparent conductive oxides. These THz switches are important elements in THz systems for various applications.

The scope of this project ranges from design of the metamaterial switches using commercially available simulation packages, to fabrication of the devices (in our state-of-the-art cleanroom facilities), to characterisation of the devices in order to gain further insight into the physics behind the operation of the devices. Depending of the interests of the student and the length of the course, various aspects of the project can be tailored to suit the student.

Required background

- Optics/Photonics, Semiconductors

Project suitability

- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisor

Fang Fang Ren

ARC Fellow
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Research fields
- Theoretical Physics

Project details
Quantum field theories are generally required to be relativistic, meaning that the space of quantum states carries an action of the Lorentz group. These group transformations are precisely those which preserve length (in Minkowski space). However, some quantum field theories admit more symmetries. If the symmetries include those which preserve angles, the conformal transformations, then the theory is called a conformal field theory. Such symmetries are especially powerful in two dimensions, because the conformal algebra is then infinite-dimensional.

In this project, we study the formalism of conformal field theory through the most basic example: The free boson. This begins with a lagrangian analysis, followed by canonical quantisation to bring out the conformal structure which is then analysed exhaustively. A standard application is then to construct the bosonic string on a flat Minkowski space, deriving the critical dimension $D=26$. Alternatively, one can study the free fermion and other related conformal field theories that appear in statistical mechanics (eg. the Ising model).

Required background
PHYS3001 is needed for the lagrangian analysis and MATH2406 would be desirable for the complex analysis.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor
David Ridout
Fellow, ARF
02 6125 9688
david.ridout@anu.edu.au
Research fields

- Theoretical Physics

Project details

Many of the theories that physicists use to describe reality are based upon so-called semisimple Lie groups. These in turn can be largely understood through their associated Lie algebras. Here, we first introduce the classical Lie groups and their Lie algebras before describing the mathematical structure of the latter. These Lie algebras appear in physics through their representations. One standard example is the spin of a quantum particle which is described by the representations of the Lie algebra $su(2)$. Another is Gell-Mann's eightfold way for categorising hadrons in terms of quarks --- this amounts to computing tensor products of representations of $su(3)$.

Required background

Being comfortable with linear algebra is very desirable. Some abstract algebra would help as well, but isn't essential.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor

David Ridout
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An introduction to string theory

Research fields
- Theoretical Physics

Project details
The student will learn the basics of string theory by following Part I of Zwiebach's "A First Course in String Theory". This not only covers stringy things but also provides an excellent introduction to the modern lagrangian approach to physics, complementing and extending what is covered in PHYS3001. It also gives the student a decent introduction to the idea of gauge fixing, albeit through a single example, which is fundamental to the quantum field theories that constitute the standard model. If there is time, the student will also study selected topics from Part II of the text, eg. superstrings, branes and dualities, black hole entropies.

Required background
PHYS3001 would be great, PHYS3002 even better. Some linear and abstract algebra would help for the quantisation part, but isn't essential.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor
David Ridout
Fellow, ARF
02 6125 9688
david.ridout@anu.edu.au
Logarithmic conformal field theory

Research fields
- Theoretical Physics

Project details
Conformal field theory has been an extremely active research area in mathematical physics since it was introduced in 1984. Much of it boils down to using the representation theory of certain infinite-dimensional Lie algebras, e.g., Virasoro, Kac-Moody (or more precisely their corresponding vertex operator algebras) to compute physically-observable quantities, correlation functions in particular. In a standard conformal field theory, the correlation functions have singularities that are either poles or roots. However, there are also so-called logarithmic conformal field theories whose correlation functions admit logarithmic singularities as well.

Mathematically, this is manifested by the Hamiltonian of the system failing to have a complete set of eigenstates. Instead, it has a non-trivial Jordan block structure. The possibilities and consequences that arise from this are still being worked out though it is now clear that logarithmic theories are the correct models for most physical applications. For example, non-local observables such as crossing probabilities for critical percolation and fractal dimensions of critical Ising model spin clusters are described, in their scaling limits, by logarithmic conformal field theories (as well as by Schramm-Loewner evolution). Similarly, the string theories that arise in the celebrated AdS/CFT correspondence are also built from logarithmic conformal field theories.

There are many possibilities for projects in this new field at the leading edge of mathematical high-energy physics research, ranging from elucidating the logarithmic structure of the ghost field theories that arise from gauge-fixing to classifying the types of representations that appear in the scaling limits of spin chains and in string theories on non-compact Lie groups. Ask me for more concrete proposals.


Required background
This is advanced mathematical physics, so strength and maturity in mathematics, particularly in abstract algebra, is essential. At the same time, a solid background in theoretical physics, PHYS3001 and PHYS3002 as a minimum, is also essential. This is an area where knowing too much cannot hurt and one must be prepared to learn more and more and more...

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
David Ridout
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02 6125 9688
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Research fields
- Theoretical Physics

Project details
The mathematical formalism of (two-dimensional euclidean) conformal field theory is based on complex analysis. However, and unlike the case of a sphere, there are infinitely many different complex structures that one can take on a torus. When space is compactified, as with a closed string, the torus is the appropriate setting for the partition function of the theory, hence this function depends upon the choice of complex structure. Moreover, the standard parametrisation of these structures is redundant with a residual action of a symmetry group, the modular group $\text{SL}(2;\mathbb{Z})$, connecting identical structures. It follows that the partition function of a consistent conformal field theory must be invariant under the action of this modular group. This leads to a physical explanation for the surprising fact that characters of certain classes of infinite-dimensional Lie algebras give rise to finite-dimensional representations of the modular group.

This project will review the appearance of the modular group in basic examples of conformal field theory and see how it relates to the representation theory of theory's infinite-dimensional symmetries. More advanced possibilities include contributing to current research efforts to understand the role of modular transformations in the logarithmic conformal field theories that describe generic statistical lattice models and string theories on non-compact or supersymmetric spacetimes.

Required background
MATH3351 and some abstract algebra are recommended; theoretical physics courses might also be helpful.

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
David Ridout
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Research fields
- Atomic and Molecular Physics
- Quantum Science and Applications

Project details
The inventions of the transistor and the optical laser have driven the rapid development of computing, the internet, and communications. Our extraordinary technological progress is based largely on the precise coherent control of electrons and photons, the foundations of which were developed more than 50 years ago.

In 1995, precise coherent control of atoms was achieved with the production of the world's first Bose-Einstein condensates of dilute alkali gases of rubidium and sodium. In 1997 the team of PI Wolfgang Ketterle also produced the world's first pulsed atom laser derived from a Bose-Einstein condensate, a direct atomic analogue of the optical laser, where the beam is composed of a 'matter wave' of atoms instead of an optical wave of photons.

Although the optical laser is now ubiquitous in everyday life, for more than ten years after Theodore Maiman first demonstrated a laser in 1960 it saw little application. From the outset, it was understood that the laser had potential in the areas of precision measurement and communications, but its failure to find broad application in its first decade prompted the description “a solution looking for a problem”.

In 2001, the Nobel prize was awarded for Bose-Einstein condensation in a dilute alkali gas. In his Nobel lecture, Professor Wolfgang Ketterle described Bose-Einstein condensation (BEC) as the “the creation of laser-like atoms”. Sixteen years after it was first produced, BEC has not yet found a viable application, a situation reminiscent of the optical laser in the early 1970s. This project will change this.

Further information http://atomlaser.anu.edu.au

Required background
A strong Honours or Masters degree and a very practical, hands on approach to experimental physics

Project suitability
- PhD or Masters project

Project supervisor
Nicholas Robins
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Ultra-high precision force sensors utilising Bose-Einstein condensates

Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

Project details
We are currently investigating the use of Bose-Einstein condensates in precision measurements of gravity. Our first prototype system used a short drop to make a proof-of-principle measurement. We focussed our initial effort on elucidating whether mean-field related dephasing would cause problems in a matter wave based interferometric gravimeter. We found that it will not limit precision until well beyond the state-of-the-art sensitivity. Beyond state of the art other techniques for generating the matter waves could be used. Simply moving from a single pulse to many pulses or to a continuous measurement will push the interaction induced dephasing many orders of magnitude lower again.

We have also made a preliminary comparison of BEC and thermal sources in the same interferometer as well as looking at large momentum transfer beam-splitting to enhance sensitivity.

We are now constructing a number of long drop, coherent atom interferometers to further our investigations in this area. The challenge is to produce a condensed source with very high duty cycle (less than 1 second) and high flux (greater than a million atoms) in the weakest possible trap - facilitating a condensate source that will 'drop like a rock'.

Further information [http://atomlaser.anu.edu.au](http://atomlaser.anu.edu.au)

Project suitability
- PhD or Masters project

Project supervisor
Nicholas Robins
Fellow
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Research fields

- Topological and Structural Science
- Materials Science and Engineering

Project details

X-ray micro-CT facilities such as the one in Applied Maths are enabling us to peer inside complex materials such as porous rocks, bones, and manufactured materials with unprecedented clarity and resolution. The need to study these data in a quantitative manner has resulted in a new computational discipline dedicated to the processing of large 3D images and to the characterisation of the complex structures that are now being unveiled. Some images and videos of data acquired from the Applied Maths X-ray CT facility are available online. ([http://physics.anu.edu.au/appmaths/capabilities/xct-gallery.php](http://physics.anu.edu.au/appmaths/capabilities/xct-gallery.php))

One of the most fundamental descriptions of structure is via topology - the mathematical description of how many connected components, independent loops and enclosed voids an object has. Topological persistence is a method for distinguishing between features that are significant and those that are introduced by noise. The text "Computational topology" by Edelsbrunner and Harer (ANU Hancock Library QA611.E353) has a detailed introduction to the field. New algorithms developed by our group mean these quantities can be quickly and reliably computed from large 3D images.

We have recently scanned a wide range of copper foams, some of which have very different mechanical properties but structurally look very similar. This project will explore whether topological measures of structure can help predict the differences.

Required background

Willingness to engage with mathematical, physical, and computational disciplines.

Project suitability

- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Biophysics
- Topological and Structural Science

Project details
Crystalline frameworks (nets) are a standard way to describe three-dimensional (3D) periodic structures in solid-state science. To achieve directed logical design of new materials, we need to know what framework structures are possible and which are most likely to form from a given set of building blocks.

The variety of 3D networks that can be realised in euclidean space is far from completely understood. We have developed a method for creating nets by mapping tilings of the 2D hyperbolic plane onto periodic minimal surfaces in 3D space. The techniques involve discrete symmetry groups, combinatorial tiling theory, computational and differential geometry, and advanced computer visualisation.

Some of the thousands of structures generated in this way are catalogued in the online database EPINET, which also includes a comprehensive overview of our techniques.

Recent applications of these ideas have included a model for the structure of keratin fibres in the outer layers of skin, and the self assembly of three-armed star copolymers into complex striped interwoven domains.

Open problems include:
- Systematic enumeration of multi-component interpenetrating nets.
- Characterisation of ambient isotopy classes of interwoven structures (periodic knot theory!).
- Data-mining physical properties (such as percolation thresholds or elasticity) of previously enumerated nets.
- Online interactive generation and caching of network structures.


Required background
Willingness to engage with mathematical, physical, and computational disciplines.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Stephen Hyde
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Particle levitation with structured laser beams

**Research fields**
- Photonics, Lasers and Nonlinear Optics
- Engineering in Physics

**Project details**
We recently introduced a new technique of trapping particles, micro- to nanometer in size, in air using optical vortices. The technique is based upon thermal forces, induced by uneven heating of light absorbing particles with a laser beam, dominating in gaseous environments, and radiation pressure, which prevails in vacuum. The laser vortices with doughnut-shaped intensity profile provide a means to trap particles and push them along the zero-intensity beam axis to a desirable location. We apply this approach to photophoretic traps in air, and investigate the dependence of trap stiffness on laser power, polarization state, and gas pressure. The aim of this study is to use a vertical hollow beam trap as a calibrated scale to weigh micron-sized objects with a mass in a range of pico- to nanograms.

During this experimental project the student will be expected to develop skills in:

- Formation of structured optical beams
- Characterisation of beam profiles such as intensity, polarisation, and phase distribution;
- Analysis of particle motion using high-speed particle tracking;
- Evaluation of radiation pressure imposed by the structured beams;
- Computer-control of hardware involved in the experiments;
- Analysis and interpretation of experimental data;
- Working as part of a team in a dynamic laboratory environment.

**Required background**
Interest in structural laser beams, in laser interaction with matter; in experimental skills working with a powerful laser beam. Laser safety course is required.

**Project suitability**
- Third year special research topic
- Honours project
- PhD or Masters project

**Project supervisors**

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Ultra-short laser induced micro-explosion: A new route to synthesise novel high-pressure material phases

Research fields
- Photonics, Lasers and Nonlinear Optics
- Materials Science and Engineering

Project details
The search for alternative high-pressure super-dense materials, some of which might be harder than diamond, has presented new and complex challenges for theoretical and experimental studies of Warm Dense Matter (WDM), the state of matter in the core of planets and stars. It can be defined as the state that is too dense to be described by weakly-coupled plasma physics yet that is too energetic to be described by condensed matter physics.

This project aims to synthesise novel metastable material phases of silicon, germanium, carbon and related compounds creating WDM by controlled ultrafast laser-induced microexplosion confined within a material's bulk, such phases as predicted to be formed at terapascal pressure but never observed in nature or in laboratory experiments. The project will include formation of microexplosion conditions with ultrashort powerful laser pulses, focused ion beam milling, analysis of various laser-processed crystals (such as silicon, sapphire, diamond) with transmission and electron microscopy, characterisation of crystal structures with Raman spectroscopy, electron and x-ray synchrotron diffraction, and analysis and interpretation of experimental data.

During this theoretical and experimental project the student will be expected to develop the following skills:

- Experimental skills in ultrafast laser interaction with matter;
- Laser processing of bulk materials;
- Scanning and transmission electron microscopy;
- Focussing ion beam milling;
- Electron diffraction and x-ray synchrotron diffraction;
- Computer-control of hardware involved in the experiments;
- Analysis and interpretation of experimental data;
- Working as part of a team in a dynamic laboratory environment

Required background
Interest in the basics of laser-matter interactions, solid state and plasma physics, electromagnetic waves and lasers, methods of experimental studies of solid state matter. Laser Safety course is required.

Project suitability
- Honours project
- PhD or Masters project

Project supervisors
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Research fields

- Physics Education

Project details

Projects in physics education suit people with an interest in teaching, statistical analysis, or psychology.

ANU has developed the Relativity Concept inventory: [http://prst-per.aps.org/abstract/PRSTPER/v9/i1/e010118](http://prst-per.aps.org/abstract/PRSTPER/v9/i1/e010118). This has revealed much that is interesting about how students learn. There is more to do: in particular understanding the difference in responses according to gender. This project has a large statistical analysis component.

ANU has developed software for simulating special relativity: [Real Time Relativity - http://www.anu.edu.au/Physics/vrproject/](http://www.anu.edu.au/Physics/vrproject/). We have also extensively researched its effectiveness for learning relativity: [http://ajp.aapt.org/resource/1/ajpaa/v78/i8/p862_s1](http://ajp.aapt.org/resource/1/ajpaa/v78/i8/p862_s1). The software can be developed and extended into other areas, such as quantum mechanics.

Project suitability

- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor

Craig Savage

Professor

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Research fields
- Theoretical Physics
- Quantum Science and Applications

Project details
The two paradigms of theoretical physics are: classical physics and quantum physics. The former applies to gravity, through Einstein's General Relativity, and the latter to everything else, through the Standard Model.

However we have no fundamental theory for how these two domains can interact. The dominant approach is find a way to quantise gravity, allowing it to move into the quantum theoretical framework. However, after more than 50 years of effort we have made little progress towards the quantum gravity goal. A much neglected approach is a theoretical structure in which gravity remains classical, such as semiclassical gravity: http://prl.aps.org/abstract/PRL/v110/i17/e170401

An emerging view is that the stalled theoretical development is a result of a lack of experimental data to guide thinking. Due to its exquisite sensitivity, optomechanics is promising area for investigating new gravitational physics: http://arxiv-web3.library.cornell.edu/abs/1307.1175

This project will investigate experimental proposals in optomechanics for new gravitational physics. The emphasis will be on testing theories in which gravity is classical.

Required background
Introductory quantum mechanics.

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Research fields

- Theoretical Physics

Project details

The primary and secondary rainbows are often seen around the direction opposite to the sun. The third and fourth rainbows, due to three and four internal reflections respectively, are around the direction of the sun and hence are very difficult to see against its glare. The third and fourth rainbows were first photographed in 2011.

The fifth rainbow has never been reported seen, nor photographed. It is in the direction opposite the sun, between the first and second rainbows.

This project will use the physics of rainbows to determine if there are any reasonable conditions under which the fifth rainbow might be imaged in nature. A hierarchy of approximations may be used: ranging from ray optics to full electromagnetic theory.


Advanced computer modelling of rainbows has been done by Disney Research.


Required background

Ray optics as a minimum. Electromagnetism to second year level to do advanced work.

Project suitability

- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Summer research scholarship

Project supervisor

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**Research fields**
- Materials Science and Engineering

**Project details**
X-ray tomography can provide a precise structural description of a material at the micron-scale, but poorly represents chemical composition. Fluid and gas-based labels containing high atomic number elements can aid identification of general structural components in biological sciences but material specific labels are not well developed for the material sciences. This project will explore some strategies for labelling specific types of surface, particularly in porous geological materials, using advanced micro-tomography facilities built in Applied Maths.

**Required background**
An experimental background is helpful but not essential.

**Project suitability**
- Honours project

A 0.5x0.5 mm section in a tomogram showing the distribution of supercritical CO2 (green) and brine (blue) in an aquifer rock.

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**Project supervisors**
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- **Adrian Sheppard**
  - Senior Fellow
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  - adrian.sheppard@anu.edu.au
Research fields
- Environmental Physics
- Physics of Fluids

Project details
Phenomena on the liquid-gas interface, such as surface waves in the ocean play important roles in the ocean-atmosphere interaction. Understanding water motion on the surface is important in near shore and off-shore engineering, oceanography, climatology, etc. Surface waves give perfect opportunity to study nonlinear phenomena and formation of chaos and turbulence. The project will include advanced experimental studies of surface waves which are beyond reach for theoretical analysis and numerical simulations.


Required background
Familiarity with fundamentals of nonlinear waves and oscillations, basic laboratory skills, background in optics and scientific visualization, basic programming skills (Matlab, IDL).

Project suitability
- Honours project
- PhD or Masters project

Project supervisors

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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<tbody>
<tr>
<td>Michael Shats</td>
<td>Professor</td>
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<td><a href="mailto:Michael.Shats@anu.edu.au">Michael.Shats@anu.edu.au</a></td>
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<tr>
<td>Horst Punzmann</td>
<td>Research Engineer and</td>
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<td>Facilities Manager</td>
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</tr>
</tbody>
</table>
Research fields
- Environmental Physics
- Physics of Fluids

Project details
Fluid flow in the rotating frame of reference differs substantially from the one at rest. The rotation supports several classes of waves generated in such systems and often leads to the generation of large coherent structures, such as cyclones, anti-cyclones, jets etc. In this project new tools for detection and characterization of such structures will be developed. The project may include studies of turbulence in the rotating frame.


Required background
Familiarity with fundamentals of fluid dynamics and geophysical flows, basic laboratory skills, background in scientific imaging, basic statistical tools, programming skills (Matlab, IDL).

Project suitability
- Honours project
- PhD or Masters project

Project supervisors

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Hua Xia
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Research fields
- Environmental Physics
- Physics of Fluids

Project details
Turbulence is one of the last unresolved problems in classical physics. Turbulence is a state of a physical system with many interacting degrees of freedom deviated far from equilibrium. This state is irregular in both time and in space. Turbulence affects flows of rivers, mixing in the ocean, it limits speed of cars and aircrafts, etc. Fluid layers present an interesting model of the naturally occurring flows whose depth is much smaller than their horizontal extent. Examples include planetary atmospheres and oceans. Particle image velocimetry using laser sheets and high-resolution cameras makes it possible to measure turbulent velocity fluctuations with high accuracy. During the project the student will develop skills in modern experimental methods of the complex flow characterization and in the statistical analysis of turbulence.


Required background
Familiarity with fundamentals of fluid dynamics, statistical physics, basic laboratory skills, background in scientific imaging, programming skills (Matlab, IDL).

Project suitability
- Honours project
- PhD or Masters project

Project supervisors
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Research fields
- Environmental Physics
- Topological and Structural Science

Project details
One major limitation in laboratory X-ray tomography is that one can only image static samples, and that the acquisition of a single 3D image takes many minutes as 2D X-ray images of the sample are acquired at hundreds of different angles. If the sample moves during this time then the reconstructed 3D image will contain artifacts. However, much as the MPEG format can compress a movie to 1/100th of its original size, theoreticians in the Department of Applied Mathematics in RSPE are developing techniques to efficiently capture the changes in a sample between one moment and the next, so that only a few radiographs are needed for each 3D frame. These techniques are tailored to the efficient

This project will collect X-ray images of dynamic systems as they evolve, and work with theoretical researchers to reconstruct this data into 4D datasets which are movies of the evolving structure. Some dynamic systems of interest are: fluid draining from porous materials; deformation of complex materials under mechanical stress; crystal nucleation and growing plants. All these systems are of scientific value in their own right as well as providing data for dynamic tomography algorithms.


Required background
This project is suitable for physics, chemistry and engineering students and has no particular requirements.

Project suitability
- Third year special research topic
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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Imaging fluid-fluid interfacial curvatures in porous media: relating physics and geometry

Research fields
- Clean Energy
- Physics of Fluids

Project details
The flow of two immiscible fluids through porous materials is of great interest to scientists in several disciplines. Flows like this occur when rainwater flows through partially saturated soils, when groundwater invades an underground petroleum reservoir as the oil is extracted or when carbon dioxide is stored in a deep subsurface aquifer. The physics of such multi-component flows results from an interplay between the energy of the interfaces and the geometry of the pore space. The curvature of the interfaces is of particular significance as it is determined by the relative pressure of the fluids.

Using the ANU X-ray micro-CT instrument we are able to make detailed 3D images of two-component fluid flows occurring inside the labyrinth-like internal pore structures of porous materials such as soils and rocks. In particular, we can now capture the microscopic configuration of the fluids in sufficient detail that curvature of the fluid-fluid interfaces can be determined, providing a wealth of new information about what’s actually going on inside the materials. A wealth of images, obtained during experiments into carbon sequestration and oil extraction, have already been acquired at the ANU facility and will form the basis for this project. This project will then focus on analysing the images and understanding the phenomena that are captured.

Required background
General physics background is ideal.

Programming experience would be a great help, either python or C++, although matlab or mathematica would also be appropriate

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Zeptosecond snapshots of a collision of two uranium nuclei. (This figure appeared on a cover of the Physical Review Letter journal)

**Research fields**
- Physics of the Nucleus
- Quantum Science and Applications

**Project details**
Nuclear collisions are so fast (few zeptoseconds) and nuclei so small (few femtometers) that they are entirely isolated from their environment during the time of the reaction.

As a result, they obey the fundamental rules of quantum physics and exhibit some of its most striking manifestations, such as entanglement of the collision partners after a transfer reaction, or the tunneling of many nucleons in fusion.

Our basic tool to investigate nuclear dynamics is the time-dependent Hartree-Fock (TDHF) theory, providing snapshots of the quantum evolution of each nucleon wave-function (see figure).

We use this approach to investigate similar reactions than those studied at the ANU accelerator: transfer, fusion, fission…

Various projects are proposed, from the modelling of these reactions with existing codes, to formal developments of beyond TDHF approaches of quantum tunnelling to investigate the role of dissipation and decoherence on sub-barrier fusion.


**Required background**
Good knowledge in (non-relativistic) quantum mechanics

**Project suitability**
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

**Project supervisor**
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Quantum tunnelling and decoherence in nuclear collisions

Research fields
- Physics of the Nucleus
- Quantum Science and Applications

Project details
Fusion of heavy nuclei involves a massive dynamical rearrangement of quantum systems with many degrees of freedom. Fusing nuclei, isolated from external environments, are proving to be a unique tool to probe the complex interactions of quantum systems. Fusion at energies below the fusion barrier occurs by quantum tunnelling, and is one of the ways to investigate quantum tunnelling of composite, many-body objects. Recent experiments show that the measured tunnelling probabilities are much less than predicted. Initiated by our group at the ANU, efforts are underway to understand this in terms of the loss of quantum coherence as two nuclei merge together.

Projects may involve measurements of fusion probabilities in the tunnelling regime through measurement of fission, which provides a signature that fusion has occurred. Coincident measurement of the two fission fragments increases sensitivity, which allows measurements to be made down to very low probabilities. Measurements of the reflected flux may also be made, to look for evidence of decoherence and energy dissipation. The experiments will use the 15 Million Volt electrostatic accelerator at the ANU, and the highly efficient CUBE fission detectors developed by the group. The multi-parameter data will be analysed using software based on the CERN ROOT analysis package.

The student will have the opportunity to compare previous and the latest theoretical formalisms describing nuclear fusion, and participate in new model developments that include decoherence, currently underway.

Project suitability
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Pear shape in octupole vibration

Research fields
- Physics of the Nucleus
- Quantum Science and Applications

Project details
Nuclei can take all sorts of shapes: spheres, rugby ball, discus, pear, banana... They can also oscillate between these shapes, leading to nuclear vibrations. The description of these vibrations is a fundamental test of quantum many-body models. In addition, vibrations strongly affect nuclear reactions such as fusion and fission. It is then crucial to have a proper description of these vibrations in order to describe such reaction mechanisms.

Our basic tool is the time-dependent Hartree-Fock (TDHF) theory which describes the time-dependent motion of each nucleon wave-function. In this approach, it is assumed that each particle (nucleon) moves freely in a mean-field generated by all the other nucleons.

The project is to perform realistic simulations of nuclear vibrations with an existing 3-dimensional TDHF code. The calculations are performed on the NCI supercomputers. The goal is to understand the role of the quantum shell structure of the nuclei on the energy and strength of these vibrations.

Required background
Basic knowledge of non-relativistic quantum mechanics (PHYS2013) is recommended, but not compulsory. Being familiar with Fourier transform would help.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- Summer research scholarship

Project supervisor
Cédric Simenel
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Quantum calculation of a fission process

Research fields
- Physics of the Nucleus
- Quantum Science and Applications

Project details
Heavy nuclei can fission due to the large Coulomb repulsion between their protons. The theoretical description of this process is not only important for applications to energy production, it is also a crucial test to our understanding of quantum many-body dynamics.

The fission process can be decomposed in two steps: (i) a slow evolution towards elongated shapes and (ii) a rapid dissociation in two fragments. We recently showed that (ii) has an important impact on the final properties of the fragment (mass, charge, kinetic energy...) by investigating the time dependent evolution of the fission process (see figure).

Our basic tool is the time-dependent Hartree-Fock (TDHF) theory which describes the time-dependent motion of each nucleon wave-function. In this approach, it is assumed that each particle (nucleon) moves freely in a mean-field generated by all the other nucleons.

The project is to perform realistic simulations of nuclear fission with an existing 3-dimensional TDHF code. The calculations are performed on the NCI supercomputers. The main goal is to understand the role of dynamical effects (deformation, vibration, viscosity...) on the formation of the fission fragments.

Required background
No specific background is required as the project can be adapted to various levels of knowledge.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
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Research fields

- Quantum Science and Applications
- Engineering in Physics

Project details

Optical interferometry is used in high precision displacement sensing, such as in the detection of gravitational waves. High precision measurements are achieved through the development of ever more quiet environments, where external noise is effectively mitigated. The reduction of mechanical motion is achieved by using low-noise seismometers to stabilise a work platform. This seismometer, based on an uni-axis mechanical pendulum, will measure the motion of the work platform, produce a signal and provide this to an actuator to reduce the motion of the platform, creating a mechanical quiet environment.

In this project, the student will initially investigate the horizontal motion of the mechanical system of this seismometer, using LED’s and photodiodes. Measurement and characterisation of the system, will allow a comparison of its performance with the mechanical model. During the project, the student will develop skills in electronics, optics, mechanical design and control systems. With sufficient progress of the project, the performance of the uni-axis seismometer may also be compared to a commercial seismometer, and the results presented in a research paper.

The Centre for Gravitational Physics, has 4 academics, 4 post-docs and 19 students, provides a vibrant research environment with research ranging from quantum opto-mechanics, classical optics, high power laser, fibre optics, fibre sensing.

Required background

Basic knowledge of optics and electronics is required, with experience in Matlab a bonus.

Project suitability

- Third year special research topic
- Honours project

Project supervisors

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Research fields
- Quantum Devices and Technology
- Quantum Science and Applications

Project details
Interferometric sensing of the quantum limit is a challenging task. Optical interferometry is used to readout the differential torsion motion of a dual torsion pendulum. With the optical readout, we aim to be limited by the quantum shotnoise and the quantum radiation pressure noise. The junction between these two quantum noise sources is called the standard quantum limit. To reach this limit a low noise mechanical system is required, in particular the system will need to have a low thermal noise level.

Reducing the mechanical resonant frequency into the milli-Hertz regime, a large enough clearance between the thermal noise and the quantum radiation pressure noise can be achieved. This project will prototype a torsion pendulum to obtain such a low mechanical resonant frequency.

The student will measure and characterise the mechanical system by comparing the data with the mechanical model. During the project, the student will develop skills in electronics, optics, mechanical design and control systems.

The Centre for Gravitational Physics, has 4 academics, 4 post-docs and 19 students, provides a vibrant research environment with research ranging from quantum opto-mechanics, classical optics, high power laser, fibre optics, fibre sensing.

Required background
mechanics, control theory, optics

Project suitability
- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisors
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Integrated quantum photonics

Research fields

- Photonics, Lasers and Nonlinear Optics
- Quantum Science and Applications

Project details

The project involves experimental and theoretical study of various integrated nonlinear and quantum optical schemes. We integrate bright lasers, optical waveguides, entangled photons, and on-chip photonic circuitry. Weird quantum physics combined with state of the art photonic technology reveals a number of exciting counter-intuitive phenomena. Potential applications include information transfer with unprecedented security and efficient simulation of complex quantum systems with information capacity exceeding the number of elementary particles in the entire universe.

Required background

Optics and/or Quantum Mechanics.

Project suitability

- Third year special research topic
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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A laser photon (truck) interacting with an entangled photon pair (red and blue cars).
Research fields
- Physics of the Nucleus

Project details
The lifetimes of excited quantum states in the atomic nucleus give extremely important information about nuclear structure and the shape of the nucleus. For lifetimes in the picosecond regime, measurements are based on a detailed analysis of gamma-ray line shapes, which are affected by changing Doppler shifts as the decaying nucleus slows down in a solid target. In effect, the stopping of the ion in a solid becomes the clock to measure the nuclear decay rate. An example of a Doppler broadened line shape, the fit and extracted lifetime is shown in the figure.

The specific problem this project will address is that recent lifetimes measured by this Doppler Broadened Line Shape (DBLS) method disagree with those determined by other methods, particularly for the semi-magic isotopes of Ni. There are two likely reasons for the discrepancy. In the first place, the stopping powers that determine the rate of slowing of the Ni nuclei in the host material could be incorrect. Secondly, it is possible that the reaction kinematics were not treated with sufficient accuracy in the computer code used to analyse the data. Along with solving this specific puzzle, this project aims to build an up-dated computer code for Doppler Broadened Line Shape analysis, that includes general options for the type of nuclear reaction used.

As well as helping achieve the aims of the project, students can gain accelerator-based laboratory experience and develop skills in scientific programming.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Research fields
- Atomic and Molecular Physics
- Physics of the Nucleus

Project details
Ions leaving target foils at high velocity are highly ionized. The electronic configurations of such ions can produce enormous “hyperfine” magnetic fields at the nucleus, which can be used to probe the magnetic field generated by the constituents of the nucleus. With modern atomic structure codes, there is a hope that these hyperfine magnetic fields can be calculated by first principles. If this hope is fulfilled new levels of precision will become possible in measurements of nuclear magnetism. Such measurements give insight into nuclear structure. There are exciting prospects for measurements on rare isotopes produced by the new radioactive beam accelerators internationally.

Recent attempts to perform ab initio calculations of free ion fields have met with some success, but cannot explain the ANU data shown in the figure, where Ge (Z=32) and Se (Z=34) ions emerge from carbon foils under the same conditions, but show different hyperfine fields. Students engaged in this project will help uncover the physics missing in the previous calculations. The project is related to our project on calculations of Auger electron spectra as it also uses the GRASP2K atomic structure code and Monte Carlo methods.

The outcome of the project will be an improved understanding of free-ion hyperfine fields for applications to measurements on nuclear magnetism and also an improved understanding of the processes that determine the charge state of an ion after electrons are stripped off by passage through a foil. Students will develop computational and modelling skills using sophisticated Fortran codes.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Research fields
- Atomic and Molecular Physics
- Physics of the Nucleus

Project details
Ions leaving target foils at high velocity are highly ionized. The electronic configurations of such ions can produce enormous “hyperfine” magnetic fields at the nucleus, which can be used to probe the magnetic field generated by the constituents of the nucleus. The aim of this project is to measure and characterize the hyperfine fields of a variety of ions emerging from thin foils at a range of velocities. These data will test the theoretical models we are developing and form the basis for measurements of the magnetism of excited rare isotopes produced at several of the world’s leading radioactive beam laboratories, such as GANIL (France), ISOLDE-CERN (Switzerland) and NSCL (USA).

Measurements of free-ion hyperfine fields are made by initiating a nuclear reaction and letting the excited nuclei that are produced recoil out of the target into vacuum. The method is thus called ‘recoil in vacuum’ or RIV. Angular momentum conservation together with the hyperfine coupling causes the nuclear and electronic spins to undergo precession about the total. This precession is observed via changes in the intensity of the gamma-rays emitted by the nucleus. The figure shows the apparatus in the Heavy Ion Accelerator Facility that will be used for most of these measurements.

The project outcomes will include an improved understanding of free-ion hyperfine fields for applications to measurements of nuclear magnetism, particularly for our international experiments granted competitive beam-time at international radioactive beam facilities. Students will gain experience with radiation detectors, electronics, data acquisition, accelerator operations, and data analysis.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Nuclear magnetism – magnetic moment measurements

Research fields
- Physics of the Nucleus
- Theoretical Physics

Project details
In most of its excited quantum states the atomic nucleus is a small magnet with a dipole field like that of the Earth. Because this nuclear magnetism is determined by the flow of charge and distribution of intrinsic spins within the nucleus, measurements of magnetic dipole moments give important insights into the internal structure of the nucleus.

This project focuses on nuclei in the sd shell. These nuclei, with proton and neutron numbers between 8 and 20, have been the subject of the most complete shell model studies to date. The figure shows experimental data for the gyromagnetic ratios of the first excited states in the N=Z nuclei in the sd shell. These are 20Ne, 24Mg, 28Si, 32S and 36Ar. Published results are shown as filled circles whereas the new precise result for 24Mg is the open circle. (This measurement, which represents a breakthrough in experimental precision, used a novel technique devised at ANU and was performed by an international team in Orsay, France.)

For many years it was thought that these gyromagnetic ratios should all be very close to 0.5, however recent calculations, shown as the solid line, predict a value about 10% larger. Only the new measurement on 24Mg has the precision to test these predictions. This project aims to perform similarly precise measurements on 28Si and 32S, and related isotopes, using the Heavy Ion Accelerator, and hence comprehensively test the shell model.

Students will gain experience working with radiation detectors, electronics, data acquisition, accelerator operations, and data analysis skills.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Research fields

- Physics of the Nucleus
- Engineering in Physics

Project details

The lifetimes of excited quantum states in the atomic nucleus give extremely important information about nuclear structure and the shape of the nucleus. One of the most accurate ways to measure nuclear lifetimes is by direct timing, i.e. by observing the time between the population of a nuclear state and its decay. Some students who do the 3rd year nuclear physics labs will have performed such measurements using a pair of barium fluoride detectors, as illustrated in the figure.

A new scintillator material, lanthanum bromide, LaBr₃, is now available, which has similar time resolution to BaF₂, but with much superior energy resolution. Two LaBr₃ detectors have been purchased and the purchase of another two is planned. These detectors will be installed in the key instruments for nuclear structure studies, including the Caesar Array, Solenogam, and the Hyperfine Spectrometer. They will make direct timing measurements possible for nuclear levels that are up to two orders of magnitude shorter-lived than is currently possible with these instruments.

The outcome of the project will be the commissioning of a new array of LaBr₃ detectors, including developing the electronics. Conventional analog electronics will be used initially, however the aim is to develop digital signal processing beginning in 2015. The new equipment will give a much enhanced nuclear lifetime measurement capability for nuclear structure studies. Students will gain accelerator-based laboratory experience and develop skills in building scientific instruments and data analysis.

Project suitability

- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors

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Research fields
- Atomic and Molecular Physics

Project details
Electron scattering from atoms and molecules is one of the most fundamental interactions in nature. A host of modern technologies rely on an understanding of electron interactions with atoms and molecules. This project has been developed to cater to the need for scattering data for use in plasma modelling related to the ITER project. In addition to applications in fusion energy, electron scattering processes are important in a number of fields, from biological studies and radiation damage, to plasma processing, lighting, astrophysics and atmospheric physics.

The experiment is part of the ANU positron beam laboratory and is based on a magnetically confined electron beam. This technique is used in the positron beamlines at the ANU for positron scattering studies. The ultimate objectives of this project is to measure electron scattering cross sections for a variety of important molecules.

The student will build on previous work towards developing the existing apparatus. Initial measurements of electron scattering from helium will be used to characterise the apparatus. Upon completion of this phase, a number of molecular targets will be measured. To achieve these goals, knowledge of vacuum systems, electronics, computer control, gas handling and data analysis will have to be developed. This experiment is housed in a laboratory with several other electron and positron scattering experiments, and will take place within a stimulating research environment involving a large and active group of researchers.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Summer research scholarship

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Research fields
- Atomic and Molecular Physics
- Biophysics

Project details
Positrons are in wide use in medical imaging through the use of PET scans. While this is a relatively mature technology, there is still a poor understanding of some fundamental aspects, such as the amount of radiation damage induced during a PET scan. There are a number of different experiments that can be performed using the equipment available both at the ANU and with our international colleagues that may be able to help improve the use of this important medical tool.

Positron scattering measurements can be performed at the ANU positron beam lab, with biomolecules as the target. This ties in with a collaboration between Australian and international research teams on modelling positron transport and interactions in human tissues. The cross sections measured in this part of the project will be critical to developing physically realistic models of radiation damage.

Additionally, there are other experiments that will be undertake to validate the output of such transport calculations, in particular using facilities developed at AIST in Tsukuba, Japan, where there are plans to measure positron transport in liquid water. This challenging experiment is only possible thanks to new developments allowing the positron beam to be taken out of the vacuum system.

The third aspect of this project is to do experiments at the PET scanner at the Canberra Hospital, using new ideas that have the potential to improve the contrast of this imaging technique. This aspect of the project is commercially sensitive, so please contact Dr. James Sullivan for further details.

Project suitability
- Honours project
- PhD or Masters project

Project supervisors
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Research fields
- Atomic and Molecular Physics

Project details
The measurement of benchmark cross sections is vital to the development of our understanding of fundamental quantum processes. The positron's matter partner, the electron, has been extensively studied and for simple systems, electron scattering is a well understood process. In the case of positron scattering, the technology for generating positron beams has lagged behind that for electron beams, and it is only recently that it has become possible to make measurements with the precision now accepted as standard in the electron case.

This project will focus on using the low energy ANU positron beamline to make measurements of positron scattering from a variety of simple targets. The project will require working as a part of a team, with collaborators from around the country and around the world. The absolute cross section measurement results from this project are expected to be invaluable towards guiding theorists in accurately developing models for calculation of positron scattering cross sections, and thereby further advance the field of positron physics.

The experiment is the only one of its kind to be performing these measurements worldwide and is at the cutting edge of positron science. The student involved in this project will need to be self motivated, able to operate both independently and as a part of a team and will be expected to develop skills such as computer programming, experiment planning, equipment design, scientific writing and data analysis, as well as a knowledge of atomic and molecular physics in general and charged particle scattering in particular.

Project suitability
- Honours project
- PhD or Masters project

Project supervisors
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Research fields
- Fusion and Plasma Confinement
- Materials Science and Engineering

Project details
The science and technology of materials under extreme heat loads are critical to the success of plasma fusion reactors, which promise to be a new source of clean electrical power. The ITER reactor is now under construction, and the next generation fusion reactor, DEMO, is at the design stage. One of the major challenges for both of these machines is to control thermal and particle transport at the boundary that isolates the fusion core ($10^{9}$ K) from the low temperature wall ($10^{3}$ K).

For this project, plasma studies using the purpose-built linear plasma device, the MAGnetized Plasma Interaction Experiment (MAGPIE), will be combined with positron-based materials characterisation methods to improve the current understanding of materials exposed to fusion relevant conditions. The research will be directed to investigate erosion and fuel retention (or surface-recombination coefficient) of materials. Of particular interest to this research program is the interdependent effect of thermal and particle fluxes at the plasma-material interface.

The project will be hosted jointly between AMPL and PRL, with the student having the chance to use cutting edge experimental equipment that has been developed here at the ANU. Skills in experimental control (mechanical, electronic and computer systems), data acquisition and analysis and vacuum handling will be developed.

Required background
Physics or materials analysis background would be an advantage

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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**Research fields**
- Quantum Devices and Technology
- Quantum Science and Applications

**Project details**
The no cloning theorem lies at the heart of quantum mechanics and is a direct consequence of the Heisenberg's uncertainty relation. While trying to measure an unknown quantum state, we necessarily perturb it. While this feature has been put to good use to provide for unconditional security in quantum cryptography, it is an annoyance in many quantum protocols, especially so when we realise that most quantum states are fragile and prone to decoherence. For example, it was long (and correctly) believed that the no cloning theorem forbids the implementation of an ideal quantum repeater and quantum noiseless linear amplifier. This is a major obstacle in the extending the range of quantum networks since the quantum signals would degrade after say 100 kilometres of optical fibre and cannot be recovered.

If we give up determinism, we can approximate noiseless linear amplification. The approximation becomes better at the expense of a lower probability of success. This protocol has a finite probability of success so that on average, the Heisenberg uncertainty relation is still satisfied. Nevertheless, the successfully noiselessly amplified quantum states can be heralded and thus useful in extending the range of loss-sensitive protocols.

Recently, we have shown that under certain conditions, the NLA could be performed via a Gaussian post-selection such that the classical outputs of a physical NLA and the postselection process are identical. We use this technique to realise quantum cloners, quantum amplifiers and extend the range of quantum cryptography.

**Required background**
The project covers both experimental and theoretical aspects. We are looking for candidates with a background in optics, electronics, quantum mechanics, quantum and classical information, labview and matlab, although they would certainly acquire these skills during this project.

**Project suitability**
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

**Project supervisors**

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Ping Koy Lam  
CQC2T Node Director  
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Energy band diagram for a photoelectrochemical cell utilising both n- and p-type photoelectrodes.

GaN and InGaN have the desirable properties that are required as the electrodes, such as the correct band alignment with redox potential of H₂/H₂O and O₂/H₂O, excellent carrier transport and charge transfer properties, strong optical absorption at wavelengths within the solar spectrum and good corrosion resistance in aqueous solutions. The aims and scope of this project cover the following:

- Study the photoelectrochemical properties of various GaN-based semiconductors and quantum wells
- Engineer the band bending at the semiconductor-electrolyte interface to improve device efficiency
- Investigate the effect of a very thin layer of passivation material
- Understand charge carrier generation, recombination, trapping and transfer processes in a photoelectrochemical cell

Depending on the interests of the student and the length of the course, any combination of the aspects listed above can be chosen to suit the student.

**Required background**
Physics, Material Science, Engineering

**Project suitability**
- Third year special research topic
- PhD (1st year project)
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

**Project supervisors**

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Research fields
- Environmental Physics

Project details
As a result of the atmospheric nuclear weapons tests of the 1950s and early 1960s, plutonium was dispersed around the globe and subsequently deposited on the earth’s surface via rainfall. This fallout plutonium then bound strongly to soil particles, and effectively labeled the top ~20 cm of soil over the years 1956-64. If this surface soil has moved in the time since deposition, the plutonium will have gone with it. Hence, it can be used as a tracer of surface soil loss and transport over the past 50 years. The plutonium concentration is, however, extremely low in river sediments. This is because the sediment is a mixture of “labeled” surface material and “un-labeled” sub-surface material, and results in concentrations that are less than one part per trillion.

The detection of plutonium by the ultra-sensitive technique of accelerator mass spectrometry (AMS) was pioneered at the ANU. It allows the plutonium concentrations present in sediments to be measured in just a few grams of material in a few minutes of counting.

This project aims to study sediment transported by major Northern Australian Rivers. It will integrate with other projects investigating the marine and coastal waters of Northern Australia. The project will require involvement in some or all of the following: fieldtrip(s) to the catchment to collect sediment samples, physical and chemical preparation of the samples, use of the 14UD electrostatic accelerator to measure the plutonium content via the extremely sensitive technique of AMS, data analysis and interpretation.


Required background
Physics or Environmental Science

Project suitability
- Third year special research topic
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Contact Information</th>
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<tbody>
<tr>
<td>Stephen Tims</td>
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</tr>
</tbody>
</table>
Research fields
- Environmental Physics

Project details
Atmospheric nuclear weapons tests in the 1950s and early 1960s produced and injected plutonium isotopes into the stratosphere. The plutonium subsequently dispersed around the globe before being deposited on the earth’s surface in rainfall. The fallout plutonium then bound strongly to soil particles, and effectively labeled what was the top ~20 cm of soil in 1956-64. If this surface soil has moved in the time since deposition, the plutonium will have gone with it. Hence, it can be used as a tracer of surface soil loss and transport over the past 50 years. The plutonium concentration is, however, very low in surface soil, and is even lower in river sediments. This is because the sediment will be a mixture of “labeled” surface material and “un-labeled” sub-surface material, and results in concentrations that are less than one part per trillion.

The detection of plutonium by the ultra-sensitive technique of accelerator mass spectrometry (AMS) was pioneered at the ANU. It allows the plutonium concentrations present in sediments to be measured in just a few grams of material in a few minutes of counting.

This project aims to study sediment from small catchments that supply Cotter Dam. It will integrate with other projects that are also investigating the catchment, to provide insight into the mechanisms responsible for the transport of eroded material within the catchment. The project will require involvement in some or all of the following: fieldtrip(s) to the catchment to collect sediment samples, chemical preparation of the samples, use of the 14UD electrostatic accelerator to measure the plutonium content via the extremely sensitive technique of AMS, data analysis and interpretation.


Required background
Physics or Environmental Science

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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**Keith Fifield**  
Professor  
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Research fields
- Environmental Physics

Project details
As a result of the atmospheric nuclear weapons tests of the 1950s and early 1960s plutonium was dispersed around the globe and subsequently deposited on the earth’s surface via rainfall. This fallout plutonium then bound strongly to soil particles, and effectively labeled the top ~20 cm of soil over the years 1956-64. If this surface soil has moved in the time since deposition, the plutonium will have gone with it. Hence, it can be used as a tracer of surface soil loss and transport over the past 50 years. The plutonium concentration is, however, very low in surface soil, and is even lower in river sediments. This is because the sediment will be a mixture of “labeled” surface material and “un-labeled” sub-surface material, and results in concentrations that are less than one part per trillion.

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Required background
Physics or Environmental Science

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors
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- Keith Fifield [Professor](mailto:Keith.Fifield@anu.edu.au)
  02 6125 2095
Research fields
- Atomic and Molecular Physics
- Quantum Science and Applications

Project details
The idea of equilibration is ubiquitous throughout nature. However, describing the out-of-equilibrium dynamics of an isolated system – be it caused by a disturbance and subsequent “rethermalisation”, or by passing through a phase transition – is both an intriguing and difficult question to answer.

Phase transitions occur throughout all the fields of science and across diverse physical systems, from the phase transition of water to ice, to the phase transitions that occurred in the early universe. Physical systems that appear completely unrelated on a microscopic level can be organized into universality classes that exhibit similar physics during the phase transition.

Phase transitions are usually investigated as equilibrium phenomena even though a second order phase transition experiences a critical slowing down and departs from equilibrium at the critical point, where the new broken symmetry phase is chosen. The description of this “choice” is at the heart of the famous Kibble-Zurek mechanism (KZM), which describes a possible mechanism for the formation of domain structures in the early universe. The subsequent merging of these spatial domains lead to the formation of defects like domain walls, monopoles, strings, and textures.

This project has two distinct directions:

(i) **Quantum Equilibration**: perturbing a quantum system (a BEC of metastable helium) and studying the equilibration process as a function of the system parameters (temperature, density, and dimensionality).

(ii) **Exploring the Kibble-Zurek Mechanism**: investigating the dynamic evolution of the system correlation length, when the second order phase transition associated with a metastable helium BEC is crossed at a finite rate.

Project suitability
- PhD or Masters project

Project supervisors

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Research fields
- Atomic and Molecular Physics
- Materials Science and Engineering

Project details
High-resolution measurements of electrons scattered from surfaces at high energies (up to 40 keV) provide information on the sample composition, electronic structure and crystal structure. These measurements have only become possible over the last few years with the development of a home-build high-resolution spectrometer in our laboratory. We are in the process of unravelling the information contained in these spectra, and the interpretation reveals an unexpected array of phenomena. The obtained understanding is highly relevant for high-energy X-ray photoemission, electron microscopy, and even neutron scattering. The long-term goal is to develop an electron spectroscopic tool for the analysis of surface layers of intermediate thickness that can be integrated in an electron microscope.

Key publications:


Oxygen Self-Diffusion in HfO2 Studied by Electron Spectroscopy


Required background
The project can be tailored to the interests and knowledge of the student. There are opportunities in spectrometer development, automation, interpretation of spectra, and the theory of the propagation of keV electrons in materials.

Project suitability
- Third year special research topic
- PhD (1st year project)
- PhD (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
Maarten Vos

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Research fields
- Atomic and Molecular Physics
- Nanoscience and Nanotechnology

Project details
Emission of Auger electrons and X-rays can be triggered by creation of vacancies through nuclear decays such as internal conversion of electron capture. Non-energetic Auger electrons are usually neglected in handling of Auger-electron-emitting radioisotopes. Recent experiments show that Auger electrons exhibit high linear energy transfer (LET) behaviour, and are effective in killing targeted cells when emitting radioisotopes are very close to the nuclear DNA (~10 nm). Auger emitters are now of great interest in internal radiotherapy of malignancies. Biological effectiveness of Auger emitters depends on their Auger yields per nuclear decay. The databases of Auger yields for medical radioisotopes are highly inconsistent and computed using outdated nuclear and atomic data.

The project is an experimental effort that will be part of a larger research program and aims to verify the theoretical calculations on this topic performed at the ANU by Boon, Kibedi and Stuchbery. It is thus an experimental test of our understanding of the Auger yield per nuclear decay.

This experimental project will involve developing methods for making thin film samples electro-chemically and measuring these samples with a modern spectrometer. First nanometer-thick films will be prepared and characterised by electron spectroscopy from stable atoms, and after this method has been perfected similar films will be grown using radioactive atoms. The Auger electrons leaving the films after nuclear decay will be measured. In this way an experimental estimate of the number of Auger electrons (and their kinetic energy) per nuclear decay will be obtained.

Required background
- An improved understanding of nuclear decay and the emission of Auger electrons
- Computational skills using C++ language in a Windows based operating system
- Learning how to prepare thin film samples and how to operate a modern electron spectrometer
- Basic programming skills to aid in the analysis of data
- Develop working skills in a team environment.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisors
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Andrew Stuchbery
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Research fields
- Photonics, Lasers and Nonlinear Optics
- Materials Science and Engineering

Project details
Glasses with special properties called nonlinearity have been used in many applications to manipulate light in optical circuitry and have been researched intensively to optimise performance. At Laser Physics Centre, there are two classes of glasses have been studying: Chalcogenides and Tellurites.

Chalcogenides contain Chalcogen elements such as Sulfur, Selenium and Tellurium bonded with network forming element such as Gallium, Germanium and Asenic. Chalcogenide glass are one of the most highly optically nonlinear glasses with nonlinear coefficient as high as 200 times of normal window glass made from Silica.

Tellurite glasses which contain mainly Tellurium Oxide (TeO2) are promising for a wide range of applications of generating mid-infrared light for sensing, spectroscopy, telecommunications. Important optical properties of Tellurite include: being a very good hosts for rare earth ions (Erbium, Thulium etc which can be used for laser amplifier), having high Raman gain coefficient (30-60 times higher than silica) and Raman shift at about double that of silica. Furthermore, Tellurite glasses can be poled to achieve second order nonlinearities with coefficient comparable with those of crystalline materials.

The project will study various aspect of integration of the two materials into one platform that utilise both strong properties of the each glass specially the high nonlinear coefficient of Chalcogenide and high gain of rare earth doped Tellurite.

Required background
Interest in optics, electromagnetic waves and lasers, methods of theoretical and experimental studies of optical nonlinear phenomena

Project suitability
- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Astrophysics
- Physics of the Nucleus

Project details
The core of a massive star collapses towards the end of its evolution. Such stars end their life in a supernova (SN) explosion. Dust formed in the ejecta of a SN contains freshly produced (radio-) nuclides and is entrained in the SN shell, which expands rapidly into the surrounding interstellar medium (ISM). A SN envelope in the vicinity of our solar system will intercept the Earth and may leave traces.

This project will search for supernova-produced nuclides to tackle the fundamental questions 'how were the heavy elements made' we observe on Earth today; where do galactic cosmic rays originate, and do supernovae produce the heavy elements in the r process? We will search for radionuclides trapped in cosmic dust particles entering the solar system and deposited over millions of years on Earth. Our focus is on anomalies in long-lived radionuclides. Their isotopic fingerprint mirrors on-going nucleosynthesis in massive stars and the galactic chemical evolution. We will refine the capabilities for accelerator mass spectrometry (AMS) for measuring these nuclides at ultra-low concentrations utilizing the world-highest particle energies in AMS.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Astrophysics
- Physics of the Nucleus

Project details
This project aims at laboratory studies of stellar nucleosynthesis applying ultra-sensitive accelerator mass spectrometry (AMS) measurements:

- what processes lead to the elemental abundances we observe on Earth today? -

This innovative experimental approach will bridge fundamental nuclear physics properties and astrophysical observations. We focus on reactions which are essential to open questions in modelling nucleosynthesis in stars, i.e. where no data exist at all, or are scarce and discrepant; in particular for neutron- and charged-particle induced reactions relevant to the s- and p-process where an extremely sensitive detection method is required. Our data will be highly beneficial for our understanding of the elemental abundance of our solar system and on Earth.

This project will be performed in a truly international environment with collaborations in Europe and the US. The experimental setup at the ANU guarantees ultra-sensitive measurements of radionuclides.

Complementary measurements will be performed at CERN within the n_TOF collaboration.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Research fields
- Physics of the Nucleus
- Environmental Physics

Project details
This work will provide important information for key reactions of reactor physics and for medical applications. We will apply the most sensitive technique for measuring long-lived radionuclides: atom-counting using accelerator mass spectrometry (AMS) at the ANU.

Our goals for these studies on crucial fundamental nuclear data for nuclear technology are as follows: the study of neutron- and charged particle-induced nuclear reactions for major and minor actinides, for constituents of structural materials of vital importance for a variety of advanced nuclear applications (fusion, medical applications, accelerator-driven systems).

Long-lived radionuclides are difficult to measure in standard activation experiments due to their low activities. This disadvantage can be overcome by counting the number of nuclides produced using AMS.

We will combine the unique capabilities at the ANU with an ensemble of collaborating partners from world-leading facilities.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisor
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Resolving doping concentration distribution and non-radiative lifetime in semiconductor nanowires using photoluminescence mapping

Research fields
- Photonics, Lasers and Nonlinear Optics
- Nanoscience and Nanotechnology

Project details
Semiconductor nanowires are becoming a promising prospect for nanoscale devices such as solar cells, lasers, photodetectors, FET, SET and LED. The ability to precisely dope these nanowires to control their electrical properties is crucial for the operation of these nanoscale devices. However there are still many challenges in controlling the doping of NWs, due to the complexity of NW growth. Compounding these challenges is the lack of a simple and efficient way of measuring the doping concentration in NWs such as conventional capacitance-voltage spectroscopy and Hall measurements, due to the small size of the NWs. Current technique requires complex nanofabrication processes to make the electrical contacts, highly skilled personnel in nano-manipulation.

In this Project, we will use a simple and non-destructive optical technique to measure the doping concentration profile along the length of individual NWs. The doping data will not only allow a quick feedback to material scientists to optimise the doping parameters but also allow them to gain further insight into the physical of dopant incorporation during NW synthesis. In addition, this technique will also allow us to determine the internal quantum efficiency and carrier lifetime of the nanowire. These parameters are important metrics for the quality of the NWs. Electrical measurements of single nanowires can also be carried out to validate the doping results from optical measurements.

Through this project, the students can develop experiences in:
- Optical spectroscopy
- Labview programming
- Matlab for analyses
- The understanding of semiconductor physics
- The understanding of laser physics and optics

Required background
Ideally students would have a background and strong interest in condensed matter physics. Students who have optics background and programming experience are preferable.

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project

Project supervisors

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Lan Fu
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Research fields
- Quantum Science and Applications

Project details
Quantum-mechanics is one of the most successful theories of physics, and it excellently describes the dynamical behavior of systems that can reasonably be called ‘small’, such as electrons or individual atoms. But does it also describe the behavior of large objects, like marbles or rugby balls? If not, at what mass/length scale does quantum mechanics break down and why? This is an open question in physics which has important consequences for theories of quantum mechanics and any quantum theory of gravity.

At the Centre for Gravitational Physics (CGP) at the ANU, we will attempt to provide clues to the answers with an experimental program in opto-mechanics of gram-scale objects. The CGP are world-leaders in the development of quantum technologies for precision measurement, due to our long involvement in the field of interferometric gravitational wave detection. We currently seek students of all levels to join our dynamic group and take part in the excitement as we attempt to discover the limits of quantum mechanics. Each project is tailored to the goals and abilities of the applicant. Interested individuals are encouraged to contact us to discuss potential research topics.

Required background
Experience with optics and lasers, MATLAB would be beneficial.

Project suitability
- Honours project
- PhD or Masters project

Project supervisors

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Adaptive optics for coherently combined laser systems

Research fields
- Photonics, Lasers and Nonlinear Optics

Project details
The ability to reliably transmit a laser field from Earth to Space is a challenging task due to fluctuations in Earth's atmosphere caused by wind and turbulence, where local areas of high/low pressure act as a lens to change the propagation of a light. Adaptive Optic (AO) systems are an enabling technology used in the large optical telescopes to overcome the distortion such lensing induces. Consisting of one or more deformable mirrors, an AO system senses the the time-varying image distortions and manipulates its mirror system to undo their impact, allowing the recovery of the telescopes 'diffraction-limited' angular resolution (set by its size).

Such AO systems may also be used in ranging or communication environments, where a local laser is transmitted from the telescope. Here the AO system 'pre-distorts' the outgoing laser to minimise distorts through the atmosphere. One modern method of coherently combining lasers potentially allows potential improvement of the AO system by modifying the transmission 'phase' of each laser to be combined. This form of 'Optical Phased Array' has the potential to greatly simplify Earth-to-Orbit laser transmission. This project aims to investigate potential architectures for such hybrid systems, focussing on laser ranging.

Required background
- Optics and lasers, MATLAB
- Preferred: PHYS2017 Wave and Optics, ENGN3223 Control Systems

Project suitability
- Third year special research topic
- Honours project
- PhD or Masters project

Project supervisors

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Research fields
- Theoretical Physics
- Materials Science and Engineering

Project details
Soft Matter is a sub-discipline of condensed matter and focusses upon chemical and biological matter that is easily deformed by thermal forces or fluctuations. These materials show their most interesting behaviour at energy scales on the order of kBT.

Examples include polymers, liquid crystals, gels, surfactants (soaps), and almost all materials of biological interest.

Of great recent interest is the subject of rotaxanes. Rotaxanes are molecules where one or more ring components is threaded onto an axle that is capped on both ends with stoppers to prevent the rings from falling off.

This field has long been the preserve of people making rotaxanes, i.e. synthetic chemists. However, these systems exhibit fascinating and complex physics, and this makes the field ripe for investigation by physicists.

Our recent work has focussed on the fact that mobile rings have translational entropy, which can be manipulated to provide a force - much like a one-dimensional gas. Other work involves the effect of potential stripes on the axle.

The list of projects in this area is rather large and little previous work has been done. Examples include:

1. the physics of threading (i.e. rotaxane creation)
2. The effect of interactions between the rings.
3. Rotational Isomerism.
4. Rotaxane gels.
5. Polyrotaxanes - i.e. rotaxanes threaded onto polymers.

All these projects are either theory or simulation (or both), and will be carried out in collaboration with Prof. Edie Sevick in the Research School of Chemistry at ANU.

Required background
Physics.

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

Project supervisor
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Transmission electron microscopy images of (a) nanovoids in ZnO, (b) and (c) GaAs nanowires cross-sections

What determines the equilibrium shapes within a crystalline nanoworld?

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
The equilibrium shape of voids or crystals is largely influenced by the total surface energies encompassing these 3D objects. In particular, these voids or surfaces are faceted on low energy surface planes and the relative surface areas of individual facets reflect the surface energies of these planes. Consequently, the surface energies of these facets can be determined by a Wulff plot of these objects as observed in a 2D projection. By determining the Wulff point which is the centre of mass of the object and determining the distances of these surfaces from the Wulff point, the surface energies of different planar facets can be determined in a unique way.

In this project especially suited for Honours or special projects, the goal will be to establish a computer program whereby the Wulff point of an arbitrary shape can be determined and a polar plot of the surface of the shape can be extracted. The computer program will be used to analyse transmission electron microscopy images of nanovoids, crystals and nanowire facets and determine the surface energies of individual facets. These surface energies determined for voids or nanowires grown or formed under different conditions will provide much needed insight in identifying optimum growth conditions for certain structures. There are opportunities to expand this project into a PhD project.

Required background
- Programming in Matlab
- Condensed matter physics and/or materials engineering course

Project suitability
- Third year special research topic
- PhB (2nd or 3rd year project)
- Honours project

Project supervisor
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Mastering control over structure, composition and homogeneity in ternary nanowire growth

Research fields
- Nanoscience and Nanotechnology
- Materials Science and Engineering

Project details
Semiconductor nanowires are small semiconductor crystals with diameter around 10-100 nm and long aspect ratio of a few microns in length. The uniqueness of its applications lies in each of these nanowires becoming a potential device after growth. Thus for large scale integration and the full functionality of ternary nanowires, it is essential to achieve absolute control on the structure and the composition of these nanowires as well as homogeneity because these factors determine the bandgap of the semiconductor and hence its emission wavelength. In this project, innovative growth strategies will be designed to engineer ternary semiconductor nanowires of uniform composition and crystal structures. The 3D structure and composition of these nanowires will be fully characterised by a range of electron microscopy techniques with a suite of sectioning techniques including FIB and microtoming. The aim of this project is to grow homogeneous nanowires with tunability over a range of emission wavelengths by controlling the composition of the ternary semiconductor.

Project suitability
- PhD or Masters project

Project supervisors

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(a) Scanning electron micrograph of InGaAs nanowire cross-section (b)-(d) Energy dispersive spectrometry (EDS) maps of In, Ga and As from a cross-section of the nanowire showing the non-uniform composition
Research fields
- Environmental Physics
- Physics of Fluids

Project details
Understanding wind structure in the lower atmosphere is of great fundamental and practical importance for areas such as turbulence physics, air traffic, wind energy, meteorology, weather and climate.

In the range of heights up to 2 km, the structure of winds is determined by a complex interplay of effects which constitute an extensive research area of boundary layer turbulence at high Reynolds numbers. A wind profiler network was established by a group of Australian universities in Canberra near Mt Stromlo. The network utilises state-of-the-art wind measurement techniques, such as, SODARs (SOnic Detection And Ranging) and full-hemisphere scanning LIDARs (LIght Detection And Ranging) covering up to 3kms height. The network will be used in studies of turbulence at the Reynolds numbers of Re > (10^7-10^9), substantially higher than those obtained in laboratory.

This project will concentrate on the reconstruction and analysis of the wind profiler data, comparative studies of effect of turbulent structures in the laboratory fluid layers and in the atmosphere. The broad scope of ideas behind this project makes it most suitable for PhD students.

Required background
Physics or engineering with basic programming skills and interest in planetary boundary layer measurements.

Project suitability
- Honours project
- PhD or Masters project

Project supervisor
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High-mobility, high-stability, energy-saving and low cost zinc oxynitride thin-film transistors

Research fields
- Materials Science and Engineering
- Engineering in Physics

Project details
Are you expecting to experience the remarkable quality display with high resolution, accurate colour imaging, and large-size touch panel on your iPad, smartphone or even smart HDTV without having to recharge for many days? Current technology in amorphous oxide semiconductor thin film transistors have enabled much high resolution and significantly lower power consumption. Such technology is the result of breakthroughs in basic research, material science and display panel fabrication, and it is based on a compound, called IGZO, (Indium Gallium Zinc Oxide) that replaces silicon in the manufacture of thin-film transistors. Thin-film transistors (TFTs) are at the heart of every LCD, and IGZO improves the performance of LCD panels in three significant ways: lower power consumption, higher resolution and a new operating mode for touch-sensitive displays. In spite of these improvements, the long-term stability of IGZO-TFTs and the high cost of indium remain the most critical issues that must be solved.

This project will explore a new class of semiconductors, zinc oxynitride (ZnON), which could replace IGZO as TFT material to deliver high-performance, low-cost, and low power-consumption displays. This project aims to deposit high mobility ZnON layers through pulsed laser deposition and/or sputtering techniques and fabricate ZnON thin film transistors. The exploitation of fundamental properties, such as electrical transport and defect behaviours, of ZnON, as well as the studies on device physics and reliability will also be conducted.

Required background
- Knowledge on semiconductor physics or solid state physics
- Knowledge on semiconductor materials and devices

Project suitability
- Third year special research topic
- PhB (1st year project)
- PhB (2nd or 3rd year project)
- Honours project
- PhD or Masters project
- Summer research scholarship

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