THE UNIVERSITY OF MELBOURNE

Faculty of Science

School of Chemistry

Research Prospectus

Contents

About the School

The School of Chemistry is dedicated to improving our world and training outstanding graduates in chemistry.

We research functional materials, chemical biology, sustainability and the environment with cutting-edge knowledge and technology.

Advanced knowledge in chemistry is essential for building a sustainable future. We address major societal challenges in energy, environment and health through education, research, training, and engagement.

The University of Melbourne's Faculty of Science acknowledges the Traditional Owners of the lands on which we work: the Wurundjeri Woi-Wurrung and Bunurong peoples (Burnley, Fishermans Bend, Parkville, Southbank and Werribee campuses), the Yorta Yorta Nation (Dookie and Shepparton campuses), and the Dja Dja Wurrung people (Creswick campus). We pay respect to their Elders, past and present. We also acknowledge and respect that Aboriginal and Torres Strait Islander people are this country's first scientists, with deep and enduring knowledge of the land, waters and skies.

Professor Uta Wille

Professor Uta Wille

Head of the School of Chemistry

- Physical organic chemistry
- Synthetic organic chemistry
- Environmental chemistry
- Computational chemistry

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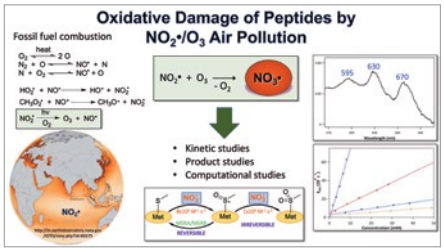
I aim to better understand the adverse effects of air pollution and increase the sustainability of agriculture, as well as training the next generation in environmental chemistry.

Air pollution and respiratory health

Nitrogen dioxide and ozone are noxious gases produced by burning fossil fuels. To better understand what happens when we inhale these pollutants, we use in vitro (test tube) model systems to study how they damage biological molecules, particularly peptides, that line the respiratory tract. We can identify hot spots for oxidative damage in peptides and have shown that the environment has a strong impact on their susceptibility to oxidation.

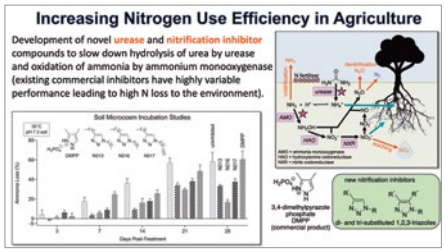


Oxidative damage of peptides by nitrogen dioxide/ ozone air pollution.

Increasing nitrogen use efficiency in agriculture

To ensure adequate global food supply by 2050, annual crop production must increase by almost 40 per cent. Nitrogen (N) fertilisers are commonly used in agriculture to maximise soil fertility and crop yield. Unfortunately, plants assimilate only a fraction of the applied N: globally, nitrogen use efficiencies (NUEs) have remained at around 50 per cent since the 1980s. Loss of N from plant/soil systems pollutes surface and ground water and adds nitrous oxide, a potent greenhouse gas, to the atmosphere.

To increase plant uptake of N, fertilisers are commonly amended with compounds that slow down microbiological processes, particularly urease inhibitors and nitrification inhibitors. Existing commercial inhibitor products have highly variable performance, so we are developing new compounds to increase NUEs in Australian soils.



Increasing nitrogen use efficiency in agriculture.

Professor Brendan Abrahams

Professor Brendan Abrahams

- Crystal engineering
- Supramolecular chemistry
- Coordination polymers
- Molecular cages
- X-ray crystallography

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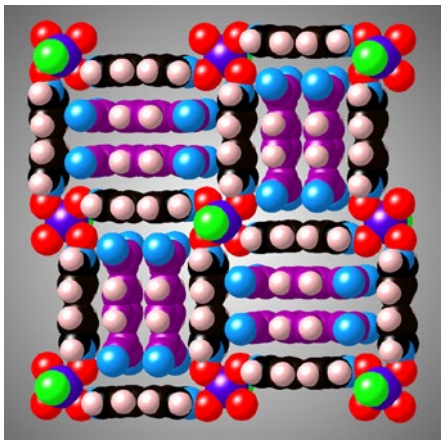
I use geometric and chemical principles to assemble molecular structures with unusual and useful properties, such as electronic communication and adsorption (where a gas, liquid, or dissolved solid adheres to the structure's surface).

Design, synthesis and properties of new materials

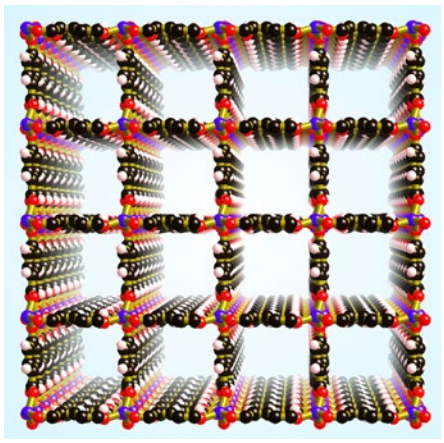
My research group applies simple geometry and anticipates chemical behaviour to design and assemble discrete, polymeric structures from molecular building blocks. Some products are tailored for adsorption applications, whilst others exhibit electronic communication between molecular components. Our research areas include:

1. Redox-active network materials
2. Porous coordination polymers
3. Hydrogen-bonded network materials
4. Molecular cages.

We use single crystal X-ray diffraction to verify the molecular structure of the materials we synthesise, and measure their physical properties, including gas adsorption and electrical conductivity, to establish structure-function relationships.



An iron-based electrically conducting network material.



A strongly adsorbing zinc-based coordination polymer.

Professor Evan Bieske

Professor Evan Bieske

- Molecular spectroscopy
- Mass spectrometry
- Molecular ions
- Astrochemistry
- Photochemistry

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My research group deploys proprietary techniques to search for exotic molecules postulated to exist in the space between star systems and in the terrestrial atmosphere, which may form the basis of new opto-electronic devices that can detect and control light.

Spectroscopy of extraterrestrial molecules

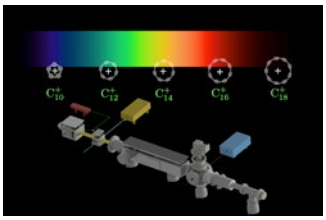
The regions between stars are populated by a range of exotic molecules identified mainly through radio astronomy. We make and characterise new molecules in the laboratory, comparing their electronic and infrared spectra with astronomical data to determine whether similar molecules exist in space. We build specialised mass spectrometers with sophisticated laser systems to achieve extraordinary sensitivity and selectivity in our spectroscopic studies.

Our current focus is on charged carbon clusters like the molecule buckminsterfullerene (C60+). We have developed new techniques to form and isolate different clusters so we can characterise their unique properties, assess whether they exist in interstellar space, and determine whether — like buckminsterfullerene — they possess useful optoelectronic properties.

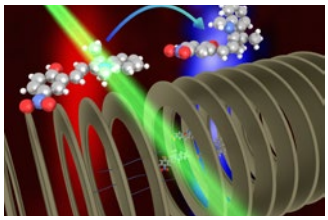
Spectroscopy of shape-shifting molecules

Some molecules change shape when they absorb light. Determining how light causes these rearrangements is important for developing better molecular photo-switches and motors, and for understanding many biological systems, including animal vision.

To investigate light-induced changes in molecular structure, we have developed a new experimental technique, which is an extension of ion mobility mass spectrometry. We deploy this approach to investigate photochemical processes in diverse molecules of biological and technological relevance.



Carbon rings absorb light across the visible region.



Photoisomerisation of charged molecular photoswitches in the gas phase.

Professor Colette Boskovic

Professor Colette Boskovic

- Inorganic chemistry
- Transition metals
- Rare earths
- Molecular materials
- Magnetochemistry

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I develop metal-based molecular materials to power the next generation of energy-efficient technology – from sensors and displays to quantum computers.

Smart molecular materials

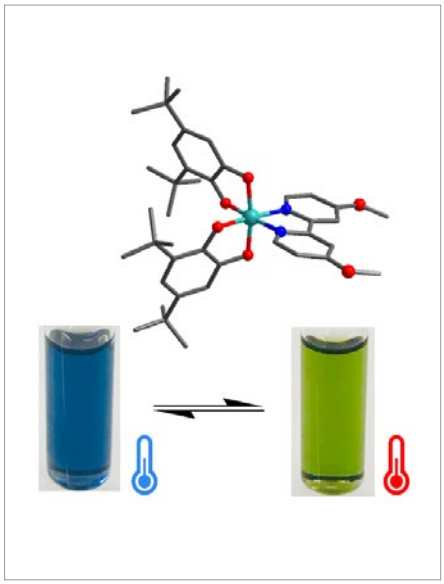
My research group is developing smart molecules made from metals like cobalt and iron. These molecules can switch between different states when exposed to heat, light, or pressure. This switching ability means they could be used in devices that respond to their environment - like ultra-sensitive sensors or energy-efficient displays.

Rare earth chemistry

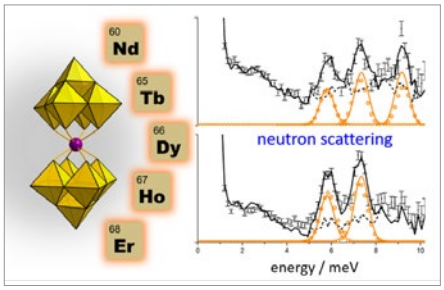
Australia holds rich reserves of rare earth elements, which are vital for high-tech applications such as magnets, lighting, and lasers. However, these metals are difficult to separate and recycle. Our work focuses on creating new rare-earth-based compounds with properties (e.g. colour) that can be controlled at the molecular level using carefully targeted chemical variation. This not only paves the way for new materials, but also informs better strategies for rare earth separation, especially for recycling rare earth magnets.

Single-molecule magnets

Quantum computers promise to solve problems far beyond the reach of today's machines. We are studying single-molecule magnets, which exhibit magnetic quantum tunnelling and have potential to act as "qubits", tiny units of quantum information. By probing their magnetic behaviour using advanced techniques like magnetometry and neutron scattering, we aim to help bring quantum computing closer to reality.



Smart molecular material.



Rare earth chemistry.

Associate Professor Brad Clarke

Associate Professor Brad Clarke

- Pollution
- Emerging contaminants
- PFAS
- Microplastics
- Analytical chemistry

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I apply state-of-the-art analytical technologies to increase understanding of the occurrence, fate, exposure, risk, hazards and remediation strategies of legacy and emerging contaminants.

Contamination of the environment with human-made chemicals is one of the most serious issues we face. The worst of these pollutants:

- Are detected frequently in air, water, soil, and biota across the globe, including 'pristine' locations far from known sources, where they can persist for decades or longer
- Biomagnify through the food chain, accumulating in humans and wildlife
- Cause cancer, reproductive health problems, reduced immune function, and neurodevelopmental impairment
- Can be difficult and therefore expensive to remediate or remove from the environment.

There are over 163 million unique chemical compounds registered in the Chemical Abstract Service database and over 147,000 of these are routinely used for industrial applications. New chemicals are constantly introduced with little thought for their potential environmental and health impacts.

For many recently discovered contaminants, we have no information on their persistence, environmental impact and/or toxicology. More research is urgently needed.

Sampling the environment.

Professor Paul Donnelly

Professor Paul Donnelly

- Inorganic chemistry
- Bioinorganic chemistry
- Metal ions in biology and medicine
- Metal ions in catalysis
- Coordination chemistry

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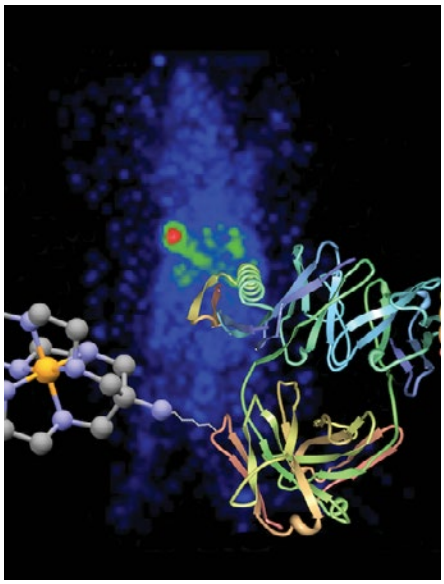
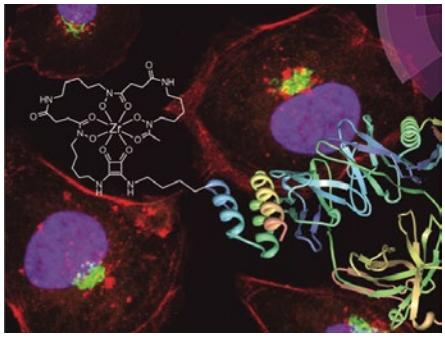
I apply expertise in synthetic chemistry to create and test new metal-containing compounds with potential applications in medicine and biology.

I design, build and evaluate metal-based compounds and coordination complexes as diagnostic and therapeutic agents. I also investigate the roles of metal ions in cellular biology, particularly chemical aspects of neurodegeneration.

I synthesise new compounds using inorganic and organic chemistry, and characterise them using a wide range of analytical techniques, including multinuclear magnetic resonance, electronic spectroscopy, electron paramagnetic resonance spectroscopy, mass spectrometry, high-performance liquid chromatography, electrochemical techniques, and X-ray crystallography.





Dr Alex Duan

Dr Alex Duan

Melbourne TrACEES Platform

- Microwave
- Rare earth elements
- Leaching
- Separation
- Pyrolysis GCMS

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My research focuses on applications of microwave leaching, separation and analytical technologies to investigate recovery of critical metals from e-waste, as well as identification of composite polymer materials using pyrolysis GCMS. The scientific studies of green chemical processes will address environmental impact in the recycling industry.

Microwave leaching and separation of REEs from permanent magnets

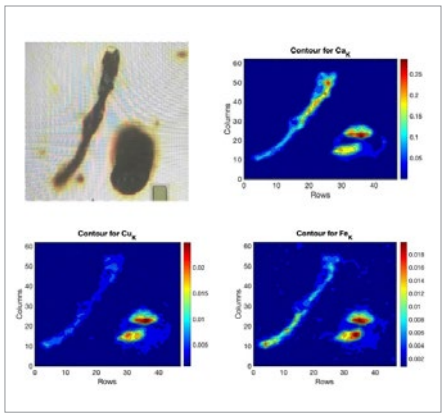
The demand for rare earth elements (REEs) has grown rapidly driven by a continuous increase in the consumption of new electronic equipment and renewable energy. However, there is only a limited fraction (two per cent) of waste of electrical and electronic equipment (WEEE) that has been recycled in Australia. Our previous studies showed selective leaching of Neodymium (Nd) and Praseodymium (Pr) from base metals with application of green chemistry principle. We will continue to explore scale-up technology so the leaching and refining of these critical metals can be fully recycled and re-used in the future, and support a sustainable environment and circular economy.

Extracting critical metals from seawater

Seawater represents a vast and underutilised reservoir of dissolved metals, including critical elements such as Li and REEs, boron (B) and rubidium (Rb), which hold high commercial potential. In particular, seawater concentrate – a by-product of desalination processes – offers a promising and sustainable source for metal recovery. Without recovery, this concentrate is often discharged back into the ocean, wasting valuable resources, and potentially impacting local aquatic ecosystems. Research indicates that in-operation membrane desalination projects in China alone discharge approximately 1.7 million cubic meters of seawater concentrate per day.

Efficient and innovative extraction methods could unlock a sustainable pathway to meet the growing demand for critical metals while mitigating ecological and geological impacts. In this project, we will explore if critical metals in seawater concentrates and microwave extraction of Li and REEs from super high level of salty solution.

Plastic identification for recycling.



Elemental localisation.

Professor Ken Ghiggino

Professor Ken Ghiggino

- Lasers
- Photochemistry
- Spectroscopy
- Polymers

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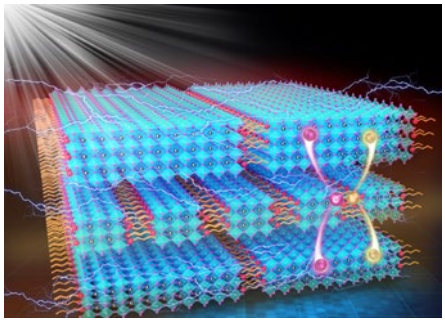
To help meet demand for sustainable energy, I develop new materials and devices for more efficient solar cells and solar fuels.

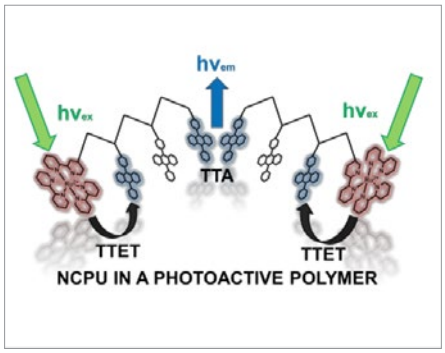
Photochemistry

Light-driven chemistry underpins photosynthesis, medical phototherapy, solar degradation of materials, and solar-driven renewable energy systems. My research group develops and applies advanced, laser-based techniques – including ultrafast spectroscopy, luminescence, and single-molecule fluorescence imaging – to understand photochemical processes in biological and human-made materials.

Our instrumentation can observe photon-initiated events occurring on the femtosecond scale (one-quadrillionth of a second) and at spatial resolutions of less than a micron, enabling imaging of light-induced processes in single molecules. We apply this to characterise new solar cell materials that can be printed onto flexible, lightweight plastic substrates, and develop novel solar-harvesting and light-concentrating devices.



Sandwich structure of a 2D perovskite solar cell film.



Light energy upconversion process in a synthetic polymer.

Dr Marcus Giansiracusa

Dr Marcus Giansiracusa

- Lanthanoid
- Electronic structure
- Computational chemistry
- Magnetism
- Spectroscopy

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I study single-molecule magnets (SMMs) for applications in data-storage and spintronics (emerging electronic technology), or as qubits (the basic information units in quantum computing).

Crystal field splitting in Erbium and Ytterbium(III) molecules

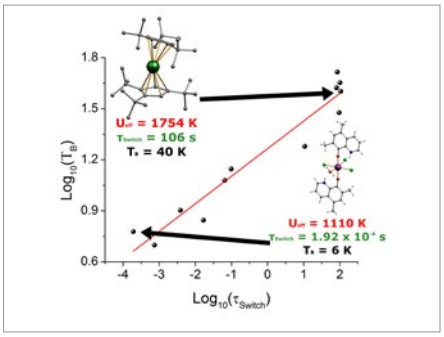
Lanthanoid metals have properties critical for specific applications. SMM research has focussed on Dy(III) complexes. In contrast, the Melbourne Magnetometry Laboratory is investigating Er(III) and Yb(III) complexes, using neutron-scattering spectroscopy and the Spartan computational platform, to create a stronger theoretical framework for predicting the properties of SMMs.

Relaxation times extracted from inelastic neutron-scattering spectroscopy (INS)

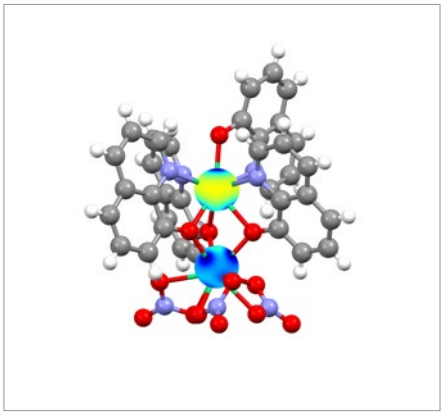
Understanding novel relaxation pathways in SMMs or qubits is essential to enhance their properties for applications. A magnetoelastic coupling relaxation model can be applied to data from older INS studies of qubit candidate complexes, even if relaxation dynamics was not the original focus.

Magnetic fingerprint for ochre samples

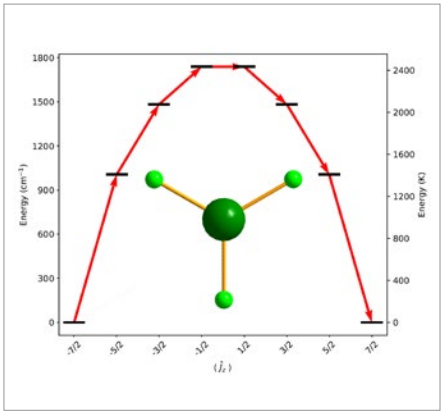
We magnetically characterise ochre samples from around the world, using the MPMS3 SQUID Magnetometer, to increase understanding of materials movement by ancient civilisations.



Studying trends in single-molecule magnets to identify magneto-structural correlations.



Understanding the impact of ligands on the electronic structure of lanthanoids.



Using ab initio calculations to understand the stabilisation of spin-orbit coupled states, wavefunction information and transition probabilities.

Associate Professor Lars Goerigk

Associate Professor Lars Goerigk

- Theoretical quantum chemistry
- Computational chemistry
- Density Functional Theory
- Noncovalent interactions
- Thermochemistry of ground and excited states

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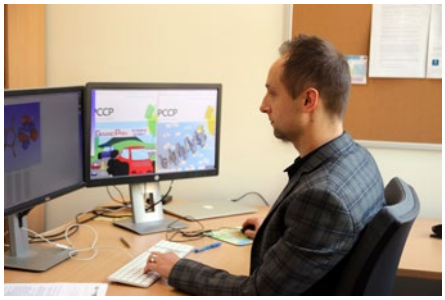
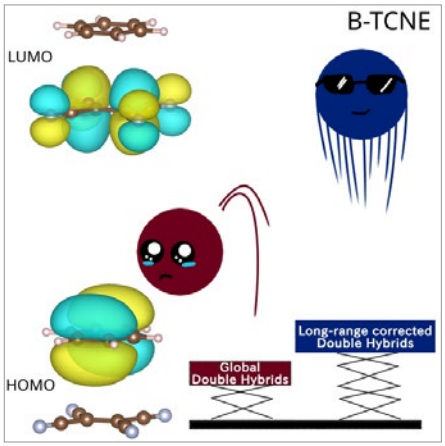
I aim to contribute to more accurate quantum-mechanical equations for real-life chemical problems, allowing us to reliably predict new experiments before they are conducted.

Theoretical and computational quantum chemistry applies the laws of quantum mechanics to predict the behaviour of electrons in chemical and biochemical systems. My research highlights include developing:

- More efficient and accurate computational treatments of chemical problems
- More accurate computational methods for electronic excited states to improve problem-solving simulations for sustainable power generation
- New guidelines and recommendations to enhance communication between computational method developers and experimental chemists.



Theoretical/computational chemists do not wear lab coats or need bench space. Our computers are our lab.



This cartoon was used for a recent article on some of our newly developed computational methods. Those methods outperform older ones and allow the treatment of processes that involve electrons that travel relatively long distances from one part of a chemical system to another. The accurate modelling of such processes is, for instance, important for the development of more efficient solar cells.

Dr Christopher Hall

Dr Christopher Hall

- Photochemistry
- Ultrafast spectroscopy
- Multi-dimensional electronic-vibrational spectroscopy
- Ultrafast vibrational spectroscopy

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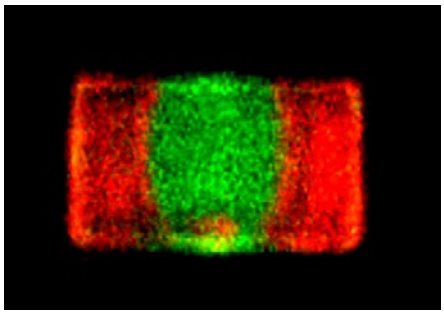
I employ advanced laser-based spectroscopic techniques to provide new insights into photoactive systems with applications including solar energy, molecular electronics, optogenetics, and drug targeting.

Electronic-vibrational spectroscopy

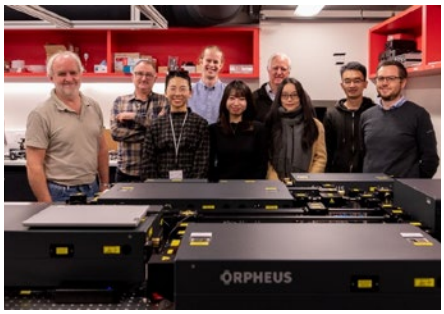
Developing sophisticated tools to analyse light-driven chemical reactions is critical for improving the performance of emerging technologies including next-generation photovoltaics, bioelectronics, optogenetics and photocatalysis.

Despite 40 years of progress, identifying and quantifying competing reactions in photochemical systems remains a major challenge. My research group combines ultrafast electronic and vibrational spectroscopies to open new avenues for investigating photochemical systems.

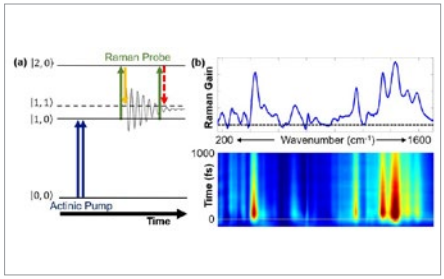
Our techniques reveal the detailed molecular structure of excited states and separate reaction pathways to enhance understanding of their roles in energy and chemical conversion in complex photochemical systems.



Scanning confocal microscope image of a single mixed-halide perovskite crystal showing emission from regions with different material compositions.



The ultrafast spectroscopy group, and the brand-new laser system.



Femtosecond Stimulated Raman Spectroscopy (FSRS). (a) The photochemical reaction is initiated by the actinic pump pulse. The excited-state structure is probed by the stimulated resonant Raman probe. (b) Example spectrum (top) and dynamics (bottom) of a dark excited-state for a molecular motor.

Dr Carol Hua

Dr Carol Hua

- Chemical sensors
- Inorganic supramolecular chemistry
- Functional nanomaterials Chirality

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I develop chemical sensors for disease detection and environmental monitoring to improve human health. We design specialist materials from the molecular scale to analyse substances and study their chemical properties.

Chiral chemical sensors for disease detection

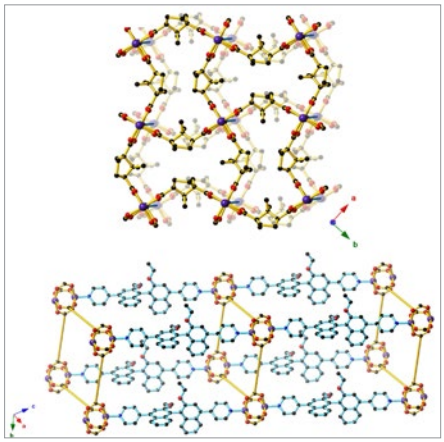
A chiral molecule has a mirror-image that cannot be superimposed (like when you stack your left hand on top of your right hand and their shapes do not match). Abnormal ratios of chiral metabolites can indicate diseases including cancer, epilepsy, and renal disease, but the almost identical properties of chiral molecule pairs make them difficult to distinguish. I develop chiral chemical sensors to rapidly and accurately detect abnormal ratios of chiral metabolites in biofluids, even at low concentrations.

Chemical sensors for environmental monitoring

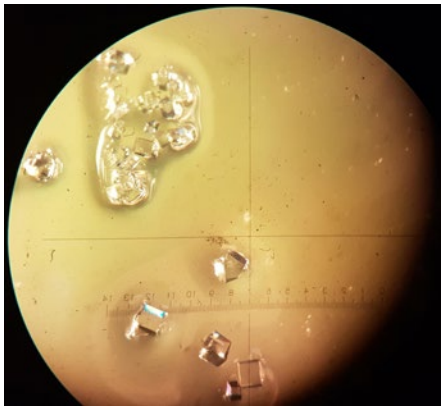
Chemical sensors can offer real-time environmental monitoring to protect human health and ecosystems, but interference from non-target substances poses a challenge, especially in complex sample environments. We are developing chemical sensors with a ‘switch’ enabling access to multiple sensing platforms to verify the presence of the chemical of interest.

Stimuli-responsive molecular switches

Molecular switches can toggle reversibly between states upon exposure to light, temperature, or electricity, which promises advances in materials science, electronics, information transfer, and biological imaging. I incorporate molecular switches into nanomaterials and evaluate whether they can process data signals in the form of light to boost data processing speed and energy efficiency.



The molecular structure of a chiral chemical sensor.



Our materials are beautiful and functional crystals.

Associate Professor James Hutchison

Associate Professor James Hutchison

- Solar harvesting nanomaterials
- Therapeutic nanomaterials
- Trace (bio)molecule sensing
- Photochemistry
- Nanophotonics

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By texturing materials on the scale of the wavelength of light (making nanomaterials), we can control energy flow within and between molecules, potentially uncovering new avenues for light-to-chemical energy conversion, photocatalysis, trace molecule sensing, and phototherapeutics.

Nanomaterials for energy harvesting and therapeutics

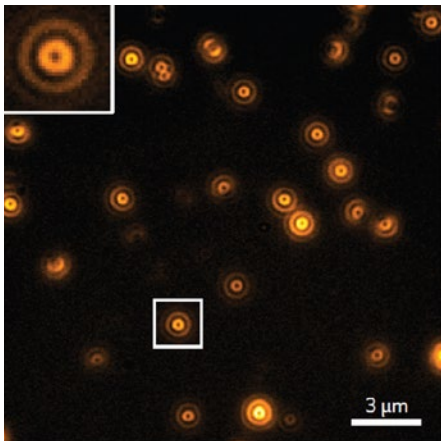
When materials are fabricated at the nanoscale, their properties can change dramatically and become highly sensitive to size. My group fabricates nanomaterials that interact strongly with light.

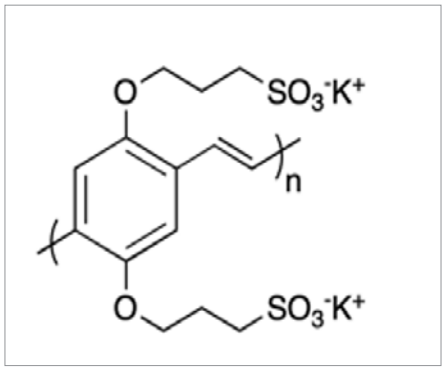
Some nanoparticles absorb light and convert it to heat or trigger toxic chemical reactions, making them promising tools for phototherapeutics, including the targeted destruction of cancer cells. Other nanomaterials, such as polymers, absorb light and transfer energy over long distances, enabling more efficient energy harvesting in optoelectronic devices such as solar cells.

Nanophotonics and trace molecular sensing

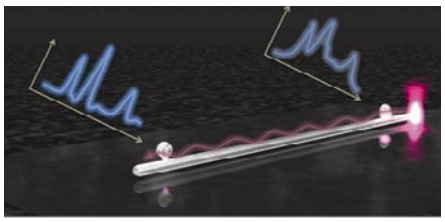
When light interacts with metal nanomaterials, it can be trapped at the surface and dramatically intensified – a phenomenon central to nanophotonics. This enhancement can increase light intensity by more than a billion times.

By placing molecules at the surface of these particles, we can amplify fluorescence and photochemical signals, enabling detection at extremely low concentrations, even down to the single-molecule level. This approach allows us to identify trace pollutants on food products and biomarkers for early disease diagnosis.





Energy transfer in light-harvesting polymers studied by fluorescence imaging.



Schematic of light captured by, and propagating along, the surface of a silver nanowire towards molecular detection.

Professor Craig Hutton

Professor Craig Hutton

- Peptide synthesis
- Synthetic methodology
- Organic synthesis
- Chemical biology

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I develop new chemical reactions for synthesising peptides and proteins to better understand and treat disease.

Novel methods for peptide synthesis and ligation

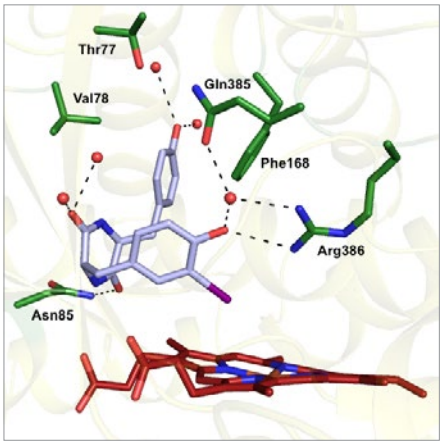
My research group investigates novel synthetic methods for forming amide bonds through silver-promoted coupling of thioamides and carboxylic acids. We have employed this method to develop a novel peptide cyclisation process that avoids common problems such as cyclodimerisation and epimerisation.

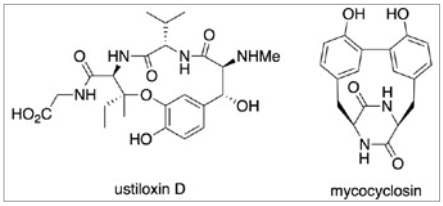
Synthesis of cyclic peptide natural products

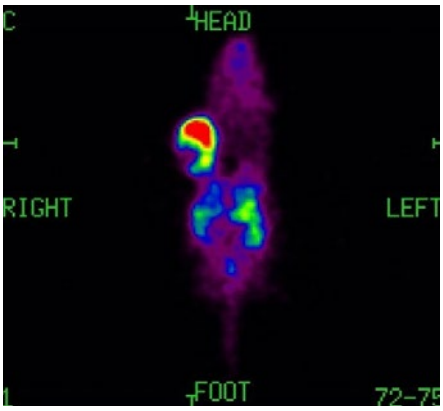
To design new, efficient, synthetic routes to biologically active complex cyclic peptides such as ustiloxin D and mycocyclosin, we develop novel strategies for stereoselective synthesis of unusual amino acids and preparation of side-chain cross-links.

Radiolabelled peptides for cancer imaging

We are developing new methods to incorporate the 18F-radionuclide into amino acids and peptides for imaging cancer by positron emission tomography.







Associate Professor Guy Jameson

Associate Professor Guy Jameson

- Iron
- Enzymology
- Mossbauer
- EPR
- Kinetics

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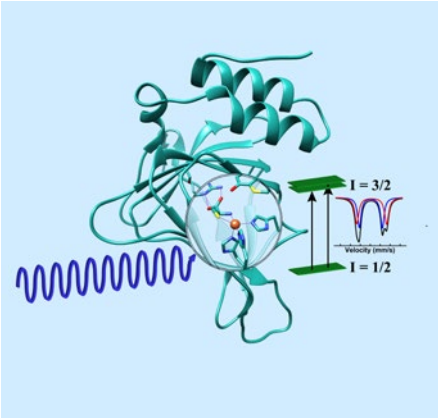
I apply expertise in spectroscopy and kinetics of proteins and small molecules to better understand how enzymes work at the molecular level and how enzyme malfunction contributes to disease progression.

Iron is the most abundant element on Earth and iron-based chemistry is central to all life. My group examines how iron-oxygen reactivity is attained and regulated in the body. This is essential for understanding physiological and pathophysiological processes. Our research into enzyme mechanisms involves molecular biology and protein purification as well as physical, chemical, spectroscopic and kinetic characterisation techniques.



We study iron containing metalloenzymes using an iron specific nuclear spectroscopy called Mossbauer spectroscopy.

Associate Professor David Jones

Associate Professor David Jones

- Organic semiconductors
- Organic solar cells
- Catalysis
- Singlet fission
- Materials synthesis and characterisation

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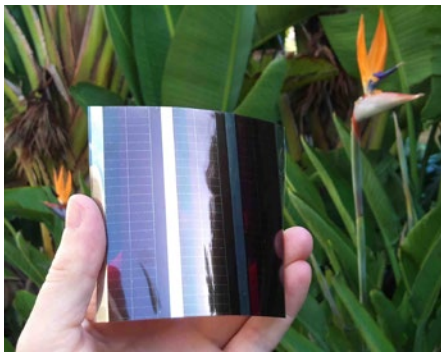
I aim to lower the cost of solar power so it can be deployed in energy storage systems (pumped hydro, super capacitors, batteries, etc.), enable the 'internet of things' such as self-powered sensors/ displays, and drive chemical reactions, such as water splitting for hydrogen generation.

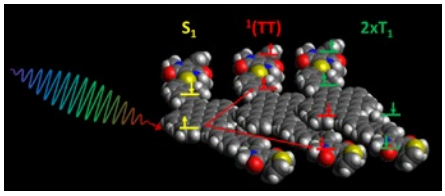
I lead a research group to develop high- performance, organic, electronic materials for large-area, printed solar cells (www.organotronics.com). We have developed new classes of materials, including p-type organic semiconductors with a high-temperature, nematic, liquid crystalline phase and exceptional materials properties, and new classes of Singlet Fission materials supporting quantum coupled states for enhanced solar cell efficiency. Our synthesis laboratory has advanced materials characterisation tools and an integrated glovebox for solar cell device assembly.

Our research programs:

- High performance p- and n-type organic semiconductors (OSCs) for organic photovoltaics (OPVs)
- Translation to large-scale printed OPVs
- Thermally activated delayed fluorescent materials for OPVs
- Molecular OSC materials for singlet fission, and
- Nanoparticle composites as photocatalysts for direct reduction of carbon dioxide to solar fuels.



Printed solar cell.



Singlet fission: one photon to two excited states.

Dr John Karas

Dr John Karas

- Peptide and protein synthesis
- Synthetic methodology
- Medicinal chemistry
- Enzymes

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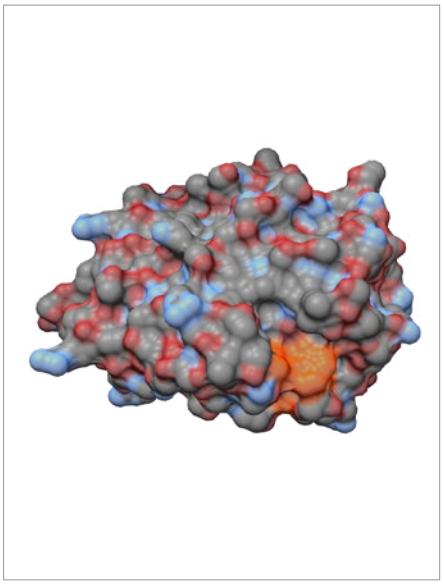
I develop new chemical methods for efficient, large-scale preparation of biologically active peptides and proteins, and improve the thermal and chemical stability of proteins and enzymes for therapeutic and industrial applications.



Enhanced chemical synthesis of proteins

Chemical protein synthesis can help answer significant questions in biology. Its key advantage over recombinant protein expression is the ability to site-specifically incorporate post-translational modifications, chemical probes, and non-native amino acids with high precision. Mirror-image proteins are also possible, forming useful research tools for X-ray crystallography and peptide drug discovery.

Currently, chemical synthesis of large proteins cannot yield large quantities at high purity. My research group focuses on developing new amino acid precursors to enhance the assembly of larger therapeutic proteins, receptors, and enzymes.

Next-generation insulin therapeutics

To manage type 1 diabetes, a basal-bolus regimen involves taking a longer-acting form of insulin to keep the blood glucose level stable through periods of fasting, with separate injections of shorter-acting insulin to prevent it rising after meals. Significant challenges remain to optimise diabetes treatment, including: (i) increasing therapeutic compliance; (ii) improving glycemic control; and (iii) enhancing formulation stability. Therefore, we are developing a new generation of glucose-responsive insulins, which only activate when blood-glucose levels are elevated. Hyper-stable analogues are also under investigation, which will be ideal for insulin pumps and oral formulations.

Hyper-stable enzymes

Enzymes are commonly used in the food, beverage, and chemical manufacturing industries to control chemical transformations. However, enzymes are typically susceptible to thermal and chemical denaturation, which can render them inactive. We are investigating new synthetic methods to improve stability, which will lead to recyclable enzymes for a broad range of applications.

Dr Ivanhoe Leung

Dr Ivanhoe Leung

Bio21 Molecular Science & Biotechnology Institute

- Enzymology
- Biological chemistry
- Inhibitor discovery
- NMR spectroscopy
- Protein-ligand interactions

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My goal is to use knowledge generated through structural enzymology to address some of the world's most pressing challenges.

Metabolic regulation of protein functions

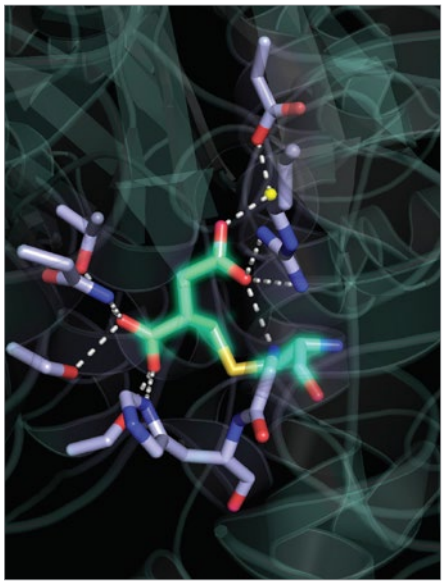
Maintaining homeostasis (a stable internal environment) is critical to all life and partly achieved through fine-tuning of cellular enzyme activities. My research group analyses how post-translational modifications and metabolites affect the structure, activity and function of enzymes to maintain stability under stress. We study enzymes involved in regulating carbon metabolism in Mycobacterium tuberculosis, to understand how the pathogen survives inside the host with limited nutrients. We are also investigating the mechanisms and structures of different isoforms of the ethylene-forming enzyme to understand their roles in plant growth and development.

Enzyme technology for bioremediation

My research group explores how we could harness enzymes as biocatalysts to degrade environmental pollutants. We are especially interested in understanding the molecular mechanisms by which laccases – a class of multi-copper oxidase enzymes – catalyse one-electron oxidation of aromatic amine and phenolic substrates to degrade organic pollutants. We also characterise degradation products of different reaction conditions to identify plausible degradation pathways.

Inhibitor discovery strategies and applications

Modulating enzyme activity has enormous potential in medicine. We apply biophysical techniques, especially nuclear magnetic resonance spectroscopy, to study protein-ligand interactions in enzyme inhibition. We aim to develop inhibitors for lipid A phosphoethanolamine transferases, which could help reverse bacterial resistance to polymyxins, a class of last-line antibiotics to treat multidrug-resistant infections.



Inhibition of the Mycobacterium tuberculosis isocitrate lyase by the human macrophage metabolite itaconate.

Professor Megan Maher

Professor Megan Maher

- Metals in biology
- Structural biology

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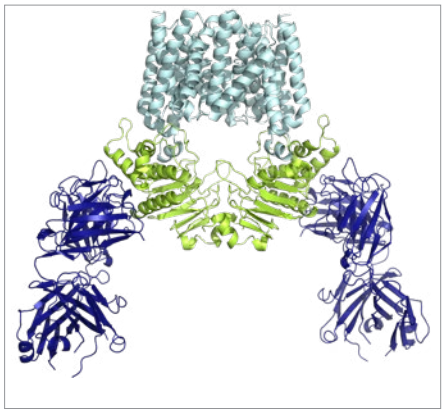
I advance understanding of the roles of trace elements in biology by studying their acquisition and balance in cellular systems.

Trace elements such as iron, copper and zinc are essential nutrients for all forms of life, play a critical role in immunity, and are used in medicines. However, they can also be toxic: trace element imbalances are implicated in neurological disorders including Alzheimer's disease, Parkinson's disease and prion diseases.

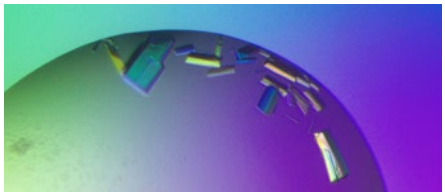
Trace element homeostasis is moderated by exquisitely tuned and synchronised protein-based cellular systems that manage nutrient uptake, efflux and trafficking. However, most research on these systems has been fragmented, focusing on isolated aspects and properties of these networks. Consequently, our appreciation of the role of metals in biology remains crude.

I use structural biology (particularly X-ray crystallography) to determine the architectures of these protein systems. By coupling these insights with functional characterisation through cell biology, biochemical and biophysical techniques, I am constructing a comprehensive overview of biological trace element homeostasis. Current projects include:

- Cellular metal homeostasis: how trace elements are balanced within biological systems
- Metal transport across membranes: structures and functions of integral membrane protein transporters
- Metals in the mitochondria: mechanisms of assembly of mitochondrial complexes relevant to mitochondrial disease
- Electron transfer within and between protein metal sites.



The structure of a bacterial metal transport protein that is a target for novel antibiotic design.



Protein crystals are not only beautiful, but are the basis for determining protein structure.

Dr Ludovica Monti

Dr Ludovica Monti

Bio21 Institute of Molecular Science and Biotechnology

- DNA-therapeutics
- Infectious diseases
- Drugs discovery
- Genomics
- Bioinformatics

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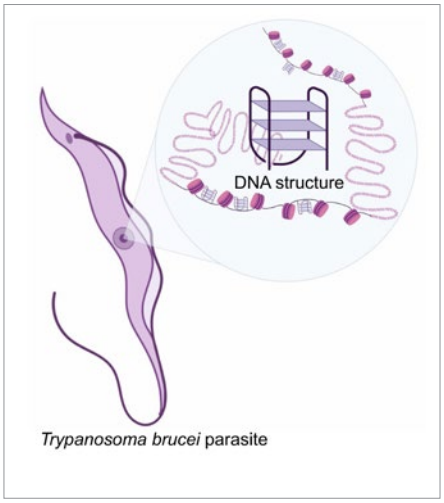
I develop new molecules that bind to bacterial and parasitic DNA, aiming to reduce infections, overcome drug resistance and improve treatment outcomes.

Designing molecules to target DNA and infectious diseases

My research group studies how the shape and structure of their DNA enables bacteria and parasites to infect hosts and resist drugs. We synthesise new molecules that bind to the DNA of harmful bacteria and parasites to disrupt important functions in these microbes, which may help prevent infections and overcome drug resistance. We collaborate with experts in chemistry, genomics, and microbiology to advance this research and develop improved therapies against infectious diseases.



A Trypanosoma brucei parasite, which causes African sleeping sickness, highlighting the unique DNA structures we study in our lab. Figure created with BioRender.

Colourful tubes containing the molecule of interest purified by column chromatography.

Mr Mick Moylan

Mr Mick Moylan

- Chemistry
- Education
- Secondary school science

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I improve understanding of students' motivations and study practices, and enhance curricula, classroom practices and teacher training.

How do chemistry students study?

I'm investigating the study practices and classroom behaviour of diverse students, uncovering the varied and creative ways that high-achieving students learn chemistry, and the different learning approaches of students who just pass (or fail) subjects. Interestingly, these different kinds of students don't spend significantly more or less time on their learning.

How should we train out-of-field science teachers in secondary schools?

An *out-of-field* teacher is someone who hasn't studied the discipline they are teaching beyond second-year university or hasn't had specialist training in how to teach that discipline. In Australia, there are around 6,000 out-of-field teachers of chemistry for Years 7 to 10.

The consequences of this include: disengaged teachers; misconceptions and knowledge gaps that teachers pass on to their students; reduced practical work; and less academic progression for the students. To address these issues, we're working with a professional body and the Faculties of Education at the University of Melbourne and Deakin University to design training programs for these teachers.

How should we teach chemistry at tertiary levels?

We want to ensure that students engage with the curriculum and build their own knowledge, so we are devising curricula and classroom teaching practices – including new demonstrations in lectures – to maximise this.

Mick performing the thermite reaction between aluminium and iron oxide.

A class of highly engaged chemistry students.

Professor Paul Mulvaney

Professor Paul Mulvaney

- Physical chemistry
- Surface science
- Spectroscopy
- Nanocrystals
- Solar energy

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excitonscience.com

Our primary research goal is to discover new materials that can help Australia transition to a sustainable energy future. We achieve this through the exploration of quantum size effects in nanoscale materials.

Our group works across three main research areas.

Nanocrystal photovoltaics

We develop new approaches to improve solar energy conversion, including printable solar cells made from earth-abundant, non-toxic materials such as CZTS (copper zinc tin sulphide). Funded by ACAP and ARENA, our goal is to create inkjet-printable solar materials that reduce fabrication energy costs and enable printing onto flexible substrates.

We are also developing fluorescent down-converters for luminescent solar concentrators ("power windows") in collaboration with ClearVue (Perth), and low-power quantum dot infrared photodetectors supported by an ARC Discovery Project with Ken Crozier and James Bullock.

Optical logic gates

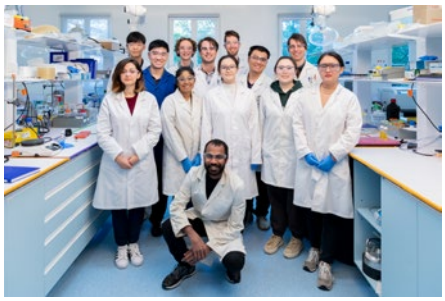
We aim to reduce the energy consumption of digital technologies by developing optical computers. This work focuses on creating optical logic gates using photoswitchable molecules and is funded through a joint PhD program with the University of Bayreuth in Germany.

Basic nanoscience and nanomechanics

Using microfluidics, we study the earliest stages of nanocrystal nucleation and growth to understand how nanoscale materials differ from bulk solids, including changes in melting point and crystal structure. This work is supported by an ARC Discovery Project with Professors Charlotte Petersen, James Hutchison and Brendan Abrahams.

We also investigate nanomechanics by electrically driving nanometre-thick films ("nanodrums") and analysing their optical response in collaboration with the Department of Electrical Engineering.

Quantum dots are small semiconductor crystals just 1-20nm across. Their size controls their optical properties. The image shows luminescence from cadmium selenide crystals, ranging in size from 1-6nm.



The Nanoscience Laboratory is part of the ARC Centre of Excellence in Exciton Science.

Professor Richard O'Hair

Professor Richard O'Hair

- Mass spectrometry
- Homogenous catalysis for organic synthesis
- Non-targeted metabolism of exogenous substances

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I analyse and design catalysts and reactions at the chemistry-biology interface.

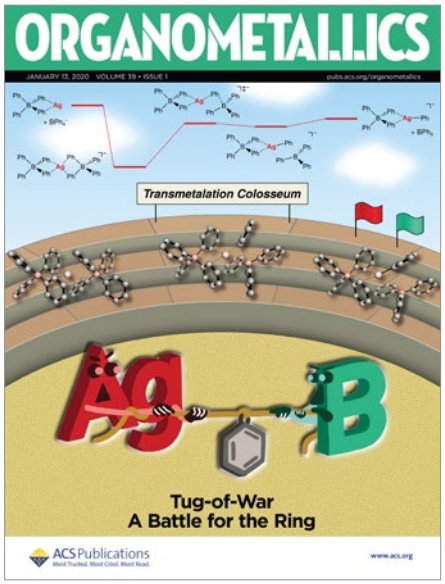
Fundamental and applied mass spectrometry

Mass spectrometry (MS) is a powerful tool to analyse a wide range of molecules and study fundamental chemistry in the gas phase.

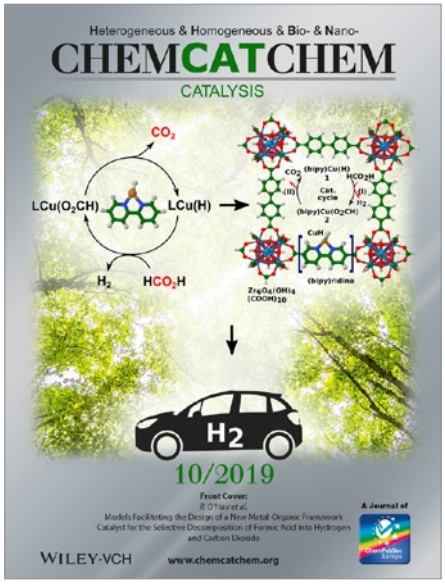
My research group generates a wide range of inorganic, organometallic and organic ions using electrospray ionization. We then apply multistage MS techniques to unmask reactive intermediates (via collision-induced dissociation) and examine their reactivity (via ion-molecule reactions). We can translate this information to the condensed phase.

I am interested in understanding the mechanisms of widely used synthesis reactions, including organometallic reactions and transition metal-catalysed reactions.

Another key area is the development of radical-based methods for analysing biomolecules via MS. Through Australian and international collaborations, we have identified small bioactive molecules and revitalised the Twin Ion Method to study the metabolism of insecticides or drugs in animal models.



Recent cover art on developing understanding of a key class of reactions.



Recent cover art on developing a new class of catalyst for release of hydrogen.

Dr Charlotte Petersen

Dr Charlotte Petersen

- Computational chemistry
- Glass
- Nonequilibrium systems
- Molecular dynamics simulations
- Statistical mechanics

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I aim to understand the astoundingly complex behaviour of some everyday materials using computer simulations and statistical mechanics theory. I apply this approach to a range of amorphous and frustrated materials, glassy liquids, and flow through porous materials.

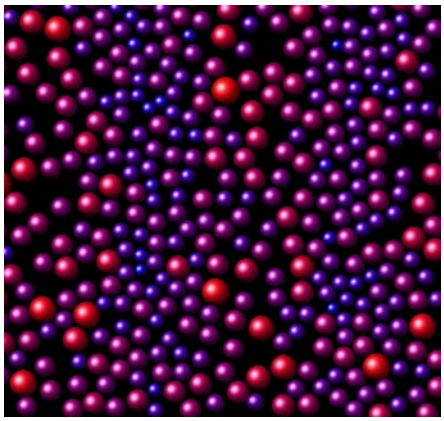
Molecular dynamics simulations of glass

At large scales, glass behaves like a solid, yet its microscopic structure is disordered like a liquid. This makes it difficult to predict the mechanical properties of new glasses, so they are designed through trial and error. To address this problem, I classify the structure of a glass material by how much the atoms vibrate, measured by the degree of blurring in the material's diffraction pattern (as is done routinely for crystals), and link this to the glass's macroscopic properties via computer simulations.

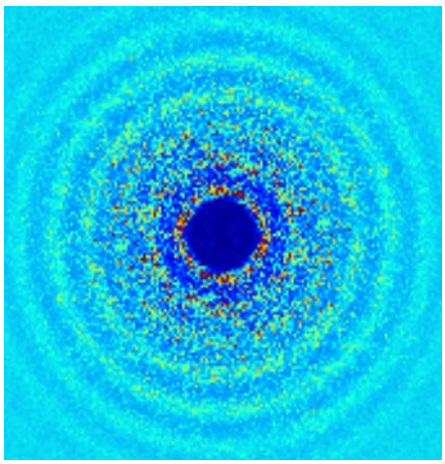
Future research plans

Violations of the Second Law of thermodynamics

Understanding how new miniaturised technologies such as nanobatteries and molecular machines violate the Second Law of Thermodynamics is essential to rational design. Recent theory is closing this gap but is challenging to apply experimentally. By studying artificial spin ice, a new material designed for easy observation of thermal fluctuations, I aim to link theoretical predictions to measurements.



Snapshot from a molecular dynamics simulation. These simulations allow us to follow the motion of individual particles. By monitoring the motion of particles in a glass, we can measure the vibrations.



Simulated diffraction experiment on a glass. Although this diffraction pattern is too noisy and complex to measure detailed structural information directly, by measuring how it changes with temperature we can infer how much the particles are vibrating.

Associate Professor Anastasios Polyzos

Associate Professor Anastasios Polyzos

- Synthetic organic chemistry
- Flow chemistry
- Catalysis
- C-H activation
- Palladium chemistry

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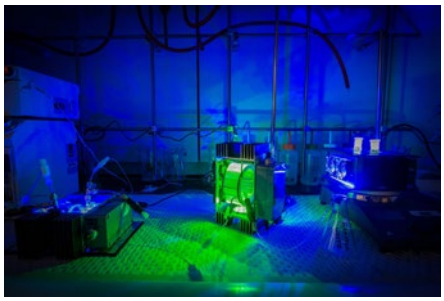
I develop novel methods for organic synthesis of biologically active molecules to support sustainable manufacturing of pharmaceuticals.

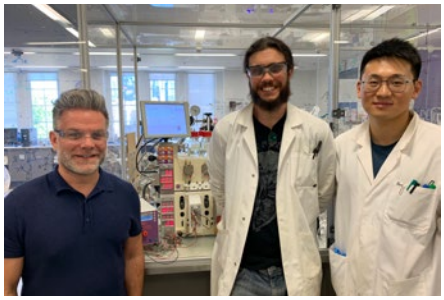
My research group harnesses catalytic reactions and flow chemistry to achieve sustainable synthesis of complex organic molecules with enzyme-like efficiency.

Key interests include:

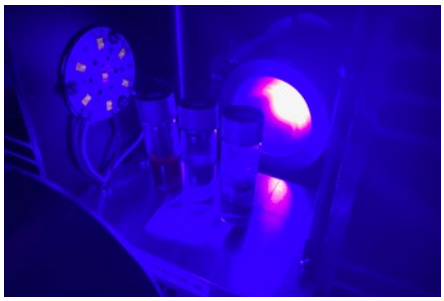
- Visible light photoredox catalysis
- Direct carbon-hydrogen bond activation with high oxidation state palladium catalysis
- Flow chemistry
- Total synthesis of natural products and medicinal chemistry.



A continuous flow photo chemistry reactor at the School of Chemistry. Image credit: UoM Image Bank.



From left to right: Dr Anastasios Polyzos and PhD students Jose Forni and Xiaocong Guan from the School of Chemistry. Image credit: Anastasios Polyzos, UoM.



A photoredox chemical reaction illuminated by light emitting diodes. Image credit: Anastasios Polyzos, UoM.

Dr Priyanka Reddy

Dr Priyanka Reddy

- Metabolomics
- Natural product chemistry
- Analytical chemistry

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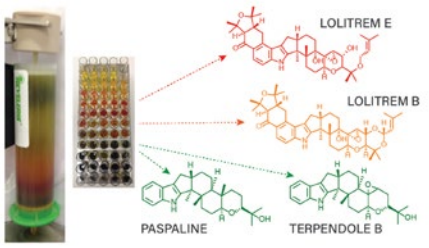
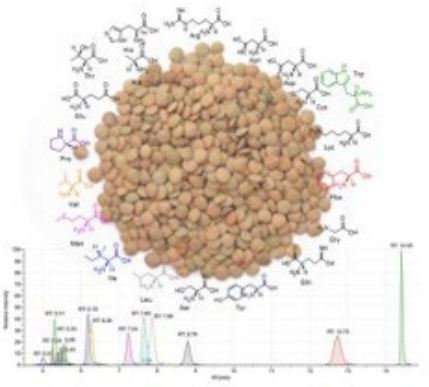
To benefit agriculture, health and the environment, I collaborate with experts from many disciplines to create strategies that support helpful microbes and limit harmful ones, and work with industry partners to turn these into simple tools and advice.

We lack understanding of many chemical interactions between plants, microbes, and their environment that support healthy crops. I apply small molecule analyses and chemical imaging – including hyperspectral-near infrared imaging, high-resolution mass spectrometry, and nuclear magnetic resonance – to deliver insights that improve crop production, detect toxins, and identify health and disease indicators, supporting sustainable agriculture and biomedical innovations.

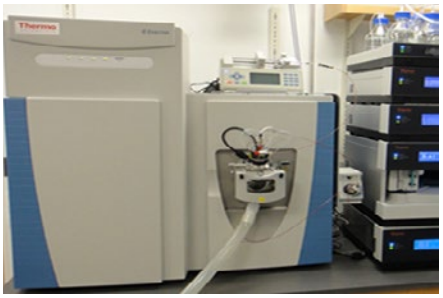
The *metabolome* is the complete set of molecules involved in metabolic (life-sustaining) chemical reactions in a biological cell, tissue or organism. I apply metabolomic analyses to track the chemical signals that microbes produce and discover how these signals affect their hosts and change with the environment. My research helps farmers improve disease resistance, raise yields, and protect the environment.



Isolation of neurotoxins from perennial ryegrass.



High-throughput analysis of amino acids for protein quantification in plant and animal-derived samples using high resolution mass spectrometry.



High-resolution mass spectrometer for precise metabolite detection and identification.

Professor Gavin Reid

Professor Gavin Reid

- Analytical chemistry
- Biochemistry
- Mass spectrometry
- Molecular 'omics'
- Chemical analysis

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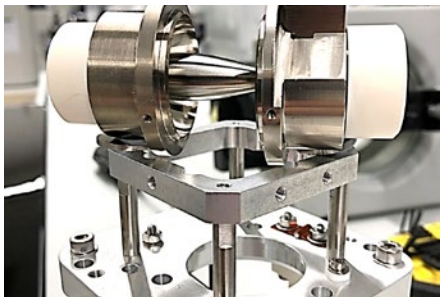
I apply novel strategies to identify and characterise diverse, complex biological and chemical molecules, thereby increasing understanding of diseases and supporting better interventions.

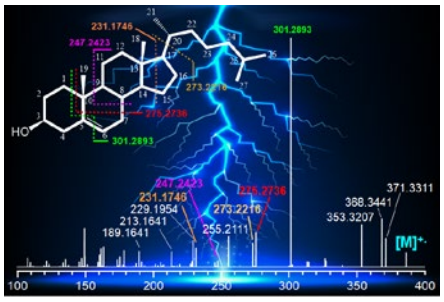
Bioanalytical mass spectrometry

My research group develops mass spectrometry instrumentation and associated measurement strategies for comprehensive and quantitative 'multi-omic' analysis (including transcriptomes, proteomics and lipidomics).

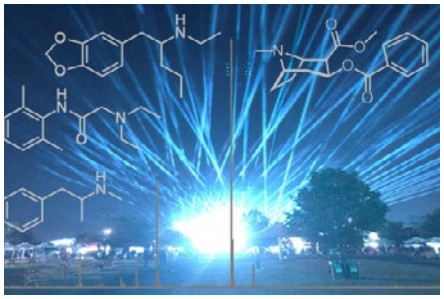
We are applying these strategies to determine the roles of lipids and proteins in the regulation of normal cellular function and in the onset and progression of diseases, including cancer. Ultimately, we aim to identify biomarkers for improved diagnostic or prognostic monitoring, or novel targets for therapeutic intervention.



An ultra-high resolution / accurate mass spectrometry OrbitrapTM mass analyser for chemical and biomolecular analysis



Advanced mass spectrometry strategies for the comprehensive structural characterisation of lipids.



An early warning monitoring system for illicit drug use.

Professor Mark Rizzacasa

Professor Mark Rizzacasa

- Total chemical synthesis
- Natural products
- Synthetic methods

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I develop new synthetic methods to enhance production of complex molecules with biological properties.

Synthesis of alkyl citrates for cholesterol lowering

To develop potential cholesterol lowering agents, my research group is pursuing efficient synthesis from cyclobutene diesters of complex fungal metabolites, such as the alkyl citrate. These natural products are potent inhibitors of squalene synthase, the enzyme that catalyses the first pathway-specific step in cholesterol biosynthesis.

Synthesis of rare biologically active natural products

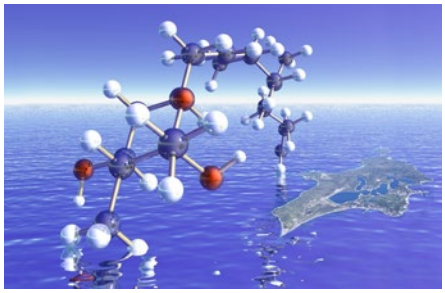
Many biologically active natural products are only isolated in minute amounts, which precludes investigation of their activities. We synthesise rare natural products to enable further study.

Development of new hydration catalysts

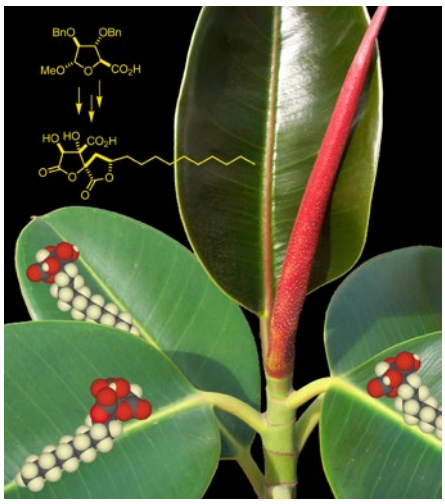
We have produced several novel metal (manganese and cobalt) complexes that act as efficient catalysts for the Mukaiyama hydration of polar alkenes, which has multiple applications in chemical synthesis.

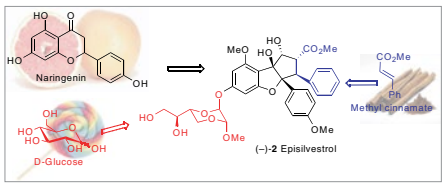
Late-stage oxidation in total synthesis

In nature, late-stage oxidation provides efficient routes to complex, bioactive natural products. Advances in catalysis, genomics and bioengineering can furnish enzymes for complex conversions that closely mimic conditions in living cells. We are investigating reactions involving novel catalysts and isolated enzymes to probe the innate reactivity of carbon-hydrogen bonds for key conversions. Our goal is to find more efficient routes to complex molecules to enable further study of these compounds.



A molecular model of the marine metabolite rottnestol with Rottnest Island WA, where the compound was first isolated, in the background.





Professor Frances Separovic

Professor Frances Separovic

- Antimicrobial peptides
- Membrane biophysics
- Phospholipid membranes
- Solid-state nuclear magnetic resonance
- Structural biology

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Through cross-disciplinary collaborations, I investigate biological macromolecules, geopolymers and ionic liquids for pharmaceutical and industrial applications. In particular, I aim to determine how antimicrobial peptides destroy cell membranes and kill bacteria, so we can design more selective peptides to attack specific pathogens.

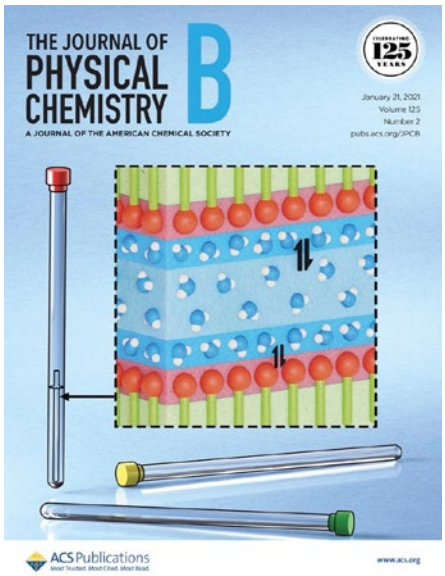
Membrane biophysics

Peptides are molecules made from a chain of amino acids, folded by chemical bonds into a specific 3D structure that determines each peptide's activity. Proteins comprise one or more polypeptides (long peptides).

My research group uses nuclear magnetic resonance (NMR) spectroscopy and other biophysical techniques to study the action mechanisms of polypeptides and proteins in models of biological membranes and in live cell.

We investigate the structure and interactions of amyloid peptides from Alzheimer's disease, pore-forming toxins, and antibiotic peptides, and have determined the 3D structure of two peptides – the antibiotic gramicidin A and the bee toxin melittin.

Cover art from Chemical Society Reviews based on our article, Chemically modified and conjugated antimicrobial peptides against superbugs, by Li et al. (2021) Chem. Soc. Rev. 50, 4932-4973.



Cover art from The Journal of Physical Chemistry B based on our article, Chemical exchange of hydroxyl groups in lipidic cubic phases characterised by NMR, by Meikle et al. (2021) J. Phys. Chem. B 125, 571-580.

Professor Trevor Smith

Professor Trevor Smith

- Ultrafast laser spectroscopy
- Microspectroscopy
- Kinetics

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I study the chemical species formed when advanced materials absorb light, to help increase the efficiency of solar energy collection, probe biological systems, and design new optical devices and sensors.

Time-resolved microspectroscopy of advanced materials

When molecules absorb light, energy or electron transfer can occur on timescales spanning many orders of magnitude: from femtoseconds to milliseconds. To map these dynamic processes, we combine advanced time-resolved and optical microscopy techniques. This research informs the development of light harvesting materials or optical switches, biological systems, and even forensics.

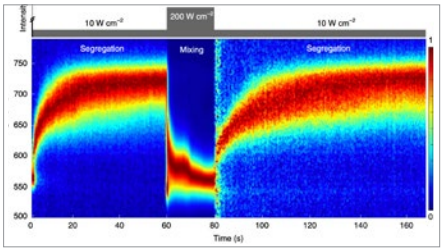
Ultrafast, transient, infrared spectroscopy

Infrared spectroscopy identifies chemical species from the vibrations of specific bonds in molecules. By combining ultrafast laser excitation with infrared spectroscopy techniques, we identify excited-state species and determine their dynamics on tiny timescales.

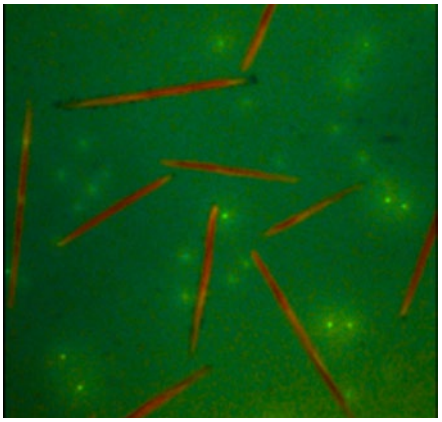
This reveals the contribution of various chemical groups to the excited-state behaviour of molecules. We aim to probe the species involved in light harvesting, particularly to identify the short-lived species involved in bimolecular processes such as singlet fission and upconversion, which could increase the efficiency of solar energy collection

Polarised fluorescence

We use polarised light to probe fluorescent molecule (fluorophore) emissions, which can be depolarised by molecular motion and energy transfer. By monitoring the rate and extent of emission depolarization, we learn about the local environment and dynamics of the fluorophore, and can use microscopy to map these processes spatially.



Light-induced reversal of halide ion segregation in perovskites.



Time-resolved fluorescence image of conjugated polymer (green) and electron acceptor rich (orange) regions in a blended film.

Dr Jegadesan Subbiah

Dr Jegadesan Subbiah

- Organic and perovskite solar cell
- Interface engineering of organic semiconductor
- Device physics of organic photovoltaics
- Synthesis of nanomaterials

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My group focus on the development of high-performance organic and perovskite solar cells through device optimisation, morphology control of the photoactive layer, and interface engineering of the photovoltaic device. We are also interested in developing renewable energy conversion and storage devices for a sustainable clean energy future.

High-performance organic/perovskite solar cells

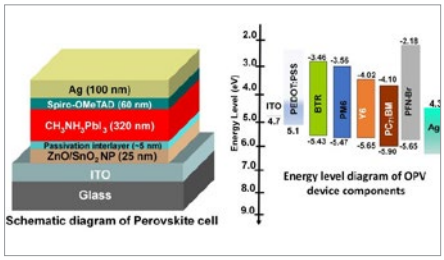
Organic/Perovskite photovoltaics are considered a promising solar energy conversion technology due to their potential to provide large-area solution-processable, lightweight, low-cost and flexible devices. In my lab, we explore the development of solution-processed energy materials, new device architectures, and developing new processing methods for high-performance photovoltaic devices.

Our current research is mainly on the technology development and process optimisation towards the fabrication of efficient organic and perovskite photovoltaic devices, with a prime focus on translational device fabrication from lab-scale devices to large-area printable devices.

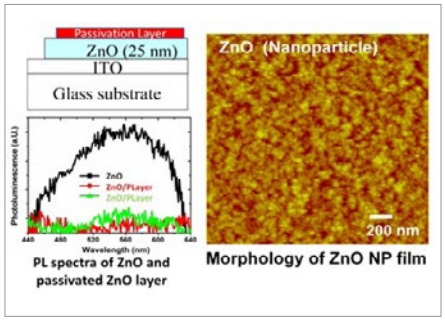
Interface engineering and photophysics of organic photovoltaics

Charge transport, extraction, and collection play important roles in the fabrication of efficient organic solar cells, and interface engineering is one of the key factors in realizing high-performance devices. A good interface can effectively improve the contact between the active layer and the electrode, promote the formation of an Ohmic contact, adjust the electrode work function, reduce bimolecular recombination, increase the charge extraction and enhance the long-term stability of the device.

In our lab, we adopt various approaches, including an ultra-thin layer of polymer materials, doped small molecule materials, and nanostructured metal oxide interlayer to improve device performance and stability.



Device geometry of perovskite solar cell and Energy level diagram of OPV device components.



PL spectra and morphology of zinc oxide nanoparticle interlayer.

Professor Georgina Such

Professor Georgina Such

- Polymers
- Stimuli-responsive systems
- Nanoparticles
- Drug delivery
- Cell interactions

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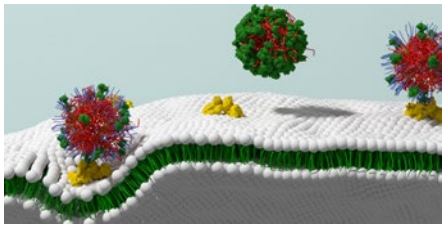
I synthesise nanoparticles that precisely mimic the stimuli-responses of biological materials, to develop solutions for diverse sectors, from drug delivery systems to industrial coatings.



Stimuli-responsive nanoparticles

My research group designs and synthesises nanoparticles that respond intelligently to changes in their environment, such as acidity, reduction-oxidation conditions, temperature, or light. We combine polymers with biological or inorganic building blocks to maximise the versatility of our new materials.

Understanding how nanoparticle structure impacts biological interactions

Nanoparticle delivery systems could improve the treatment of many diseases by targeting drugs to a specific site. We create libraries of nanoparticles with tailored characteristics, and use them to study the impact of nanoparticle structure on biological properties, such as cell association and uptake. This informs the design of polymer nanoparticles for more efficient drug delivery.

Professor Spencer Williams

Professor Spencer Williams

- Carbohydrates
- Enzymes
- Chemical biology
- Medicinal chemistry
- Glycoimmunology

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I collaborate widely to design and synthesise biologically active molecules, probe biological systems, improve human health, and increase the sustainability of industry and agriculture.

Glycolipid immunology

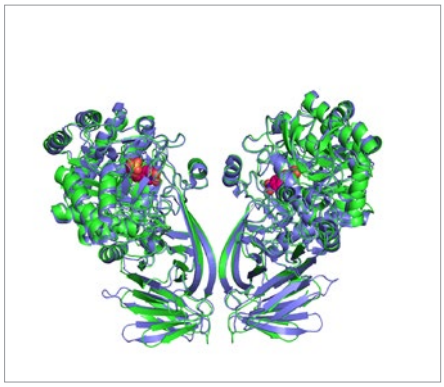
My research group synthesises glycolipids that are difficult or impossible to obtain from nature, so we can explore the relationships between their structure and biological activity. We study how the immune system recognises foreign glycolipids from pathogens and commensals (species living in close association without harm).

Chemistry and biology of carbohydrate-active enzymes

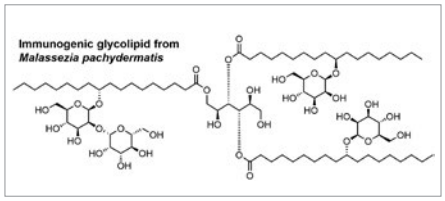
We investigate the molecular mechanisms of enzymes that process carbohydrates, using synthetic substrates and inhibitors in kinetic and structural studies.

Medicinal chemistry

We are developing drugs to treat several human diseases, including lung and kidney fibrosis, cardiovascular disease, and sterile inflammation. Projects in this area involve structural optimisation to enhance potency or improve pharmacokinetic and metabolic liabilities.



3D structure of bacterial sulfoquinovosidases revealed how it binds substrate and perform catalysis.



Total synthesis of an exotic fungal glycolipid from Malassezia pachydermatis.

Associate Professor Wallace Wong

Associate Professor Wallace Wong

- Dyes
- Organic semiconducting materials
- Exciton science
- Light harvesting
- Chemical sensing

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I design and synthesise materials for emerging technologies addressing problems in energy, the environment, biology and medicine.

Organic electronics

Emerging organic electronics promise lightweight flexible devices such as foldable displays, building-integrated lighting and low-cost solar cells. Maximising efficiency and durability of devices require precise control of material structure and properties from molecular to bulk scales. This remains a challenge because materials' bulk properties derive not only from their molecular structure but also from intermolecular association and macromolecular arrangement at the nanometre scale. We address this by designing smart materials that can self-organise and enhance the properties required for specific applications.

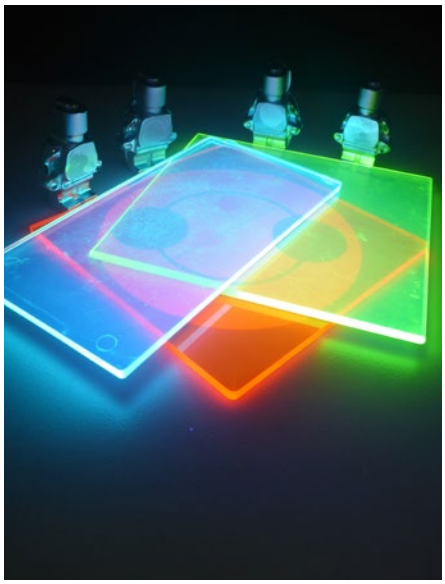
Light harvesting

My research group designs and studies triplet fusion and singlet fission materials to efficiently harvest the full solar spectrum and reduce the cost of solar energy. We work on highly fluorescent materials for luminescent solar concentrators that can be easily integrated into buildings and other urban structures.

Biological imaging

Advanced fluorescence microscopy techniques greatly increase the information obtained from imaging biological samples. Carefully designed organic fluorophores (fluorescent molecules that absorb photons and emits photons of lower energy in return) can target specific cells, organelles, membrane receptors and/or protein-active sites. We apply expertise in synthesising and characterising multi-functional stimuli-responsive fluorescent dyes to track proteostasis and other biological processes.

Beautiful colours as a result of highly tunable organic dye structures.



Fluorescent sheets used in luminescent solar concentrators to harvest solar energy.

Dr Lukas Zeininger

Dr Lukas Zeininger

- Soft matter
- Responsive and adaptive colloids
- Chemo- and biosensors
- Emulsions
- Polymers

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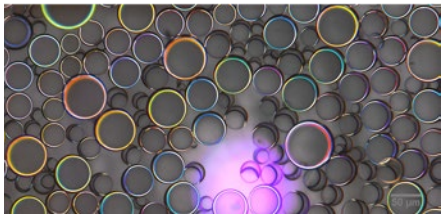
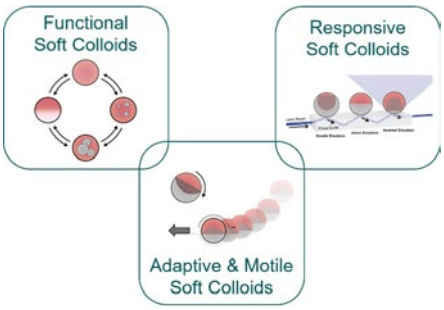
I tailor new, active and dynamic soft materials (emulsions and polymers) for applications in chemical and biological sensing, diagnostics, environmental monitoring, biomimicry, and self-assembled structure formation.





Soft colloids with programmable structural transience

I study the thermodynamics and dynamics of complex active matter, focused on the autonomous regulation of chemical reactivity in living systems. A *colloid* is a mixture (gas, liquid or solid) in which dispersed particles of one substance are suspended in another substance. I aim to emulate the self-regulating mechanisms found in biological colloidal systems that are crowded with macromolecules, and program microreactors with unprecedented autonomous capabilities, ultimately rivalling the regulatory functions of natural systems.

Self-regulating droplets as nano-to-macro messengers

A *surfactant* decreases the surface or interface tension between a liquid and a gas, a solid or another liquid. Surfactant-stabilised droplets constantly exchange information with their environment. Dynamic and reversible interfacial reactions can trigger changes in the form and structure of complex droplets, and this resembles living cell surface environments. Interface-sensitisation of droplets gives them up- and down-regulating capabilities, so they can selectively and dynamically present, hide, or expand liquid–liquid interfaces, and thereby represent and report force gradients in temperature, chemistry, and concentration with 10^{-15} moles per litre sensitivity.

Droplets as adaptive and motile sensors

Focusing on emulsion droplets, I explore how simple materials can exhibit complex, lifelike behaviours observed in natural multi-body systems, including a self-regulated ability to actuate, move, communicate, evolve, and organise into patterns or networks. I aim to deliver a wide range of transformational science that will help to progress the state of the art in soft matter research and empower many new and improved applications.

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