Project Examples 2024/25

The following list outlines some of the research areas that are offered as projects in next academic year. It is important that you think carefully about the type of project that will suit you, your interests and also consider what you want to do after you graduate – a project related to your future plans can be a useful addition to your CV. **We encourage students to come up with their own project ideas** but it is important that you discuss these with a relevant member of staff to check that the idea is both safe and feasible and that the required support is available. In the first instance, study the list, as this will help you understand the research interests of the staff. Decide on one or two project types and arrange to discuss these with a chosen supervisor.

If you have a very specific interest, such as in acoustic, medical, geological, biological, archaeological physics etc. then it may be possible to organise a project with experts from other schools within the university. In the first instance please discuss these with the module coordinator.

Speed is of the essence, if a member of staff has accepted his/her quota of students then you may be disappointed.

The following is only an example of what is offered, but it should give you an idea as to the areas of expertise/interest of each member of staff.

Marina Leontiadou (Experimental, Analytical)

Marina offers a range of projects related to her research interests, which focus on exploiting femtosecond pulses of light (on the order of 0.000000000000001 second) from modern ultrafast laser technology to understanding and exploit the physical processes taking place at the heart of a range of advanced materials. These incredibly short flashes of light can be used to build high-speed cameras and watch physics in action. She has used this state-of-the-art technology to develop next generation photovoltaic materials to address the climate crisis, and exploited the spin of the electron to develop energy efficiency memory devices.

Proposed projects for this academic year are:

- **Efficiency limits of light emitting nanostructures.**
- **Next generation light harvesting materials: photovoltaic technology for the 21st century.**
- **Spintronic materials – harnessing the power of the electron spin.**
- **Spectrophotometry of thin films.**

These project titles are provided to give you a flavour of what projects are available. If you are interested in a project in this field, please contact me at m.leontiadou@salford.ac.uk.

Additional projects:

- **STEM subjects** - Marina also offers projects related to the current challenges facing STEM subjects in the areas of equality, diversity and inclusion. These projects are more essay based and will critically review the latest ideas and methodology in the field.

Marina can supervise external projects related to

- **Energy House –** Opportunity to have a research project focusing on the energy efficiency of domestic buildings. Based at Energy House 2.0, a globally unique research facility, you will perform an experimental study characterising the fabric thermal performance of UK housing, through u-value, heat transfer coefficient (HTC) and air tightness measurement. Please contact Marina if you wish to explore this opportunity as she can supervise a project collaborating with Prof. Richard Fitton and his team.

- **Medical Physics** – Opportunity to have a research project in medical physics. Please contact Marina if you wish to explore this opportunity as she can supervise a project using the Digital Skill and Medical Imaging facility in collaboration with Dr Katy Szczepura, or on rehabilitation technology with Prof. Laurence Kenney.

Tiehan Shen (Experimental, Computational)

Tiehan offers a range of both theoretical and practical projects and is happy to discuss your ideas. As he tends to spend most of his time in Maxwell building, you are advised to e-mail him to arrange a meeting.

1) Fourier analysis of polarimetric microscopic images
Stokes polarimetric microscopy offers the ability to image the full polarisation information of the object at the focal plane. This allows the acquisition of important information such as the phase retardations. The project is to explore the possibility of numerically reconstruct the wavefront at the focal plane and the potential of numerical holographic reconstruction of the microscopic images.

2) The accessibility of science
The project is to survey the public accessibility of science contents and to apply statistical methods to investigate the impact of 'pay-wall' to the access of scientific journals.

3) Measuring polarisation and polarisation imaging
An experimental project to use a polarimeter and continue the work on the determination of sugar contents in solutions. There is also a possibility to explore the application of a polarimetric microscope for the study of novel materials/biological systems.

John Proctor (Experimental and computational)

I like to squash things. You can listen to me talking about my work on youtube here. At the time of writing I have already agreed to take on 2 project students so I only have one project left to offer. It follows on from our recent work in which we developed a method to directly measure the equation of state (density versus pressure) of hot fluids in the diamond anvil high pressure cell for the first time. The work (that took place over the course of several undergraduate projects) has just been published in Physics of Fluids, and can be conveniently accessed here.

To calculate the density of the fluids it was necessary to measure the refractive index of the fluid, and this is very difficult to measure in the diamond anvil high pressure cell - for fluids or solids. It therefore seems like a good idea to adapt our experimental method to do something different: Determine the refractive index of (transparent) solids at high pressure. The density of transparent solids at extreme pressures is generally known (it can be measured very accurately using synchrotron X-ray diffraction) so we can use this (along with our new experimental method) to make far more accurate measurements of the refractive index of transparent solids at extreme pressure than has hitherto been possible. You probably won't need to do any experiments as part of this project as we already have *masses* of data for you to use. You would need to do analysis, calculations and hopefully write a paper about this work.

Dan J Bull (Experimental, Computational)

Dan offers computational modelling projects. Some example areas related to his research are below; he is happy to discuss other ideas.

Integrated Energy Conversion and Storage Systems

The use of renewable energy conversion systems, such as wind turbines and photovoltaic cells, is likely to increase significantly in the coming years. For this to be viable, efficient systems for storing excess energy are needed. This project will use existing models for the characteristics of energy conversion and storage devices such as photovoltaic cells, batteries and hydrogen fuel cells to simulate integrated energy systems. The aim is to produce dynamic models of energy generation and consumption, involving input data, such as hourly solar irradiance, and output data, such as typical domestic consumption.

Lattice Boltzmann Simulations

Lattice Boltzmann simulations are used for modelling fluids on the mesoscopic scale, sitting between atomistic simulations - which are limited to the number of atoms that can be modelled, and continuum models – which are not able to capture details on the microscopic scale. Outside of scientific research, they are routinely used in CGI animation of fluids, due to its computational efficiency. This project will examine the interaction of fluids with solid interfaces using a variety of Lattice Boltzmann algorithms. For some animations of lattice Boltzmann simulations, see: https://pylbm.readthedocs.io/en/latest/gallery.html#

Monte Carlo Simulation of Diffraction

The McStass software was developed to aid in the designing of new diffractometers and spectrometers for neutron scattering. It uses a ray-tracing method, whereby the initial trajectory of a neutron is selected at random and then it is followed through the simulated instrumentation. This is then repeated a large number of times to build up the simulation. This project will investigate the effect of various diffractometers on the diffraction patters obtained from hydrogen and deuterium in palladium, but can be extended to look at other systems of interest.

Thermodynamics of Hydrogen Isotopes in Palladium

Palladium can absorb large quantities of hydrogen gas without fracturing due to the lattice expansion. This makes it ideal as a membrane for hydrogen purification. In addition, the thermodynamics of the three hydrogen isotopes, protium, deuterium and tritium, in palladium are significantly different. This offers a route to isotope separation; this method is already employed for tritium recovery for experimental fusion reactors. This project will look at developing models to determine the fraction of the different isotopes that are present in a gas following absorption and desorption from palladium as a function of pressure and temperature.

James M. Christian (Mathematical, Computational)

The projects below are offered to students on both the Physics and Mathematics BSc programmes. Projects on nonlinear waves and electromagnetics are complemented by the *Photonics & Nanotechnology* module, while key background for dynamical systems projects is covered in the computing pathway of *Physics Laboratory 3*. Feel free to email j.christian@salford.ac.uk to enquire about specifics.

NONLINEAR WAVES: ***Vector solitons beyond slowly-varying envelopes***

Solitons are robust self-localizing waves that can emerge whenever linear spreading effects (e.g., group-velocity dispersion) are opposed by system nonlinearity. This project will build upon recent work addressing spatiotemporal vector *cnoidal waves*, extending the analysis to vector *solitons*. The two governing partial differential equations are fully second-order in both space and time coordinates, and they are coupled by cross-phase modulation terms whose origin lies in the Kerr effect. The project could be predominantly mathematical (e.g., deriving new vector soliton families before exploring solution hierarchies and their interconnectedness) or predominantly computational (e.g., deriving and implementing vectorized numerical algorithms to solve a range of perturbed initial-value problems).
See also: www.youtube.com/watch?v=R0cK3YcV7Fs

NONLINEAR WAVES: ***Solitons of the Ablowitz-Ladik equation***

The Ablowitz-Ladik (AL) equation models a periodic lattice comprising an infinite number of discrete channels. The (complex) wave amplitude in each channel is coupled to those in its nearest-neighbours both linearly and nonlinearly. The first part of the project will focus on using ansatz methods to derive families of bright and dark discrete solitons (robust self-localizing waves that travel on a periodic nonlinear lattice). The second part will explore soliton stability using computation to solve sets of perturbed initial-value problems. Later stages of the project could consider various generalizations of the AL equation, capturing more sophisticated nonlinearities or an augmentation of the $i\mathrm{d}/\mathrm{d}z$ operator in order to formulate a more complete (i.e., nonparaxial) description of discrete diffraction.
See also: link to SIAM talk by T Moorcroft.

ELECTROMAGNETICS: ***Scattering of electromagnetic waves by fractal screens***

The scattering of plane waves by apertures in a thin screen is a fundamental problem in acoustics and electromagnetics. This project will involve learning about some mathematical techniques for computing such diffraction patterns. Some of the most widely-used tools are Fourier transforms and Fresnel integrals. The divergence theorem can also be deployed to convert the integration over a constituent aperture domain into a circulation around its boundary. The far field is well-described by Fourier decomposition but, closer to the screen, Fresnel integrals are required. The focus will be on calculating diffraction patterns for pre-fractal iterates of the Apollonian (or curvilinear-Sierpinski) gasket and/or the circle-triangle gasket. To date, these types of screens have not been considered.
See also: www.youtube.com/watch?v=fhldT0cvfEg

DYNAMICAL SYSTEMS: ***Fractal sets and symmetries on*** $\mathbb{C}$

Julia sets are fundamental elements in the study of nonlinear maps on the complex plane $\mathbb{C}$. They are nearly always fractal in nature and play a central role as boundaries between Fatou domains. This project will deploy some set theoretic ideas alongside symbolic and numerical computation with the objective of understanding dynamics in two-dimensional maps (e.g., those from root-finding algorithms on $\mathbb{C}$). Topics to explore include instabilities, convergence, connectedness, periodic points

and escape points, Fatou sets, and the Wada property. At the heart of such maps lies the phenomenon of (low-dimensional) chaos: long-term solutions can be extremely sensitive to fluctuations in the initial conditions, appearing to behave unpredictably despite being governed by purely deterministic rules.
See also: www.youtube.com/watch?v=v-du-KjqniE

DYNAMICAL SYSTEMS: ***Chaotic scattering and fractal sets***
Point particles colliding with three hard-edged circular discs placed on the vertices on an equilateral triangle scatter elastically. This arrangement, known as the Gaspard-Rice (GR) problem, might be thought of as an abstract game of pinball. The GR problem can also be generalized to ballistic scattering from hard spheres in three-dimensional space, and those considerations are the main focus of this (predominantly computational) project. Its objective is to further develop an existing ray-tracing code for predicting scattering from polyhedral structures. The fractal character of the exit basin boundaries is of particular interest since published works on this topic are not entirely satisfactory. A key objective is to estimate the entropy and dimension of these boundaries.
See also: www.youtube.com/watch?v=umZaYWv14ao

DYNAMICAL SYSTEMS: ***Analysis and simulation of the double pendulum***
This project will investigate the double pendulum. The derivation of the equations of motion requires a somewhat involved application of Lagrangian dynamics but, beyond that, most of the investigation must be carried out computationally. Research last year added velocity-dependent damping and external periodic forcing, which gives the double pendulum even richer dynamics including the possibility of dissipative (rather than Hamiltonian) chaos. Possible topics to address include: (i) finding the linear eigenmodes of the double pendulum (and perhaps generalizing to capture the triple pendulum), (ii) deploying a symplectic integrator to solve the equations of motion prescribing free oscillations, and (iii) studying different attractors and bifurcations in the full driven-damped system.
See also: www.youtube.com/watch?v=eMQ6D8gcb-M

DYNAMICAL SYSTEMS: ***Dissipative chaos in the extensible pendulum***
The classic mass-on-a-spring problem is an extremely complicated Hamiltonian system when motion in the vertical plane is ascribed two degrees of freedom. Even when the spring is Hookian (i.e., linear), the equations of motion turn out to be highly nonlinear—the spring mode (‘up-down’ bounce) couples geometrically to the pendulum mode (‘side-to-side’ swing) and the phase space is now $\mathbb{R}^4$ rather than the much simpler $\mathbb{R}^2$. This project will build on research from last year, where velocity-dependent damping and external periodic forcing were included. Possible aspects to be addressed this year include: (i) quasiperiodicity as a route to (dissipative) chaos, (ii) limit cycles and strange attractors, (iii) exploring bifurcation structures, and (iv) replacing the Hookian spring with a non-Hookian response.

Mark Hughes (Experimental, Computational)

Project students will be actively involved in my current research projects and will work with my research team, which includes PhD students and post-doctoral researchers. Projects students are encouraged to produce publishable work and work closely with my industrial collaborators.

Experimental

Quantum technologies based on erbium implanted silicon

I am aiming to develop the building blocks of quantum computers and quantum communication systems using erbium implanted silicon. I have a number of projects related to this looking at electrical, magnetic and optical measurement of some unique materials that I have fabricated.
Some of this work has been published recently.

https://www.nature.com/articles/s41598-019-55246-z

Fabrication and characterization of non-volatile memory devices

Using the incredible ability of a family of materials known as chalcogenide glasses to allow the diffusion of metal ions through them, we have demonstrated a new type of metallization cell memory device based on the formation and breaking of nanoscale metal filaments through a chalcogenide thin film. Work done by a previous project student was published in a prestigious journal where we demonstrated the fasted know chalcogenide metallization cell memory devices, which could one day replace RAM and hard drives.

https://iopscience.iop.org/article/10.1088/1361-6528/aac483

Solid-state electrolytes for lithium ion batteries

The ability of chalcogenides to allow the diffusion of metal ions through them could also be exploited in Li ion batteries, which currently use a flammable liquid electrolyte. A solid-state electrolyte would massively increase the safety and energy density of Li ion batteries. John B Goodenough, the Nobel prize winning inventor of Li ion batteries, is working on a related idea.

https://news.utexas.edu/2017/02/28/goodenough-introduces-new-battery-technology/

Ion implanted chalcogenide thin films

Chalcogenide glasses are important for optical device application such as optical switches, but until recently they only existed as p-type semiconductors. I have demonstrated the ability to switch chalcogenides to n-type using ion implantation. This could lead to the development of ultra-fast optical computers. I have a number of projects related to this looking at electrical, and optical measurement of ion implanted chalcogenide thin films.

https://www.extremetech.com/extreme/193794-new-phase-change-material-lights-the-way-to-all-optical-super-fast-computing

https://www.nature.com/articles/ncomms6346

Photolithography technology development

Photolithography is the technology used by the likes of Intel to fabricate microchips. We have a basic photolithography setup in Salford, and I have a project looking at optimising the processing parameters for photolithography of experimental integrated circuits.

Origin of the optical centre in bismuth doped glasses

Bismuth doped glasses produce broad luminescence covering the entire telecommunications window (the wavelengths of light sent down optical fibre). An efficient Bi doped glass optical amplifier could massively increase internet speeds; however, the origin of the luminesce is still under debate despite extensive research, and this has hindered the development of high-performance optical devices. I have spent most of my research career trying to solve this problem. I have a number of projects involving optical measurements Bi doped glasses to help solve this problem.

https://www.osapublishing.org/oe/abstract.cfm?uri=oe-21-7-8101

Carbon nanotube optoelectronic devices

Carbon nanotubes CNTs are one dimensional crystals that can be used to fabricate electronic devices such as transistors. If used to fabricate integrated circuit, CNT electronics could switch significantly faster than silicon based integrated circuits. I have a few thousand CNT based field effect transistors and diodes that can be measured for a research project.

https://aip.scitation.org/doi/full/10.1063/1.4823602

Hall Instrument development to measure electrical properties of thin films

The Hall effect is used to determine the carrier concentration, resistivity and mobility of carriers within conductive thin films. Data accuracy and size of sample which can used depend mainly on the sample holder. This project will assess the present equipment and look at developing the sample holder.

Computational

Quantum computer programming

Large scale quantum computers, once demonstrated, will be almost unimaginably faster at solving certain types of problem than todays computers. The ability to program quantum computers is currently a rare skill, that will likely be highly sought after in the future. This project will use access to IBM's rudimentary quantum computers via the IBM q-experience portal. The project student will learn the basics of quantum computer programming and will run experimental code on real quantum computers.

https://quantum-computing.ibm.com/

Crystal field analysis of rare-earth spectra

The interaction of a rare-earth ion with its environment produces a complex splitting of energy levels that can be observed spectroscopically and used to determine symmetry, structure and energy transfer mechanisms. This has applications in photonics and quantum technology.

https://www.nature.com/articles/s41598-019-55246-z

https://www.osapublishing.org/oe/abstract.cfm?uri=oe-22-24-29292

Ian Morrison (Theoretical, Computational, Experimental)

Ian offers a range of both theoretical and practical projects and is happy to discuss your ideas.

Ab-Initio simulation of materials

These are computer simulation based projects that use existing software packages that solve quantum mechanical equations (with a denicity functional framework) using high performance computing to predict the structural, electronic and dynamical properties of molecules and solids. Predictions can be used to both interpret experiments and in the in silico design of new materials. Examples of systems of interest include:

- hydrogen storage materials: materials that will absorb and desorb hydrogen under ambient conditions that can be used for the safe storage of hydrogen in cars.
- Thermoelectric Materials: Materials with high electrical conductivity and low thermal conductivity – can be used to generate electricity from heat or provide cooling.
- Materials under high pressure: computer simulation allows the exploration of material properties at pressures that are difficult to achieve experimentally – examples include phase transitions in ice and silica under high pressures.

Computer Simulation

These projects involve the development of computer programmes to implement numerical methods and simple models to simulate and predict the behaviour of a diverse range of systems. Students will gain experience of software design through the project. Examples include:

- Traffic Simulation – application of simple models to simulate and investigate the onset of traffic jams.
- Monte-Carlo simulation of lattice based phase transitions, diffusion and pattern formation in atomistic systems.
- Simulation of Chaotic Systems – the computer simulation of chaotic systems including mechanical and chemical systems (can be combined with the building of real demonstration systems).
- Voice Recognition – the exploration of algorithms to compare recorded words and phrases against an audio dictionary.

Practical Computer measurement and control:

Projects will be practical in nature and use automated computer measurement and control as part of a design and construct project. Skills needed will be a combination of experimental design and construction, basic electronics and computer interfacing. Examples include:

- Practical Chaos – design and build of a mechanical system that will exhibit the onset of chaotic motion. Can be combined with aspects of computer simulation and theory.
- The Inverted Pendulum – design and build of a system to maintain a pendulum in its inverted position (an unstable equilibrium) through feedback control. Can be extended to a double pendulum.

Radio Astronomy – practical projects designing and making systems that will detect extra-terrestrial sources of radiation and monitor such radiation over a period of time. Projects will involve practical system design and electronics. Examples include:

- Radio Jove – the use of dipole antennae to directly detect em radiation emitted from Jupiter and its moons.
- Direct and indirect measurement of solar activity – using either dish based direct detection or antennae based indirect detection of solar flares.

Graham McDonald

Graham offers a range of projects outlined below.

- **Simple Global Population Models**

The rate of global human population growth was once described as an explosive, run-away effect. In the last century, this description has started to break down - as overall growth rates have slowed. Traditionally, modelling has involved accounting for countless unknowns - leading to uncertain predictions. But, can simple models actually capture the overall trends? This project proposes theoretical work to develop and test simple models for historical and more recent global human population figures. It could involve attempting to capture the interplay between global human population and a potentially new, emergent variable labelled as 'information' (which now may have been established through 'globalism'). The nature of 'information' would include the combined effects of factors (such as technology, knowledge, communications and social & medical advances) on the global growth rate.

- **Classes of Propagation-Invariant Beams**

Beams are typically transversely localised patterns that map out a 'pencil-like' shape as they evolve along a longitudinal coordinate. With wave-based beams (such as optical, acoustic or matter waves), this pencil-like shape is expected to be subject to transverse broadening due to the fundamental process of diffraction. This project proposes to review, study, analyse and simulate different classes of beam that can locally maintain (or periodically repeat) their transverse features. Such special beam patterns are often termed as 'propagation invariant', allowing pattern features (such as an intense central peak) to be transmitted over much longer distances, when compared to conventional beam shapes. Limitations to such 'propagation invariance' arising from finite-width effects can also be investigated in each case.

- **FPU Problems (chains, NLS, NLH, KdV)**

Back in 1953, Fermi, Pasta, Ulam, and Tsingou (FPUT) conducted what were considered as the first 'numerical experiments' - to complement and to extend what was known from existing mathematical analyses and practical experiments. Their numerical investigations centred around considering a section of periodic lattice (such as in solid state physics) where there is a nonlinear contribution to nearest-neighbour coupling - the 'FPU problem' or 'FPUT problem'. Their findings were surprising and have stimulated much further mathematical analyses, practical experiments and numerical simulations in the decades since. This project proposes to re-trace their earlier calculations and findings, and then to extend such considerations to, for example, other model types and different classes of starting points (initial value problems). In additional to being a mainly computational project, there is the possibility of working through some classic mathematical calculations that have been associated with this subject area.

- **Paraxial and Helmholtz Kerr solitons and vortices**

This project area is a direct extension of the concluding sections of the third year, semester one, Photonics and Nanotechnology course - where the subject of self-stabilising (non-spreading), localised wavepackets called 'solitons' is introduced. The essence of their existence is that, instead of the usual (linear) dispersive spreading of wavepackets, materials can exhibit a (nonlinear) lensing effect that may attain a stable/balancing equilibrium point with respect to linear dispersion. There is a wide and open-ended scope for potential study within this project area, and so the project will focus on one of the simplest types of (dispersive) nonlinearity – the Kerr effect. In the Kerr effect, nonlinear lensing arises as a contribution to the refractive index that is proportional to the intensity of the wavepacket. Investigations can involve the propagation of different types of bell-shaped solitons, interactions of solitons (and what determines the strength of their interactions), perturbations to solitons and their robustness to different additional effects, the stability and quantification of the refraction of solitons (as they encounter an interface, such as a boundary between different regions of linear refractive index), and what effects might arise when the Kerr nonlinearity is non-local (able to diffuse across the profiles of the solitons involved). There is also scope to consider so-called 'dark solitons', whose profile presents a dip in a higher-intensity background, and the extension of this idea to vortices.