Project Examples 2025/26

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 0.00000000000001 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. The projects I can offer this year follow on from our recent work in which we developed a method to directly measure the equation of state (EOS) (density versus pressure and temperature) 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, can be conveniently accessed here, and was featured in New Scientist. Proposed projects:

1) Performing accurate EOS measurements on methane under planetary interior conditions (up to 200°c, 10 GPa) for the first time (experimental).
2) Same for water (but with more of a focus on the optical properties - dispersion in the refractive index etc.) (experimental)
3) Examining the effect of systematic errors in the experimental data on the resulting EOS by generating synthetic data and running it through the iterative fitting procedure outlined in the publication linked above. (computational)

Dan Bull (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.

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. Feel free to email j.christian@salford.ac.uk to enquire about specifics. Further details on research can be found on my ORCID page.

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 $i\text{d}/\text{d}z$ operator in order to formulate a more complete (i.e., nonparaxial) description of discrete diffraction.
See also: link to SIAM talk by T Moorcroft.

NONLINEAR WAVES: ***Counterpropagating waves in the Salerno equation***
The analysis of counterpropagating waves in nonlinear systems is a difficult problem but one that is of fundamental physical importance (e.g., in optics). While classic analyses have focused on slabs of Kerr material, a more recent context has addressed discrete diffraction in periodic waveguide arrays. This latter system is typically modelled by discrete nonlinear Schrödinger (dNLS) equations. The counterpropagation project this year will build on recently established mathematical results, namely the derivation of the threshold instability spectrum for counterpropagating waves whose interaction is modelled by Ablowitz-Ladik (AL) equations. Here, attention will be paid to counterpropagation captured by Salerno equations. Such an approach provides an interpolation between the local and nonlocal nonlinearities as prescribed by dNLS and AL models, respectively.
See also: link to SIAM talk by T Moorcroft.

ELECTROMAGNETICS: ***Scattering of electromagnetic waves by fractal screens***
The scattering of waves by apertures in a plane 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 an 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

ELECTROMAGNETICS: ***Boundary integral equations in electromagnetic scattering***
Scattering in electromagnetics is typically a boundary-value problem and it is always difficult (usually impossible) to solve exactly. Computation is inevitably required at some stage, especially when the scattering set has a complicated shape or ‘rough’ substructure. This project will involve learning how to: (i) formulate boundary integral equations, and (ii) discretize constituent boundaries so that the problem can be solved numerically. The boundary element method (BEM) is a cousin of the more famous finite element method (FEM) and it offers several key advantages. The perfectly-conducting circular cylinder will provide a testbed, with subsequent development of the analysis and code to other axisymmetric scatterers (e.g., with elliptical cross-sections or screens based on the Cantor set).

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. Topics to explore include instabilities, the structure of asymptotic-stability domains in parameter space, convergence, connectedness, periodic points and escape points, Fatou sets, the Wada property, and entropy. 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 randomly 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 of 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 the exit basins and their boundaries.

See also: www.youtube.com/watch?v=umZaYWv14ao

DYNAMICAL SYSTEMS: ***Analysis and simulations of the double pendulum***

The double pendulum is a mechanical system whose free oscillations are famously known to exhibit chaos (that is, sensitive dependence on initial conditions in combination with a bounded phase space). Last year, research added velocity-dependent damping and external periodic forcing in the vertical direction. Such a regime gives the double pendulum even richer dynamics, including the possibility of dissipative (rather than Hamiltonian) chaos. This project will continue from last year, building on recent new results. Possible topics to address include: (i) finding the linear eigenmodes of the driven-damped double pendulum (with applications of 4×4 matrix exponentiation), and (ii) investigating resonance phenomena and the ensuing nonlinear dynamics when external forcing is at normal-mode frequencies.

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 Hookean in nature (i.e., characterized by a linear response), the equations of motion turn out to be highly nonlinear—the spring mode ('up-down' motion) couples geometrically to the pendulum mode ('side-to-side' motion) and the phase space is now $\mathbb{R}^4$ rather than the much simpler $\mathbb{R}^2$. This project will build on research from the previous two years, where velocity-dependent damping and external periodic forcing were included and the phase space becomes $\mathbb{R}^4 \times S^1$. The next steps in the extensible-pendulum research will comprise two distinct topics:

> **Project 1:** analysing dynamics in the presence of a fully nonlinear response, where the restoring force F in the presence of a length change δl is modelled by $F = -k_1\delta l - k_3\delta l^3$.
>
> **Project 2:** dual periodic forcing at pairwise resonant frequencies (e.g., when the suspension point follows a parabolic arc).

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 density 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.

Machine Learning for Materials Prediction

Projects will explore both the use both the use of machine learning to describe atomistic interactions to facilitate large scale simulations of materials properties as well as the use of AI techniques to predict materials properties from data bases of first principles predictions.

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).

Practical design, build and demonstrate projects

Projects will incorporate design and construction of a physics-based demonstration system. Projects will typically incorporate 3D CAD design, electronics and sensors and computer control. Some specific 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.

- Design and build of a cloud chamber for the detection of cosmic rays.
- Design and build of a diploe antennae system for the detection of EM eradiation emitted by Jupiter's moons.
- Design and build of microwave antenna system for the detection of solar flares or meteors.

Graham McDonald (Theoretical and Computational)

This year I am completely changing my suggestions and focusing down **to just three new project areas** - each of which I personally plan to make progress on this year. Each of the (first) **two 'Academic Research' topics** has strong novelty (e.g. featuring on-going, unpublished work) and where there are a lot of theory calculations ready to be checked. This should provide a well-informed and well-documented platform to make a good, early and thorough start to your project. There are also plenty of planned theoretical and numerical further avenues of investigation - meaning that there will be no shortage of ideas for developments within the project duration. Finally, as I personally intend to have these three works swiftly progressed, there will also be no shortage of supervisor review, input and participation in the project developments. It is difficult for a student to make full-researched, impactful and novel contribution to real research areas unless the work is undertaken in a collaborative fashion with an experienced researcher. This is the proposed context for these investigations - with a focused aim on facilitating and delivering substantial project works.

I am classifying the **third project area as 'Educational Research and Professional Development'**. As the world and workplaces rapidly evolve with the introduction of AI systems, how should physics education evolve to embrace the usage and teaching of new smarter (?) tools, exactly what should be taught in future physics degrees, and what experiences and expertise might future employers expect from physics graduates? This new project area makes a novel start to attempt to answer all of these important questions. After completion of this project, the student involved is expected to have gained and documented new insights into the applications of AI in physics teaching and in physics problem-solving. This latter component is the aspect of 'Professional Development' – hopefully including skill developments that almost no other physics undergraduates have to date either explored or have been taught.

1. <u>Academic Research</u>. "Detuning in Broadband Nonlinear Optics"

Some time ago, I was leading in the field of introducing the possibilities of (ultra-broad bandwidth) multi-frequency laser beams. The broadband beams have subsequently featured in very many experimental and application contexts. The key enabling mechanism for the generation of such beams is launching two beams of different frequency into a 'nonlinear medium'. In linear systems, light tends to remain at precisely the same frequency, but nonlinear media are of a character that is changed by the incident light. These medium changes can then also change the light beams which, in turn, can further change the medium, etc. - a nonlinear ('feedback') loop. This type of responsive medium character includes possibilities of generating new light frequencies as light beams progress through the medium. It is often considered that the two input light beams should optimally have a frequency difference that exactly matches a material transition frequency (such as an electronic transition frequency or the frequency spacing between two rotational or vibrational modes of the molecules).

This project returns to the fundamental (dimensionless) equations governing such interactions of light and media and investigates the role of 'detuning' the frequency difference of the two input beams slightly away from exact resonance with the medium characteristic. Both substantial theoretical and computational explorations are involved. Further extended considerations are also possible and these include examining the same detuning effects for media that are placed within a resonator (such as a ring cavity).

2. Academic Research. "3D-Space Helmholtz Modes"

Beams or pulses of light naturally tend to widen due to fundamental processes (diffraction or dispersion, respectively). In nonlinear media, the way that the medium responds to the light can effectively create a lensing property that can balance such fundamental widening processes. This gives rise to a now well-known and widespread phenomenon in nonlinear science called (spatial or temporal) 'solitons'. These beams or pulses can sustain the balance between widening and focusing to create wave packets that travel without any spreading (they are shaped-preserving 'modes'). Such non-spreading wave packets have innate appeal as 'information bits' - as they may preserve their character as they progress, or are processed, within novel all-optical IT architectures. The all-optical IT context has obvious advantages in terms of much higher potential speeds of information transfer or information processing.

Some of my own contributions in this area included the first proposals and designs for spatial soliton optical memory and processing systems. To allow for the angular multiplexing of such soliton beams (or 'bits'), I later extended the theoretical framework of spatial solitons to models and exact solutions that permit the soliton beams to travel at significant angles with respect to a single reference direction. I named this new class of solitons as "Helmholtz Solitons", as their governing equations were nonlinear Helmholtz equations (rather than nonlinear Schrodinger equations). A key constraint of optical solitons is that the solutions strictly assume that the light is confined within an essentially 2D environment (such as pulses constrained to travel in optical fibres or beams in similarly restrictive 2D waveguide environments). Even the published Helmholtz solitons solutions are still basically 2D solutions. This project has had substantial (unpublished) groundwork undertaken and is the subject of a current collaboration with co-workers in Mexico. The theme is to extend our analytical Helmholtz soliton solutions to consider their counterparts as modes in full 3D-space. There are different types of solitons and different types of media for which we have already published solutions and related numerical investigations involving extended studies. There is thus a very rich and diverse platform of 2D results that we have, and each of these can be considered within a systematic theoretical and computational exploration of generalising their 2D context to full 3D space.

3. Educational Research and Professional Development. "Formative Introduction of AI Tools in STEM Teaching"

What AI tools should be introduced into the teaching of a physics degree?
How can such tools be introduced into university physics courses?
What new working methods and methodologies arise from their introduction?
How does one keep up with rapid developments in the world of AI technologies?
What are the expectations of future employers regarding the AI experiences and skills of graduates?

All these questions are actually related, and this novel project area attempts to explore and document some of the answers. Under examination are: methodologies, efficiencies, limitations and potential inaccuracies of AI tools, with an emphasis on the importance of verification and critical assessment of AI-generated content.

A proposed starting point is to use AI engines themselves to generate 'formative' assignments for students, suggesting a wide range of specifically named AI tools, to solve and explore slightly more demanding problems on specific topics (using the lecturers' presentations as inputs, and thus involving the same methods and notations as used in the topic introduction). Such assessments are termed 'formative' as they would not form part of officially assessed work, but such assignments could feasibly be introduced into various courses in the following academic year (as additional student development activities). Clearly, the suitability of the AI-created assessment has firstly to be critically examined, and the proposed 'ideal solution' given by that particular AI engine. Then, a 'solution journal' can be compiled to document the further findings and experiences when following through the instructions with the various suggested AI tools. The project work could also continue with exploring the wider scope of AI usage within educational environments.