Project Examples 2022/23

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 medical, geological, biological, archaeological physics etc. then it may be possible to organise a project with experts from other schools within the university.

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)

Marina offers a range of projects related to her research interests, which focuses on exploiting experimental physics to understand and develop novel photovoltaic and spintronic materials.

Proposed projects for this academic year are:

- ***Understanding the efficiency limits of light emitting semiconductor materials and nanostructures***
- ***Optical properties of light harvesting solar cell materials***
- ***Optical properties of spintronic materials***

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.

Dr Heather Yates (Experimental)

Heather offers projects relating to the Chemical Vapour Deposition (CVD) of various oxides and metals. These include the materials characterisation (optical, electrical and morphological) of CVD produced thin films to give 'added value' in the form of photoactive, biocidal, conducting or optical anti-reflection behaviour.

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.

Infection control via CVD
Controlling the spread of infection is of particular interest. Use of thin layers of bacteria killing materials on high use surfaces such as door plates or touch screens would help reduce microbial transmission. This topic could involve characterisation of these surfaces, working with microbiologists or testing the accelerated effects of standard cleaning reagents on the anti-microbial surfaces.

Study of thin film surface energies
Use contact angle measurements to study the effects of UV light, cleaning procedures and material type on the surface energies of thin films. A study of hydrophobic and hydrophilic behaviour. Alternatively, compare and contrast the methods for calculation of 'contact angle'.

Study weathering in thin films
Thin films are used in many outdoor applications so their resistance to the effects of weathering are highly important. Explore effects of weathering on physical, electrical and optical properties of thin films.

Spectrophotometry of thin films
Measure optical properties and then fit theoretical curves to model the thickness and refractive index of thin films. Alternatively, study effect of thickness, film chemistry, substrate type and/or instrument parameters on optical properties.

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) The effects on polarisation of light from optical components.
The boundary conditions of the Maxwell's equations determine any possible changes in the state of polarisation of light at the surfaces of optical components. The project is to build a numerical model to study the effects on the polarisation states when light traverses through optical components in an optical imaging system.

John Proctor (Experimental)

John offers a range of experimental projects and one theoretical project related to my research interest of high pressure; use of high pressure (often combined with high temperature) to recreate the conditions inside the interiors of the planets and investigate the nature of the liquid and supercritical fluid states of matter. He can also offer electronics projects where you get to build an electronic circuit of your choice (decided in consultation with him). In the past people have built a single sideband radio transmitter and receiver, a seismometer, a circuit to monitor a shadow tank for shrimp movement and many other varied and interesting circuits.

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 Christian (Theoretical, Computational)

Dr. Christian's research interests include various areas of theoretical physics (complex domains, mathematical fluid dynamics, spontaneous pattern formation, and nonlinear waves). For further details, see

https://orcid.org/0000-0003-2742-0569

This year, he will be offering projects mainly in the field of **dynamical systems** following various topics that appear in the *computing pathway* of the new module Physics Laboratory 3. Topics will include the double pendulum (with its generalization to three and more oscillators), the extensible pendulum (with the inclusion of parametric forcing), the magnetic pendulum (testing for fractality in basin boundaries and quantifying entropies), chaotic scattering in 2D and 3D, generalizations of Newton-Raphson fractals (with numerical estimations of uncertainty dimension), and the analysis of nonlinear-oscillator equations (e.g., with Poincaré-Lindstedt perturbation theory and the Krylov and Bogoluibov method of averaging). Email j.christian@salford.ac.uk to enquire about specifics.

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

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: BSc Project Areas Only

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.

- **Video Feedback Modelling (modelling & experimentation)**

In its simplest form, video feedback consists of pointing a video camera at its output – hence creating a feedback loop. Video feedback systems present a table-top model for pattern formation in a wide class of Nature's system (such as in biology, chemistry, geology, etc). They also represent a particular class of optical system; at difference with most of our own studies of optical pattern formation (that involve coherent waves in laser-driven nonlinear systems), video feedback is typically an incoherent process. So, it is the intensity of the light that matters rather than both its intensity and phase. A further interesting feature of video feedback systems is that they can generate patterns either when the feedback loop is entirely linear or when there is nonlinearity in the feedback loop (such as contrast control in the image reproduction electronics). This project aims to model video feedback systems, and to potentially include also those modified by the introduction of one or more mirrors. Modelling investigations may involve various approaches (from pixel-mappings, accounting for image discretisation effects, to the solution of evolution equations) – in an attempt to understand existing and new video feedback systems, and potentially also other complex physical systems. Effects such as magnification, rotation, nonlinearity, and mirror boundary conditions can be investigated. Comparison of theory results with experimental video feedback patterns would be advantageous.

- **Multi-Frequency Raman Effects**

In linear physical systems, waves (such as light) do not change their frequency. In nonlinear systems, the governing equations contain terms involving the local wave amplitude to a power other than one. Consequently, nonlinear systems permit energy to be converted into new frequencies. Such systems can represent a variety of different nonlinear processes (each represented by specific nonlinear terms in the governing differential equations). One class of nonlinear terms (i.e. physical processes) is called 'the Raman effect'. In our earlier work, we established that Raman generation of new frequencies can be extreme in some systems. We found that certain laser system designs will not only output one or two new frequencies but can give rise to *cascade new frequency generation*. And, that this can lead to a massive range of simultaneous optical frequencies, whose total frequency range can be as wide as the entire visible spectrum - or even broader than this. This project proposes to investigative simulations of such broadband multi-frequency generation. There are many contexts that can be considered - such as single pass, multi-pass in cavities, fast media/transiency, multiple pump pulse sequences, and the roles of variation of specific physical effects such as dispersion and detuning. At its most adventurous, this project could be extended to consider new classes of multi-frequency micro-resonators that are currently being developed. As the overall context is rather complex, the investigations here are expected to be mostly computational.

- **Gain Suppression in Parametric Frequency Generation**

Nonlinear systems can entail a variety of different types of processes that generate new output frequencies. This project considers the analysis and simulation of a generic class of so-called 'parametric' nonlinear processes. One characteristic feature of such parametric processes is their high sensitivity to the phase of the interacting waves. The strength of the frequency conversion process is often expressed as an amount of gain, i.e. amplification, experienced at the new (lower frequency) 'Stokes' and (higher frequency) 'anti-Stokes' frequencies. This gain can, however, depend on a number of different factors. Indeed, in some circumstances, the gain can be completely suppressed and the conversion of light energy to the new frequencies can be completely halted. The analytical description of how much frequency conversion occurs, and the degree to which any suppression of the process arises, has stood unchanged as a classic result for many decades. However, we found that this standard description of gain (and its potential suppression) can give highly erroneous results in certain cases. We were able to trace this error to something that had been neglected in the original analysis. This allowed us to derive a much more accurate description of this important process. There are several contexts that this project can investigate, such as: 2-wave interactions, 3-wave interactions, many-wave interactions, and cavity contexts. The last case is where the process of parametric generation is enclosed in a cavity, and new frequencies generated are allowed to pass through the same nonlinear medium many times.

- **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.

EXTERNAL PROJECTS – We cannot guarantee that these will be available this year.

If interested in these types of project then in the first instance contact the member of Physics Staff listed**.**

You should be aware that if you decide to work outside of the physics group then it is important that, as a representative of physics, you act responsibly and follow the specific health and safety regulations that are pertinent to these organisations.

Richard Fitton – **Energy House** - Contact via Heather Yates

A number of projects relating to building physics are always available connected to work being undertaken in the energy house.

Victor P. Debattista UCLAN (Theory) see Graham McDonald

Galactic Modelling - Bulge formation

The bulges at the centres of galaxies often host supermassive blackholes (SMBHs), with masses as large as 10^9 M sun. The masses of SMBHs correlate with properties of bulges. Therefore, it is important to understand how bulges form in order to understand how they can control the SMBHs that form within them. Classical bulges are thought to form from the mergers of pre-galactic clumps. In this project the student will use simulations to explore how classical bulges evolve and how this impacts SMBHs. This project area is only suitable for a high-achieving student that has a good knowledge of computers and linux.

Health Faculty – Medical Physics – contact via Ian Morrison

Prof Laurence Kenney - Professor of Rehabilitation Technologies

Dr Katy Szczepura (medical Physicist) - Radiography