DEPARTMENT OF PHYSICS

Fourth Year Research Projects

2016/17

Table of Contents

Health and Safety

Undergraduate students need to undergo appropriate safety training for their projects. The University Occupational Health & Safety Arrangements state:

16.4 Supervision of Students

- Departments recognise that most undergraduate students are initially untrained in matters of health and safety, therefore, Academics will provide information, instruction, training and "such supervision as is necessary", for all aspects of coursework, to ensure, so far as is reasonably practicable, the health and safety of both postgraduate and undergraduate students;

- Coursework will cover, practical work, project work, fieldwork, work placements and any other aspect required of students by their courses;

- Departments will record the means of delivery of the health and safety programme for each course, each year;

- Academic Supervisors will determine the appropriate level of supervision, based on an assessment of risks of the research or teaching activity etc. and documented training received by students; Academic Supervisors will personally provide necessary supervision, unless others are identified by the relevant risk assessment.

An Undergraduate safety induction training record is required to be completed for each project student. Please ensure that the training is completed and the form returned to Shirley Wylie before the project work begins. (see Appendix 1)

With thanks,

Mr Ron Weston

Nanoscience Division

Spectroscopic Studies of Dye Aggregation

(1) Dr Jens U Sutter, (2) Prof David JS Birch

Project Description: The objective is to investigate the aggregation of fluorescent dye molecules on silica using excitation, fluorescence and absorption spectroscopy. In solution, where diffusion occurs aggregation of molecules is often difficult to study, but when deposited from solution on a nanoporous surface such as silica aggregation effects are enhanced. Possible effects include ground state dimer formation, excited dimer (excimer) formation, quenching of fluorescence, J-aggregates and H-aggregates. Dyes to be studied include xanthenes such as rhodamine 6G, fluorescein and aromatics such as pyrene and napthalene.

The objectives are to observe, characterise and explain the effects that will be observed. The instruments to be used include a Horiba SkinScan spectrometer for fluorescence and excitation spectral measurement, and a Perkin Elmer spectrophotometer for absorption measurement.

Skills to be learned include sample preparation, handling, the sol-gel process for making silica and spectroscopic techniques.

Key Reference:

Lakowicz JR. Principles of Fluorescence Spectroscopy. 3rd ed. New York: Springer; 2006.

Ratio of effort: Exp/Theo/Comp

Exp:	65 %
Theo:	25 %
Comp:	10 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Additional comments: The student will need a good foundation in laboratory based measurement techniques.

Safety Training Requirements: The Lecture 'Introduction to laboratory safety' provided by the Photophysics Group is compulsory before work with research equipment and chemicals can be undertaken.

Spectroscopic Studies of Melanin Fibrils; Spectra, Kinetics, Modulators

(1) Dr. Jens U Sutter, (2) Prof. David JS Birch

Project Description:

Based on recent research by the Photophysics Group an opportunity arises to conduct a research project characterising fluorescence from melanin fibrils. Melanin can form a multitude of different nano particles providing a range of functions in the human body and throughout virtually all things living. We are researching the formation of regular, ordered structuresin melanin synthesis. Initially the student will optimize conditions to synthesise melanin fibrils and will analyse the surface fluorescence of these melanin structures. Kinetic studies of absorption and emission will characterize the development of melanin fibrils over time.

In the second phase of the project the influence of external effectors - pH, ion concentration or temperature - on the final structure and the kinetic of melanin synthesis will be investigated. The project is part of the Photophysics Group's work to understand the formation of different melanin types in the human body and is linked to research into malignant melanoma and neurodegenerative diseases and to research noto the development of melanin as a bio-engineering tool.

Key Reference:

'Eumelanin Fibrils', R McQueenie, JU Sutter, JO Karolin & DJS Brich, J. Biomed. Opt. (2012) 17(7) 075001
'Metal ion influence on eumelanin fluorescence and structure'
JU Sutter & DJS Birch, Methods Appl. Fluoresc. (2014) 2 024005 8pp

Ratio of effort: Exp/Theo/Comp

Exp:	65 %
Theo:	25 %
Comp:	10 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Additional comments: The student will need a good foundation in laboratory based measurement techniques.

Safety Training Requirements: The Lecture 'Introduction to laboratory safety' provided by the Photophysics Group is compulsory before work with research equipment and chemicals can be undertaken.

Noble Metal Quantum Dots

(1) Dr. Yu Chen, (2) Dr. Olaf Rolinski

Project Description:

Nanoscale noble metal particles have unique properties different from bulk. Indeed, small metal nanoclusters of sizes comparable to the Fermi wavelength of electrons (ca. 0.7 nm), no longer possess metallic properties, but have molecule-like behaviour including size-dependent luminescence [1] and discrete electronic states [2]. Recent advances in this area have seen the development of a variety of syntheses that produced a new class of fluorescent noble-metal quantum dots such as Au and Ag nanoclusters [3]. These nanosized emitters have great potentials in biological imaging and sensing because of their small sizes, tunable optical properties and low toxicity. This project intends to develop protein encapsulated gold quantum dots and explore their applications in biological sensing using optical spectroscopies.

Key Reference:

J. Zheng, C. W. Zhang and R. M. Dickson, Phys. Rev. Lett. **93**, 077402 (2004).

S. Chen, R. S. Ingram, M. J. Hostetler, J. J. Pietron, R. W. Murray, T. G. Schaaff, J. T. Khoury, M. M. Alvarez and R. L. Whetten, Science **280**, 2098 (1998).

R. Jin, H. Qian, Z. Wu, Y. Zhu, M. Zhu. A. Mohanty and N. Garg, J. Phys. Chem. Lett. ***1****, 2903 (2010).*

Ratio of effort: Exp/Theo/Comp	Exp:	95%
	Theo:	5%
	Comp:	0%

Suitability: MPhys, BSc

Safety Training Requirements: laser safety

Pathological modifications in proteins detected by their intrinsic fluorescence

(1) Dr Olaf Rolinski , (2) Dr Yu Chen

Project Description:

Protein glycation consists on multiple modifications of proteins by carbohydrates. During glycation protein-carbohydrate reactions lead to formation of several intermediate forms, then, through different pathways, give rise to so called advanced glycation end-products (AGEs). AGEs may be involved in different forms of pathophysiology if the original function of the protein has been compromised. Despite broad implications of glycation in human health (it is related to disorders like diabetes, inflammation, neurodegenerative diseases and to human ageing), the formation of glycated proteins is poorly investigated.

In this project the methods of fluorescence spectroscopy will be applied to investigate the process of molecular-level glycations related to different diseases, e.g. complications of diabetes mellitus, cataract and skin ageing. The student will develop his/her skills in a number of research techniques used in Photophysics group: non-routine use of the up-to-date fluorescence instrumentation, modelling fluorescence kinetics in complex environment, numerical data analysis, and molecular medicine.

Key References:

1. K.Nomoto et al., Identification of advanced glycation endproducts derived fluorescence spectrum in vitro and human skin, Anti-Aging Medicine, **10**(5),92-100 (2013).
2. D.K.Karumanchi et al., Non-enzymatic glycation od alpha-crystallin as an invitro model for aging, diabetes and degenerative diseases, Amino Acids, **47**, 2601-2608 (2015).

Ratio of effort: Exp/Theo/Comp	Exp:	80%
	Theo:	10%
	Comp:	10%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Attending PH554 class in the second semester (fluorescence part) is recommended.

Additional comments: The student needs to enjoy the analytical aspect of physics experimentation.

Safety Training Requirements: The lecture “Introduction to laboratory safety” provided by the Photophysics Group in compulsory before the experimental part can be undertaken.

Calibration of Spatial Light Modulators for Adaptive Optics Microscopy

(1) Dr. Brian Patton , (2) TBC

Project Description:

Super-resolution microscopy won the Nobel prize in Chemistry in 2014 for allowing imaging of objects beyond the classical diffraction limit. We are performing research into adaptive optical technologies to improve the performance of planned super-resolution microscopes that will be contrasted and operated within the department.

Adaptive optics uses dynamically controlled components to correct for optical aberrations in an imaging system, restoring near-perfect performance. In the context of microscopy, it allows imaging deep into tissue, where the imhomogeneous refractive index causes problems for standard microscopes. The liquid-crystal spatial light modulator (SLM) is one class of device that finds widespread use in adaptive optics enhanced microscopy. However, in order to correctly incorporate the SLM into the design of the microscope, it is necessary to know its optical performance parameters such as the optical flatness of the device and the magnitude of optical-phase change induced by each pixel of the device. This project involves setting up an interferometric characterisation apparatus to evaluate the performance of a low-cost, but useful, SLM. The project will entail optics design, programming of some software to drive the SLM and analysis of the data derived from the setup.

Key References:

"Optimisation of a low cost SLM for diffraction efficiency and ghost order suppression", R. Bowman et al., DOI: 10.1140/epjst/e2011-01510-4
M. J. Booth, "Adaptive optical microscopy: the ongoing quest for a perfect image," Light Sci. Appl. 3, 165 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	40%
Theo:	20%
Comp:	40%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: Experience of programming is strongly advised, experience of optical design would be helpful but not essential. Some experience of data analysis with Matlab would also be beneficial.

Safety Training Requirements: Low power laser diodes will be required, so Laser Safety Training is essential.

Digital Light Projectors for Dynamically Reconfigurable Microscopy

(1) Dr. Brian Patton, (2) TBC

Project Description:

This project will contribute to the development of next generation super-resolution and dynamic optical microscopes within the department. Traditional wide-field microscopes use simple illumination configurations with their design being fixed by the imaging mode (brightfield, darkfield, phase contrast) to be performed. Switching imaging modes is typically not a trivial task and may even be impossible in some designs. Adaptive optics enhancement of the widefield microscope using dynamically reconfigurable devices such as deformable mirrors or spatial light modulators has typically only addressed the detection path of the microscope and has left the illumination path untouched. A recent paper has shown how the incorporation of a low-resolution liquid crystal display (LCD) into the illumination path greatly expands the usefulness of a given wide-field microscope.

This project aims to develop a testbed for these dynamically reconfigurable illumination systems. Instead of using an LCD, the project will use a digital light projector (DLP). The combination of higher pixel count and variable colour illumination will add to the possible parameter space in which improvements to the performance over a traditional microscope design can occur.

The project will initially involve some simple optical design and construction to build the testbed. The majority of the project will involve programming the DLP to generate the test patterns used in the different imaging modes and analysing the data generated by the imaging system.

Key References:

"Microscopy illumination engineering using a low-cost liquid crystal display", Kaikai Guo et al., DOI: 10.1364/BOE.6.000574

M. J. Booth, "Adaptive optical microscopy: the ongoing quest for a perfect image," Light Sci. Appl. 3, 165 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	40%
Theo:	20%
Comp:	40%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: Experience of programming is strongly advised, experience of optical design would be helpful but not essential. Some experience of data analysis with Matlab would also be beneficial.

Safety Training Requirements: Laser Safety Training is required due to the nature of the other work performed in the group.

Doping profile measurements in silicon p-n junctions via capacitance-voltage measurements

(1) Dr. Carol Trager-Cowan, (2) Dr. Paul Edwards

Project Description:

By measuring the capacitance of a p-n junction as a function of applied voltage it is possible to determine the doping profile through a device. Capacitance-voltage measurements will be used to characterise a series of silicon diode structures ranging from commercial silicon photodiodes to silicon p-i-n diodes used for electron detection.

Key References:

[1] Simon M. Sze and Ming-Kwei Lee, Semiconductor Devices: Physics and Technology, 3rd ed. Wiley, New Jersey (2012) (copy in the library)

[2] D. Schroder, Semiconductor Material and Device Characterization, 3rd ed. Wiley, New Jersey (2006) (available electronically through Suprimo)

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	20%
Comp:	10%

Suitability: MPhys, BSc, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *None*

Additional comments: *N/A*

Safety Training Requirements: *General laboratory safety*

Optical spectroscopy of distant sources

(1) Dr. Carol Trager-Cowan, (2) Dr. David McKee

Project Description:

Optical spectroscopy involves analysis of the spectral distribution of light emitted or absorbed by a material, and can be used in the analysis of material composition. Compared to other analytical techniques, one of the key advantages of optical spectroscopy is that it can be used to investigate materials without any need for direct contact. Examples of this include satellite remote sensing and astronomical spectroscopy of stars and nebulae. The availability of solid state detector systems has resulted in increasingly compact spectrometer systems that can be easily integrated into standard optical systems such as microscopes and telescopes. The aim of this project is to integrate a hyperspectral optical spectrometer into the optical train of an astronomical telescope and to use this system to obtain spectra from a range of terrestrial, atmospheric and astronomical targets. Lab work will include characterisation of the optical system and calibration of the spectrometer. Field observations will be planned using characterisation information for the telescope / spectrometer (e.g. resolution and sensitivity) to identify a list of increasingly challenging targets. The project requires strong instrumentation / experimental skills and some image processing and data analysis.

Key References:

[1] Ken M. Harrison, Astronomical Spectroscopy for Amateurs , Springer, New York, (2011) (available electronically through Suprimo)

[2] http://oceanoptics.com/wp-content/uploads/Spectroscopy-Introduction-and-Applications.pdf

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	10%
Comp:	20%

Suitability: MPhys, BSc, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *N/A*

Additional comments: *None*

Safety Training Requirements: *General lab safety*

Phosphorescence of glowstones™.

(1) Prof. K.P. O'Donnell (2) Dr. P.R. Edwards

Project Description:

Glowstones are luminescent plastic chips, resembling stone pebbles, that are used mainly for decorative purposes [1]. Following exposure to light, they glow for long periods of time, a phenomenon known as phosphorescence [2].

We propose an open-ended investigation of the time-dependent decay of the emission intensity of some glowstone samples over a relatively long period of time, likely to be several hours or even days. A strictly (single-) exponential decay, often expected to be the norm for various natural events, is in fact a relatively rare experimental result. The decay may be better described as a multi-exponential, a stretched exponential, a power law, for example, or may even be non-analytical, depending ultimately on the statistics of the luminescence mechanism [3].

The project will involve experimental work, including some design of apparatus, and data fitting by computer.

Key papers:

[*1] http://www.jncht.net/photoluminescent_stone.HTM*
[2] See Wikipedia.
[3] Luminescence decay in disordered low dimensional semiconductors, X. Chen, B. Henderson and K.P. O'Donnell. Applied Physics Letters 1992, Vol.60, No.21, pp.2672-2674.

Ratio of effort: Exp/Theo/Comp

Exp:	60%
Theo:	10%
Comp:	30%

Suitability: B.Sc. M.Phys, Nano, Optics

Additional comments: Requires working knowledge of optical properties of solids and the statistical nature of quantum processes. Involves data processing capability.

Safety Training Requirements: Laser Safety. High Intensity light sources.

Hysteretic Photochromic Switching (HPS) of europium-magnesium (Eu-Mg) defects in GaN.

(1) Prof. K.P. O'Donnell (2) Dr. P.R. Edwards

Project Description:

Rare earth ions in semiconductors have been studied for several decades [1] with the aim of extending the range of emission wavelengths of optoelectronic devices [2]. Optical spectra of tri-positive rare earth (RE3+) ions in crystalline solids feature sharp lines at characteristic wavelengths that depend rather weakly on the host material. At the same time, the spectral patterns of such transitions are sensitive to the symmetry of the RE local environment in a way that can be described by simple crystal-field theory. Double-doping of epitaxial GaN samples with Mg and Eu introduces both metastable and quasistable defects associated with an extrinsic hysteretic photochromism, which may form the basis of a novel solid-state qubit.

In this project, we will utilize RE spectroscopy as a probe to monitor Eu3+ photochromism and photo-induced migration of Mg acceptors in GaN.

Key papers):

[1] P.N. Favennec, H. L'Haridon, M. Salvi, D. Moutonnet and Y. Le Gillou, Electronics Letts. **25**, 718 (1989); see also K.P.O'Donnell, P hys. Status Solidi C, 1–3 (2015) / DOI 10.1002/pssc.201400133
*[2] K.P. O'Donnell and V. Dierolf (eds.), Topics in Applied Physics **124** (Springer, Dordrecht, 2010)*

Ratio of effort: Exp/Theo/Comp

Exp:	60%
Theo:	10%
Comp:	30%

Suitability: M.Phys, B.Sc. Nano, Optics

Additional comments: Requires working knowledge of semiconductors/solid state physics and understanding of atomic term notation in the Russell-Saunders approximation. Involves advanced data handling skills or access to a Mac.

Safety Training Requirements: Laser Safety. High Intensity light sources.

RE-doped III-nitrides for solid state lighting applications

(1) Prof. Kevin O'Donnell, (2) Dr. P.R. Edwards

Project Description:

Nitride–based semiconductors, in particular InGaN QW (indium gallium nitride quantum wells) have delivered a new generation of solid state lighting units for domestic and industrial use. The light emitters use epitaxial GaN junction diodes with an active layer of InGaN. However, several fairly well understood physical mechanisms conspire to reduce the efficiency of nitride devices with peak wavelengths greater than about 450 nm (blue light). In fact, although solid-state devices containing III-phosphides are available for the orange and red spectral regions, there is a 'green gap' in the solid state lighting market, presently, and imperfectly, filled by the use of phosphor coatings, similar to those used in familiar 'fluorescent' light fittings.

An alternative to InGaN for the green and red spectral regions is GaN 'doped' with ions from the lanthanide series of Rare Earth (RE) ions. The project will investigate the spectroscopic properties of GaN thin films implanted with suitable RE, for example erbium (Er) for green emitters, and europium (Eu) and praesodymium (Pr) for red. While mainly experimental, the data collection and analysis for the project requires some computational input from the student as well as familiarity with the spectroscopic background that can be found in the key reference [1].

Key papers:

[1] *RE-doped III-Nitrides for Optoelectronic and Spintronic Applications* (Topics in Applied Physics 124, Springer 2010. Kevin O'Donnell and Volkmar Dierolf, Eds.)

Ratio of effort: Exp/Theo/Comp

Exp:	55	%
Theo:	15	%
Comp:	30	%

Suitability: BSc, M.Phys

Additional comments: Combines solid state physics, spectroscopy and quantum mechanics. Involves data handling capability.

Safety Training Requirements: Laser Safety. High Intensity light sources.

Modelling of X-ray fluorescence spectroscopy

(1) Dr Paul Edwards, (2) Prof. Robert Martin

Project Description:

X-ray fluorescence spectroscopy is a technique used to determine the elemental composition of solid-state materials. While two variants of this technique—energy and wavelength dispersive X-ray (EDX/WDX) analysis—are often used in electron microscopes, they have not been widely applied to the quantification of trace elements (such as dopants) in semiconductor materials [1,2]. This project will make use of NIST-developed software tools [2] to simulate the interaction of electron beams with semiconductor samples with different doping concentrations, and to model both the generation and detection of X-ray fluorescence. This will be used to quantify the sensitivity and detection limit of this technique when applied to doped and alloyed semiconductors, and the results will be compared with experimental WDX and EDX data.

Key References:

[1] C. J. Deatcher, K. Bejtka, R. W. Martin, S. Romani, H. Kheyrandish, L. M. Smith, S. A. Rushworth, C. Liu, M. G. Cheong, and I. M. Watson (2016) "Wavelength-dispersive X-ray microanalysis as a novel method for studying magnesium doping in gallium nitride epitaxial films", *Semiconductor Science and Technology* **21** p. 1287.

[2] D. E. Newbury, N. W. M. Ritchie (2016) "Measurement of trace constituents by electron-excited X-ray microanalysis with energy-dispersive spectrometry", Microscopy and Microanalysis **22** p. 520

[3] http://www.cstl.nist.gov/div837/837.02/epq/dtsa2/index.html

Ratio of effort: Exp/Theo/Comp	Exp:	10%
	Theo:	10%
	Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Colour properties and efficiency of white LEDs

(1) Prof. Robert W. Martin, (2) Dr. Jochen Bruckbauer

Project Description:

Light-emitting diodes (LEDs) are already in everyone's life, for example they can be found in homes used for general lighting, illumination of displays, indicator lights or outside in traffic and streets lights. A breakthrough in the fabrication of blue LEDs based on III-nitride semiconductors further revolutionised the lighting industry making highly-efficient white LEDs possible. This was recognised by the award of the 2014 Nobel Prize in Physics to three Japanese scientists crucial to this development [1]. One of the main advantages of LEDs is their ability to convert electrical energy into light very efficiently. This led to the replacement of highly-inefficient conventional lights, such as fluorescent tubes and incandescent light bulbs, with highly-efficient white LEDs. White LEDs can be fabricated by combining a red, green and blue LED (RGB LEDs) or, more commonly by combination of a blue LED with a colour converter, which is generally a rare earth doped phosphor [2]. Recent research has also led to the development of organic colour converters [3]. This project will explore the current status of white LEDs using the different approaches for their efficiency and colour properties. For this photometric measurements will be taken using an integrating sphere to investigate colour parameters, such as colour temperature, colour rendering index and chromaticity coordinates and efficiency parameters, such as luminous efficacy. The project will also consider the effect of drive current and heating of the devices.

Key References:

[1] https://www.nobelprize.org/nobel_prizes/physics/laureates/2014/
[2] E. Fred Schubert: Light-Emitting Diodes, 2nd Ed., Cambridge University Press
[3] N. J. Findlay et al., *Adv. Mater.* **26**, 7290 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	75%
Theo:	25%
Comp:	0%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *Attending the PH453 Semiconductor Physics and Devices course*

Additional comments: *Location of experimental equipment is in the TIC building and appropriate access will need to be arranged which may involve extra safety training.*

Safety Training Requirements: *see above (TIC access)*

UV Laser diodes: pushing the boundary

(1) Prof. Robert Martin, (2) Dr. Gunnar Kusch

Project Description:

Semiconductor based laser diodes (LDs) are part of everyday life, with a wide range of commercial applications (telecommunication, barcode scanners, laser pointers, DVD readers, etc.). The key advantages of these lasers being their small size, low power consumption and wide variety of available wavelengths, which ranges from 405nm for lasers in DVD readers into the deep infrared for telecommunication and gas sensing applications. Similar technology can be used to manufacture LDs based on wide bandgap (EG>3.4eV) Aluminium Gallium Nitride (AlGaN) semiconductors to emit light in the ultra violet (UV) spectral region. These devices are of significant current interest due to the numerous possible applications of UV light emitting devices, including: water purification, gas sensing, and medical diagnostics.

However, a number of challenges have to be overcome for the realization of these devices. One of the key challenges limiting the output power of group-III nitride UV light emitting devices is the p-doping of AlGaN. This project will explore the current status of the p-doping in the group-III nitrides and experimentally characterise a number of UV LDs with different doping levels. Electroluminescence and current-voltage data will be investigated using a probe station, while cathodoluminescence measurements on the samples will be performed in an environmental scanning microscope.

Key References:

1. M. Kneissl et al. Advances in group III-nitride-based deep UV light-emitting diode technology, Semiconductor Science and Technology, V26, N1, P 014036, 2011
2. H. Yoshida et al. AlGaN-based laser diodes for the short-wavelength ultraviolet region, New Journal of Physics, V11, N12, P125013, 2009

Ratio of effort: Exp/Theo/Comp

Exp:	85%
Theo:	15%
Comp:	0%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: PH453 Semiconductor Physics and Devices

Additional comments: Location of experimental equipment is in the TIC building and appropriate access will need to be arranged which may involve extra safety training.

Safety Training Requirements: See above. Laser training is not essential as devices will not be operated in lasing mode. Should the project develop to include this, laser training will be required.

Investigating non-ideal behaviour in current-voltage curves from GaN-based LEDs

(1) Prof. Robert Martin, (2) Dr. Paul Edwards

Project Description:

The electrical current flowing through a p-n junction, such as lies at the heart of light emitting diodes (LEDs), is conventionally described by the Shockley diode equation ($I = I_s(\exp(eV/kT)-1)$). However, this rather simple equation is for an "ideal" diode and in real diodes there are a number of factors that result in deviations from this expression. This project will combine careful measurement of I-V data from blue- and green-emitting GaN-based LEDs with simulation of I-V curves for such real-life devices. Factors to consider will include an equivalent circuit involving resistors and other diodes in the full circuit connecting to the LED as well as the consequences of recombination of the charge carriers within the depletion region. The aim will be to identify and quantify the key factors causing the non-idealities in the measured I-V curves. The I-V measurements and simulation will be supplemented by investigation of the light output from the LEDs, using an integrating sphere. This will enable changes in the spectral output and efficiency to be related to the electrical properties.

Key References:

S.W. Lee et al., Origin of forward leakage current in GaN-based light-emitting devices, Applied Physics Letters 89, 132117 (2006).

Ratio of effort: Exp/Theo/Comp	Exp:	50%
	Theo:	20%
	Comp:	30%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: PH453 Semiconductor Physics and Devices

Additional comments: The "theory" and "computation" is of a level that could be completed using a spreadsheet program such as Excel, although use of Matlab or other may assist taking it to a higher level.

Safety Training Requirements: Some of the equipment is within the Technology and Innovation Centre and access will require satisfaction of the building's safety requirements, although the most dangerous aspect of the project is likely the software on the computers.

Gravity Gradiometry with Satellite Constellations

(1) Dr. Nicholas Lockerbie, (2) Dr. Daniel Oi

Project Description:

The Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite mission delivered a wealth of data to bring about a whole new level of understanding of the Earth's gravity field by mapping variations in the gravity field. This project will explore the possibility of drastically improving the accuracy and detail of these measurements by using a formation of low orbiting satellites and tracking their relative positions to probe the gravity gradient tensor.

The project will involve understanding the theory underlying gravity gradiometry and applying it to the modelling and analysis of a low-Earth orbit drag-free satellite constellation in order to assess the feasibility of the concept.

Key References:

The location of subterranean voids using tensor gravity gradiometry, N A Lockerbie, Classical and Quantum Gravity 31, 065011 (2014)

Earth Gravity Field from Space - from Sensors to Earth Sciences, G. Beutler, M.R. Drinkwater, R. Rummel, Springer (2003)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	50%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Energy upconversion in nano-crystallites for application in ultra-high definition display technology.

(1) Dr. T.P. J. Han, (2) TBC

Project Description:

This research project combines fundamental physics research programme with the development of a new type of display technology based on energy transfer upconversion (ETUC) processes of lanthanide ions doped in nano-crystallites host. The spatial resolution offered by the size of the nano-particles and the means to excite each individually in a spatially selective manner holds promises for a quantum leap in the next generation of ultra high definition display systems. This research proposal is to form the foundation of a detail and systematic spectroscopic investigation to optimise the ETUC efficiency of lanthanide ions doped in fluoride materials for display applications. Fluoride host is judicially identified of their excellent physical properties and low phonon host which is ideally suited for ETUC processes. A number of lanthanide ions are investigated for their colour saturation, ETUC efficiency and performance under different operation environment and particle sizes. Different excitation scheme are examined for optimum ETUC and colour selectivity. Simple wet chemistry of producing these nano-crystallites by precipitation method are investigated for particle size control, crystallites quality, ease of use and scalability.

Key References:

1) C. *Jiang, F. Wang, N. Wu, X. Liu, Adv. Mater., 20, (2008) 4826.*
2) *L. Yang, H. Han, Y. Zhang, J. Zhong, J. Phys. Chem. C, 113, (2009) 18995.*
3) *V. Mahalingam, R. Naccache, F. Vetrone, J.A. Capobianco, Chem. Eur. J., 15, (2009) 9660.*
4) *M. Wang, G. Abbineni, A. Clevenger, C. Mao, S. Xu, Nanomedicine: Nanotechnology, Biology and Medicine, 7, (2011) 710;*
5) *F. Wang, X. Liu, Chem. Soc. Rev. 38, (2009) 976.*

Ratio of effort: Exp/Theo/Comp

Exp:	90%
Theo:	10%
Comp:	0 %

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *Either Solid State Physics or Laser Physics, ideally both.*

Additional comments: *This project has the potential to accommodate up to 2 students working parallel on different lanthanide ions and fluoride hosts.*

Potential project student should be comfortable with the handling of simple chemicals, the use of laser system.

Safety Training Requirements: *Laser safety.*

An optical study of lanthanide ion doped BaY_2F_8 single crystals.

(1) Dr. T.P. J. Han, (2) TBC

Project Description:

The luminescence intensity of trivalent lanthanide ions depends in parts on the host material they are incorporated in. Amongst different host matrices, crystals of the fluoride compounds with ordered structure play an important role due to their unique chemical, mechanical and thermal properties. The very low phonon energy of BaY_2F_8 (~ 360-380 cm^{-1}) makes multi-phonon relaxation inefficient, hence luminescence intensity of the trivalent lanthanide ions increases, compared with oxide crystals. This project is to study the optical properties of the lanthanide doped BaY_2F_8 single crystal. The absorption, photoluminescence, fluorescence decay and energy transfer processes will be investigated as a function of temperature.

Key papers:

1) *A.C.S. de Mello, A.B. Andrade, G.H.G. Nakamura, S.L. Baldochi, M.E.G. Valerio, J. Luminescence, 138, (2013) 19.*
2) *F. Cornacchia, D. Parisi, C. Bernardini, A. Toncelli, M. Tonelli, Optics Express, 12(9), (2004) 1982.*
3) *H.J. Eichler, J. Findeisen, B. Lui, A.A. Kaminskii, A.V. Butachin, P. Peuser, IEEE Journal of selected topics in quantum electronics, 3(1), (1997) 90.*
4) *V. Toccafondo, A. CerqueiraS., S. Faralli, E. Sani, A. Toncelli et al., J. Appl. Phys., 101, (2007) 023104.*
5) *S.A. Pollack, D.B. Chang, R.A. McFarlane, H. Jenssen, J. Appl. Phys., 67, (1990) 648.*

Ratio of effort: Exp/Theo/Comp

Exp:	85%
Theo:	10%
Comp:	5%

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Either Solid State Physics or Laser Physics, ideally both.

Additional comments: Potential project student should be comfortable with the use of laser system.

Safety Training Requirements: Laser safety.

An optical study of lanthanide ion doped $NaYF_4$:Yb:Er single crystals.

(1) Dr. T.P. J. Han , (2) TBC

Project Description:

The development of new upconversion (UC) materials has recently drawn much attention because of their potential in a multitude of possible applications ranging from laser materials, near infra-red quantum counters and biolabelling to lighting and display technologies []. The most promising materials are lanthanide ion doped crystalline materials sensitized by Yb^{3+} ions, in particularly $NaYF_4$:Yb:Er. This project aims to investigate in details the optical properties of the micro-crystalline particles of $NaYF_4$:Yb:Er. The excitation, photoluminescence, fluorescence decay and energy transfer processes will be investigated as a function of temperature.

Key papers:

1) G. Yi, H. Lu, S. Zheng, Y. Ge, W. Yang, D. Chen, L. Guo, Nano Lett. 4 (2004) 2191.
2) E. Downing, L. Hesselink, J. Ralston, R. Macfarlane, Science 273 (1996) 1185.
3) M. Joubert, Opt. Matter. 11 (1999) 181.
4) A. Shalav, B.S. Richards, T. Trupke, K.W. Kramer, H.U. Gudel, Appl. Phys. Lett. 86(1) (2005) 013505.

Ratio of effort: Exp/Theo/Comp Exp: 90% Theo: 10% Comp:

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Either Solid State Physics or Laser Physics, ideally both.

Additional comments: Potential project student should be comfortable with the use of laser system and working in a dimly lit room..

Safety Training Requirements: Laser safety.

Lanthanide-doped fluoride sub-micron crystalline particles for biomedical applications.

(1) Dr. T.P. J. Han , (2) Dr. Yu Chen

Project Description:

Lanthanide-doped fluorides sub-micron crystalline particles, have been widely investigated over the past few years owing to their potential applications in three-dimensional displays [1], solar cells [ii] and especially in biological labelling, imaging and therapy [3, 4]. Compared with the traditional biolabels, such as organic fluorophores and quantum dots, these crystalline particles have many merits, including sharp emission peaks, large anti-Stoke shifts, long lived excited electronic states, and high photo-stability. This project investigates the suitability of a number of fluoride hosts doped with lanthanide ions as suitable biolabel. Two objectives are explored here (a) an ambient temperature processing route that is expected to provide a water dispersible product and also retain the luminescence intensity of the lanthanide ions, and (b) surface functionalization of the particles to create nanoprobes for specifically targeting cancer biomarkers [5].

Key papers:

1) E. Downing, L. Hesselink, J. Ralston, R. Macfarlane, Science 273 (1996) 1185.
2) A. Shalav, B.S. Richards, T. Trupke, K.W. Kramer, H.U. Gudel, Appl. Phys. Lett. 86(1) (2005) 013505.
3) Q. Xia, X. Zheng, W. Bu, W. Ge, S. Zheng, F. Chen, H. Xing, Q. Ren, W. Fan, K. Zhao, Y. Hua, J. Shi, J. Am. Chem. Soc. 135 (2013) 13041.
4) C. Liu, Z. Gao, J. Zheng, Y. Hou, F. Fang, Y. Li, R. Qiao, L. Shen, H. Lei, W. Yang, M. Gao, ACS Nano 7 (2013) 7227.
5) P. Qiu, N. Zhou, H. Chen, C. Zhang, G. Gao and D. Cui, Nanoscale, 5 (2013) 11512.

Ratio of effort: Exp/Theo/Comp Exp: 95% Theo: 5% Comp: 0%

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Either Solid State Physics or Laser Physics, ideally both.

Additional comments: (e.g. course suggested)

This project has the potential to accommodate up to 2 students working parallel on different lanthanide ions and fluoride hosts.

Potential project student should be comfortable with the handling of simple chemicals, the use of laser system and working in a dimly lit room.

Twisted Nanostructures

(1) Dr. Ben Hourahine (2) Prof. Maxim Fedorov

Project Description:

In addition to the familiar repeating arrays of atoms in crystals, there are several other types of large ordered arrangements of atoms which occur in nature which are not periodic. For example there are many structures that are fundamentally helical in nature, these include carbon nanotubes, screw-dislocated nanowires, the tails and capsids of many viruses, amyloid fibrils, and perhaps most famously, DNA.

Traditionally these are investigated by either using large clusters of atoms to describe segments of the helical structure, or as a crystal with a large number of atoms in its unit cell to include a complete twist of the helix. Both of these approaches require the simulation of very large numbers of atoms (in principle up to an infinite number in some cases), even though the fundamental repeat unit of the structure is often much smaller.

This project applies the recently developed idea of simulating this fundamental repeat unit (the so called 'objective' cell) to study twisted nanostructures. Potential systems to be studied in this project are helical tubes of modern 2D materials (phosphorene or transition-metal dichalcogenide nanotubes), twisted semiconductor nanowires or the DNA single and double helix.

Key References:

Formation of helices in graphene nanoribbons under torsion. Nikiforov, Hourahine, Frauenheim, and Dumitrică, Journal of Physical Chemistry Letters 5, 4083 (2014).

Ewald summation on a helix: a route to self-consistent charge density-functional based tight-binding objective molecular dynamics. Nikiforov, Hourahine, Aradi, Frauenheim, Dumitrică, Journal of Chemical Physics 139, 094110 (2013).

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	20%
Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments: This project is available for two students, provided they are simulating different physical systems.

Safety Training Requirements: N/A

Simulating topological materials

(1) Ben Hourahine (2) Luca Tagliacozzo

Project Description:

Within the last 10 years, systems with topologically non-trivial electronic states have gone from an initial theoretical model system to a wide range of real two and three dimensional materials with several different types of topological ordering. The properties of these are different from previously known solids, as the global behaviour of the electrons is dictated by how the states are "wrapped around" a symmetry present in the material, which happens in a fundamentally different way to normal insulating solids. These are very unusual solids, but their differences from ordinary insulators only become obvious at surfaces or interfaces, where topologically protected states can appear as the electrons unwind from the symmetry they are wrapped around. A common manifestation of this is a robust metallic surface conductivity, which persists despite disorder or impurities at the edges of the material.

This project will investigate proximity and modulation effects that can induce or, potentially, destroy topological ordering of electronic states using electronic structure models to simulate some real materials.

Key papers:

Topological insulators. Hasan and Kane, Rev. Mod. Phys. **82**, 3045 (2010)

Topological insulators and superconductors. Qi and Zhang, Rev. Mod. Phys. **83**, 1057 (2011)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	30%
Comp:	70%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments: This project is available for two students, provided they are investigating different physical effects.

Safety Training Requirements: N/A

Optics Division

Beam Quality of Broad-area Diode Lasers

(1) Prof. Thorsten Ackemann, (2) Dr. Michael Strain

Project Description:

Power scaling of semiconductor laser diodes and maintaining at the same time a high beam quality is a notoriously difficult challenge, since increasing the emission aperture leads to numerous instabilities limiting the brightness of a broad-area laser (BAL) [2].

Recently, a novel approach to control the beam quality of edge-emitting BALs maintaining their attractive monolithic compactness was proposed [1]. The suggestion is to implement a two-dimensional spatial modulation- *simultaneously transverse and parallel to the cavity axis* – of the gain characteristics, i.e. of the imaginary part of the susceptibility, by a modulation of the current injection. Similar to the case of photonic crystals (relying on a modulation of the real part of the susceptibility), the modulation is predicted to lead to a modification of spatial dispersion curves, in particular to a spatial filtering and a highly directional gain along the optical axis. As a result, *noise triggered by inhomogeneities or dynamically generated via instabilities* is quenched.

The project will set up a probe station to measure beam quality of BALs and perform measurements of samples processed at the University of Glasgow.

Key Reference:

[1] R. Herrero et al., Beam shaping in spatially modulated broad-areasemiconductor amplifiers, Opt Lett. 37, 5253 (2012);

*[2] Crump et al., Experimental and theoretical analysis of the dominant lateral waveguiding mechanism in 975 nm high power broad area diode lasers. Semicond. Sci. Technol. **27** (2012) 045001*

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	10%
Comp:	20%

Suitability: MPhys, BSc

Additional comments: *The student is required to attend PH445 and PH453 to obtain the necessary background.*

Safety Training Requirements: *laser*

Analysis of mode-locked laser dynamics

(1) Prof Thorsten Ackemann, (2) Prof Gian-Luca Oppo

Project Description:

The locking of longitudinal modes of lasers by nonlinear effects is an established way to create short-pulses [1]. Recently, the group discovered mode-locking of spatial laser solitons [2] without the typical ingredients like saturable absorbers [3]. The experiment combines self-localization to spatial solitons in the transverse domain (orthogonal to the cavity axis) with self-localization in the temporal domain (along the cavity axis) with the intriguing prospect of achieving spatio-temporal soliton or light localization in all three dimensions. The project will consist of the statistical analysis of earlier acquired data in order to characterize and understand the observed dynamics and coherence properties of radiation. We will look at pulse height and jitter statistics and correlations between them. Depending on progress and interest of the student, it could be augmented either by some experimental studies or theoretical simulations using existing code known to reproduce the experimental observations at least in some parameter regimes. Investigations might be also extended to data on conventional mode-locked lasers.

Key References:

[1] P. Grelu, Nail Akhmediev, Dissipative solitons for mode-locked lasers. Nature Phot 6, 84 (2012)
[2] T. Ackemann, W. J. Firth, G.-L. Oppo, Fundamentals and Applications of Spatial Dissipative Solitons in Photonic Devices, Adv. At. Mol. Opt. Phys 57, 323 (2009)
[3] T. Ackemann et al., Self-pulsing dynamics in a cavity soliton laser, Proc SPIE 7720, 772007(2010)

Ratio of effort: Exp/Theo/Comp

Exp: (30?)%
Theo: 10+(30?)%
Comp: 60(+30?)%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: Useful courses to underpin the project are PH445, PH453 and PH456.

Additional comments: The project requires interest in programming and computational data analysis and the will and drive to develop the Matlab knowledge acquired in year 2.

Safety Training Requirements: laser

Observing Beam Propagation by Fluorescence

(1) Dr. Aidan Arnold, (2) Dr. Paul Griffin

Project Description:

You will make a thorough investigation of the Beer-Lambert Law (and its generalisation) by imaging the fluorescence (spontaneous emission) of rubidium atoms in a vapour cell to detect the local intensity of laser beams propagating through the cell. Key variables include the beam initial intensity, beam shape, and cell temperature. Possible extensions are the investigation of multiple beam interference, and dynamically scanned beams. The project requires a student with good experimental and analysis skills.

Key Reference: *N. Radwell, M. A. Boukhet, and S. Franke-Arnold, Opt. Express **21**, 22215 (2013).*

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	20%
Comp:	10%

Suitability: MPhys

Additional comments: *Lab JA3.04A*

Safety Training Requirements: *Laser safety training required.*

Bose-Einstein condensate experiments

(1): Dr. Aidan Arnold, (2) Dr. Paul Griffin

Project Description:

Highlight: This project involves performing experiments on the coldest material in the known universe – a Bose-Einstein condensate, at a chilly 10nK. You will observe and manipulate a real quantum mechanical object that can be seen on a video camera.

Caution: This experiment involves a vast array of lasers, optics, vacuum equipment, computer control and electronics – there is a steep learning curve. Normally reserved for PhD projects, but available for hard-working 2-year (MPhys) project students.

Key References:

*[1] M.E. Zawadzki, P.F. Griffin, E. Riis, and A.S. Arnold, Spatial interference from well-separated split condensates, Phys. Rev. A **81**, 043608 (2010).*
*[2] A.S. Arnold, C.S. Garvie, and E. Riis, Large magnetic storage ring for Bose-Einstein condensates, Phys. Rev. A **73**, 041606(R), (2006).*

Ratio of effort: Exp/Theo/Comp	Exp:	70%
	Theo:	20%
	Comp:	10%

Suitability: MPhys only

Additional comments:

Safety Training Requirements:

Generation and propagation of spatially structured light

(1) Dr. Paul Griffin, (2) Dr. Alison Yao

Project Description:

Light with an electric-field pattern (either amplitude or phase) that varies across the transverse dimension has applications in a range of fields; telecommunications, quantum information, optical trapping of living cells, single-pixel cameras, and measurement of turbulence, to select but a few. This project is aimed at developing rapid and robust methods of generation of such light beams from standard laser systems using Spatial Light Modulators. The project will examine how such beams propagate and how their subsequent detection can be used for measurement of physically interesting properties.

Key References:

Ratio of effort: Exp/Theo/Comp

Exp:	60%
Theo:	30%
Comp:	10%

Suitability: MPhys, BSc, BSc Maths and Physics, ~~BSc Physics with Teaching~~

Recommended Classes/Pre-requisites:

Additional comments: This project is suitable only for a student with a strong interest in experimental physics, and with a strong background in computer systems, or interfacing with computers.

Safety Training Requirements: Laser Safety

Signal processing for Atomic Magnetometry

(1) Dr. Paul Griffin, (2) Dr. Stuart Ingleby

Project Description:

Atomic magnetometers can now achieve magnetic field sensitivity of a few fT/√Hz and below [1]. To fully exploit this technology in environments without magnetic shielding, we must develop signal acquisition and processing techniques that allow maximal information to be extracted from an atomic system (in an arbitrary magnetic field) while minimising the effects of noise and field inhomogeneity. The project will involve one of the following:

1) Extraction of vector field information from observed phase of modulation response.
2) Increasing dynamic range through development of FPGA-based data acquisition.
3) Development of a gradiometer system to allow active noise reduction.

Key References:

H. B. Dang, A. C. Maloof, M. V. Romalis, Applied Physics Letters **97**, 151110 (2010)

Ratio of effort: Exp/Theo/Comp

Exp:	50 %
Theo:	20 %
Comp:	30 %

Suitability: MPhys, BSc, BSc Maths and Physics,

Additional comments:

Safety Training Requirements: Laser safety training required

Domain Walls in Optical Fibre Resonators

(1) Prof. Gian-Luca Oppo, (2) Dr. Alison Yao

Project Description:

Domain walls (also known as kinks) separate regions of different physical behaviours in magnetic systems, in chains of coupled pendula and in collision-less plasmas. In the optical domain, domain walls have been described in the plane perpendicular to the propagation of laser beam for coupled waves with orthogonal polarization and in optical parametric oscillators [1]. Recent developments have shown that nonlinear features in the transverse plane have one-to-one counterparts in optical fibres in resonators [2].

This project aims at investigating domain walls between left and right circular polarizations in an optical fibre resonator. In particular, we study and compare the formation of periodic structures, locked domain walls and solitons in theoretical and computational models of polarized light propagating in fibres with or without an optical resonator. The project is done in collaboration with experiments carried out at the University of Auckland (New Zealand).

Key References:

[1] R. Gallego et al., “Self-similar domain growth, localized structures, and labyrinthine patterns in vectorial Kerr resonators”, Phys. Rev. E **61**, 2241 (2000); G.-L. Oppo et al, “Characterization, dynamics and stabilization of diffractive domain walls and dark ring cavity solitons in parametric oscillators”**,** Phys. Rev. E **63**, 066209 (2001)

[2] J.K. Jang et al., “Controlled merging and annihilation of localised dissipative structures in a driven damped nonlinear Schrödinger system” New Journal of Phys. **18**, 033034 (2016)

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	40 %
Comp:	60 %

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None.

Entangled Optical Turbulence

(1) Prof. Gian-Luca Oppo, (2) Dr. Alison Yao

Project Description:

Light propagating in lasers or in optical parametric oscillators under the action of an external laser injection can display a transition to optical turbulence where creation and annihilation of vortices takes place in random spatial positions [1]. In the case of optical parametric oscillators, the output is composed of two light beams, the signal and the idler which can have the same frequency (degenerate case) or different frequencies (non-degenerate case). The photons of the signal and idler beams are emitted simultaneously and are quantum-mechanically entangled [2].

This project aims at investigating quantum correlations between the signal and the idler in a turbulent regime. On one side the randomness of the turbulent state tends to destroy spatial correlations while on the other, the quantum nature of twin photons tends to maintain the strong link between signal and idler waves. We will establish if these two processes cooperate or suppress each other and how to use these features in the encryption of coded messages in optical communications.

Key References:

[1] C. J. Gibson, A. M. Yao, and G.-L. Oppo, "Optical Rogue Waves in Vortex Turbulence", Phys. Rev. Lett. **116**, 043903 (2016).
[2] D. Cuozzo and G.-L. Oppo, "Two-color continuous-variable quantum entanglement in a singly resonant optical parametric oscillator", Phys. Rev. A **84**, 043810 (2011)

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	40 %
Comp:	60 %

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None.

Opto-mechanics of Bose-Einstein Condensates in Optical Cavities

(1) Prof. Gian-Luca Oppo, (2) Dr. Gordon Robb

Project Description:

Bose-Einstein Condensates (BEC) inside an optical cavity and under the action of a coherent laser, can display exotic oscillations and even deterministic chaos [1]. This is quite unexpected for a quantum gas moving along the cavity via the tunnelling effect, a purely quantum phenomenon. The chaotic oscillations can also be enhanced by small modulations of the driving laser amplitude [1].

This project aims at investigating a new physical state of BEC in optical cavities. When the cavity finesse is increased, experiments in Hamburg have revealed that opto-mechanics with resonant momentum transfer takes place [2]. This results in the BEC atoms moving from zero to quantised momenta in a sequence of modal jumps. We investigate this phenomenon via theoretical and simulation methods to discover the basic mechanisms that combine cavity scattering and strong coupling between light and ultra-cold atoms. Please note that numerical codes are already in operation.

Key References:

[1] M. Diver, G. R. M. Robb, and G.-L. Oppo, "Nonlinear and chaotic dynamics of a Bose-Einstein condensate in an optical cavity", Phys. Rev. A 8**9**, 033602 (2014) and "Chaotic resonances of a Bose-Einstein condensate in a cavity pumped by a modulated optical field", Phys. Rev. A **91**, 033622 (2015)

[2] H. Keßler et al., "Optomechanical atom-cavity interaction in the sub- recoil regime", New Journal of Physics **16,** 053008 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	40 %
Comp:	60 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None.

Soliton Glass

(1) Prof. Gian-Luca Oppo, (2) Dr. Francesco Papoff

Project Description:

Spatial optical solitons are beams of light in which nonlinearity counter-balances diffraction, leading to robust single-hump structures that propagate without change of form. In the case of light propagating through a medium, the simplest spatial soliton is due to self-focusing and Kerr nonlinearity, that is, a refractive index which changes in proportion to the intensity of the light. More general schemes where dissipation and driving are included can also support stable soliton-like solutions with lots of intriguing and new properties. Among these, localized bright spots in driven-optical cavities have received a great deal of attention because of their applications in information processing [1].

This project aims at investigating a new physical state for spatial optical solitons: a glass. Normal spatial solitons in random positions are susceptible to background noise fluctuations and can be described as a soliton gas. Above certain thresholds, however, spatial solitons in media pumped by two laser beams [2] can freeze at certain distances and form conglomerates similar to those observed in amorphous media such as glass. Characterization of the soliton glass phase, its origin and possible melting are among the objectives of the project. Please note that numerical codes are already in operation.

Key References:

[1] T. Ackemann, W. J. Firth and G-L Oppo, "Fundamentals and Applications of Spatial Dissipative Solitons", Adv. At. Mol. Opt. Phys. **57**, 323 (2009)

[2] M. Esalmi et al., "Complex structures in media displaying electromagnetically induced transparency: Pattern multistability and competition", Phys. Rev. A **90**, 023840 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	40 %
Comp:	60 %

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None.

Cold Atom-Light Interactions

(1) Dr. Gordon Robb, (2) Dr. Brian McNeil

Project Description:

It is now possible to cool atoms down to temperatures close to absolute zero. At these temperatures, the interaction between light and atoms can change dramatically; with the optical forces acting on the atoms can play a significant effect.

The project will involve analysing and simulating interactions between optical beams and a gas of cold atoms, in particular considering cases where the light-atom interaction is nonlinear, offering new possibilities for e.g. optical pattern formation, light amplification and atomic self-organisation.

Key Reference:

E. Tesio, G.R.M. Robb, T. Ackemann, W.J. Firth, and G.-L. Oppo, Phys. Rev. A 86, 031801(R) (2012)

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	30%
	Comp:	70%

Suitability: MPhys BSc

Additional comments: *This project may be run simultaneously with 2 students in parallel.*

Bose Einstein Condensate (BEC) Simulations

(1) Dr. Gordon Robb, (2) Dr. Aidan Arnold

Project Description:

When a gas of atoms is cooled to a temperature < ~1K , it can stop behaving as a cloud of classical particles and instead behave as a “matter wave” or Bose-Einstein Condensate (BEC), whose behaviour is governed by the laws of quantum mechanics [1]. BECs were first realised experimentally in 1995 and the only one in Scotland is here at Strathclyde.

This project will involve theory and simulation of a BEC in a storage ring [2].

References :

[1] Allan Griffin, D. W Snoke, S Stringari , Bose-Einstein condensation
Cambridge, New York : Cambridge University Press (1995).
[2] A. S. Arnold, C. S. Garvie, and E. Riis, Phys. Rev. A 73, 041606(R) (2006)

Ratio of Experiment/Theory/Computation: Exp: 0 %, Theo: 50 % Comp: 50 %

Suitable for: PH450 MPhys BSc

Additional Comments: *Some experience of programming would be preferred, but is not essential.*

Safety Training Requirements: *Contact the project Supervisor for further advice*

Interactive Physics Simulations

(1) Dr. Gordon Robb, (2) Dr. Nigel Langford

Project Description:

Many interactive Physics simulations have been developed over the years in a variety of different languages e.g. JAVA, Adobe Flash, Shockwave etc.

However, for several reasons many existing simulations have now become obsolete, e.g.

- Most modern browsers do not run JAVA easily, as it is perceived as a security risk
- Many existing simulations cannot run on tablets or mobile phones

The project will involve developing one or more interactive Physics simulations using HTML5, which allows them to be run on modern browsers and on mobile devices. Recent examples of such simulations and teaching activities which use them can be found in [1].

The physics topic and the exact method of developing the simulation can be adjusted to suit the student's degree programme and level of previous programming experience.

Key Reference: *https://phet.colorado.edu*

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	20%
	Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Additional comments:

Safety Training Requirements: *N/A*

Four-wave Mixing in Atomic Gases

(1) Dr. Gordon Robb, (2) Dr. Aidan Arnold

Project Description:

Nonlinear optical wave-mixing phenomena, such as sum-frequency generation, difference-frequency generation and four-wave mixing are important processes in optics with a number of applications e.g. generating coherent light at wavelengths where lasers sources are not available [1]. Experiments are currently in progress at Strathclyde which involve using four-wave mixing in Rb gas to produce coherent blue light [2].

This project will involve modelling nonlinear four-wave mixing in atomic gases and will involve numerically solving coupled equations describing the evolution of the atomic and optical field dynamics.

Key References:

[1]"Nonlinear Optics" by R. Boyd
[2] A. Vernier, S. Franke-Arnold, E. Riis, and A. S. Arnold , Optics Express 18, 17020 (2010)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	40%
Comp:	60%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *none*

Additional comments: *Experience of programming in any language would be an advantage but is not essential – it will be developed during the project.*

Safety Training Requirements: *None*

Quantum State Comparison and Correction Amplifier

(1) Prof John Jeffers, (2) Dr Luca Mazzarella

Project Description:

The development of secure quantum communications over long distances is a prominent challenge for this century, its importance being acknowledged by both public funding agencies and private companies.

One of the key requirements for pushing the implementation of quantum communication networks up to the global scale is the design of high-rate quantum repeaters. A quantum repeater has to amplify unknown quantum states, the optimal performance of such a task is limited by the fundamental principles of quantum theory, via the non-cloning theorem and the indeterminacy principle.

The state comparison and correction amplification protocol (SCCAMP) is a non-deterministic method that exploits a feed-forward correction strategy to amplify coherent states, from a known set. It operates at high gain, high success probability and high fidelity and it is implemented with relatively simple resources (linear optical components and APD detectors).

The goal of this project will be:

1) to investigate the optimization of the key feature of the SCCAMP, such as success probability and fidelity.
2) To compute the "key rate" that can be obtain in various quantum communication protocols by using the SCCAMP as a quantum repeater.

Key References:

Quantum Optical State Comparison Amplifier, E Eleftheriadou, SM Barnett, J Jeffers, Physical Review Letters 111 (21), 213601, (2013)

Experimental Implementation of a Quantum Optical State Comparison Amplifier, RJ Donaldson, RJ Collins, E Eleftheriadou, SM Barnett, J Jeffers, GS Buller. Phys. Rev. Lett. 114 (12), 120505, (2015)

Ratio of effort: Exp/Theo/Comp

Exp: 0%
Theo: 80%
Comp: 20%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: Attendance at Quantum Optics and/or Quantum Information Classes would be desirable.

Additional comments: Students should have passed well (~70%) third year quantum physics.

Safety Training Requirements: N/A

Optimisation of secure imaging

(1) Prof. John Jeffers, (2) Dr. Wojciech Roga

Project Description:

This project concerns security against jamming in imaging based on quantum mechanics. Due to indistinguishability of quantum states of photons' polarisation legitimate imagers who prepare the states have an informational advantage over an intruder. Our aim is to recognise optimal strategies of the imagers to detect the intrusion. We will analyse the scenario with two non-orthogonal polarisation states. In this case, the optimal scenario of the intruder is related to the Helstrom formula for the probability of correct discrimination between the states. Knowing this, we can recognise the best strategy of the imagers to detect the intrusion and deliver analytical formulas for the detection probability. The project can be extended on more complicated situations.

Key References:

1. W. Roga, J. Jeffers, Security against jamming and noise exclusion in imaging Phys. Rev. A (2016).
2. M. Malik, O. S. Magana-Loaiza, and R. W. Boyd, Quantum-secured imaging, Appl. Phys. Lett. 101, 241103 (2012).

Ratio of effort: Exp/Theo/Comp

Exp: 0 %
Theo: 50 %
Comp: 50 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Computational Physics, Quantum Mechanics

Candidate must have taken and passed well (>=65%) the following courses:

- Quantum Physics and Electromagnetism (year 3)
- Computational Physics (year 2)
- Linear Algebra and Differential Equations (year 2)

Additional comments:

The numerical simulations using MATLAB and Mathematica will be essential.

Safety Training Requirements: None

Quantum Back-Action in the Jaynes-Cummings Model

(1) Dr. Daniel Oi, (2) Dr. John Jeffers

Project Description:

Measurement plays a vital role in quantum information theory. Non-destructive measurement of optical fields is challenging to implement. One method is to couple a two-level atom to a cavity mode and through the interaction extract information from the field via the atomic state. Due to bosonic enhancement, the resulting measurement operators can be complicated and this project will investigate the resulting cavity dynamics.

Key Reference:

Nondemolition measurement of the vacuum state or its complement, D.K.L. Oi, V. Potoček, J. Jeffers, Physical Review Letters ***110****, 210504 (2013)*

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	50%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Pre-requisites: *Topics in Quantum Theory (PH458)*

Additional comments:

Safety Training Requirements:

Ancilla-driven Quantum Dynamics

(1) Dr. Daniel Oi, (2) Dr. Marco Piani

Project Description:

The ability to perform information processing tasks using quantum systems depends on the resources available. In the Ancilla Driven Quantum Computation model, the main resource is a single two-qubit unitary interaction that can drive evolution of a system via coupling to an ancilla. By suitable preparation and measurement of the ancilla, different effects can be applied to the system, but this depends on the form of the interaction. This project would investigate the relationship between the form of the unitary and what can be achieved.

Key Reference:

Ancilla-driven universal quantum computation, J. Anders, D.K.L. Oi, E. Kashefi, D.E. Browne, E. Andersson, Physical Review A ***82****, 020301 (2010)*

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	90%
Comp:	10%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Pre-requisites: *Topics in Quantum Theory (PH458)*

Additional comments:

Safety Training Requirements:

Floquet theory for trapped atoms in optical lattices.

(1) Dr Luca Tagliacozzo (2) Dr Daniel Oi

Project Description

In the last years we have observed an impressive improvement of the experimental control of quantum systems. In particular cold atoms can be trapped in optical lattices and observed individually [1].

In order to obtain such a control the atoms need to be very diluted and thus their only interactions are contact two body collisions. Recently people have proposed to drive the optical lattices periodically in such a way to effectively give rise to novel and interesting types of interactions [2,3].

When the driving is periodic at sufficiently high frequencies one can use the Floquet theory [4] to obtain an effective Hamiltonian that describes the slow dynamic on the top of the fast one. In this project we will review the theory beyond such ideas and compare the effective Hamiltonian with the exact dynamics for very small systems using exact diagonalization techniques for small systems in several exemplary cases.

Key References:

[1] I. Bloch, Ultracold quantum gases in optical lattices. Nature Physics 1, 23 (2005).
[2] A. Eckardt, C. Weiss, M. Holthaus PRL 95 (26), 260404 (2005)
[3] N. Goldman and J. Dalibard Phys. Rev. X 4, 031027 (2014)
[4] https://en.wikipedia.org/wiki/Floquet_theory

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	50 %
Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *Topics in Quantum Theory (PH458)*

Additional comments: The student should be interested in working with numerical techniques and comfortable working with computers. Specific numerical methods will be covered over the course of the project as required. The student should also be comfortable with basic concepts of quantum mechanics.

Safety Training Requirements: No special safety training requirements.

Matrix product state representation of quantum states

(1) Dr Luca Tagliacozzo (2) Dr Daniel Oi

Project Description

Many body quantum systems, systems made by several identical constituents, like materials, quantum gases, nuclei etc., are exponentially hard to describe. This means that we can at most describe exactly few tens of interacting particles but all interesting collective phenomena tend to appear when several thousand of particles interact strongly. This is at the origin of our incomplete understanding of several interesting effects, such as i.e. high temperature superconductivity.

In some cases, manly for systems organized in one dimensional structures such as wires and spin chains, however, people have been able to find extremely compact descriptions of specific states that allow to study very large systems and observe interesting emerging phenomena.

In this project we will discover one of these descriptions, the matrix product state representation of quantum states [2]. Originally introduced in the context of exactly solvable models [1] it is at the core of the Density Matrix Renormalization Group [3], the current standard tool to perform numerical simulations of 1D strongly correlated quantum systems. We will use this description to perform some simple out of equilibrium dynamics for 1D spin chains.

Key References:

[1] I. Affleck, T. Kennedy, E. H. Lieb, H. Tasaki, Comm. Mat. Phys. 115 477 (1998)
[2] D. Perez-Garcia, F. Verstraete, M.M. Wolf, J.I. Cirac, Quantum Inf. Comput. 7, 401 (2007)
[3] White S. PRL 69, 2863 (1992)

Ratio of effort: Exp/Theo/Comp	Exp:	0 %
	Theo:	50 %
	Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *Topics in Quantum Theory (PH458)*

Additional comments: The student should be interested in working with numerical techniques and comfortable working with computers. Specific numerical methods will be covered over the course of the project as required. The student should also be comfortable with basic concepts of quantum mechanics.

Safety Training Requirements: No special safety training requirements.

Resonances in Clouds of Cold Atoms

(1) Dr. Francesco Papoff (2) Dr. Gordon Robb and Dr. Ben Hourahine

Project Description:

Spherical clouds of cold atoms and Bose-Einstein condensate have electromagnetic resonances that are similar to the Mie resonances of spherical dielectric particles. In most experiments, however, the atomic clouds are more similar to elongated cigars than to spheres. In this project we will develop a theory for bodies with axially symmetric density that will apply to these experiments and we will consider whether the scattering of light from these clouds can become an effective diagnostic tool to measure the density of the cloud.

Ratio of Experiment/Theory/Computation:	Exp:	0%
	Theo:	50%
	Comp:	50%

Suitability: MPhys, BSc

Modelling scanning near-field microscopy

(1) Dr. F. Papoff, (2) Dr. B. Hourahine

Project Description:

Scanning Near Field Optical Microscopes have been essential to investigate the optical properties of nano particles and nano cavities with a resolution higher than the diffraction lengths typical of conventional microscopes. One of the most remarkable recent developments has been the detection of the magnetic component of light at visible frequencies. This impressing ability has however highlighted the fact that the response of these microscopes depends crucially on the coupling between the metallic tip of the microscope and the nano structure investigated. In this project we aim to model this important effect and this will enable us to disentangle the properties of the nano structure investigated from those of the metallic tip.

Key References:

M. Burresi et al.,Magnetic Light-Matter Interactions in a Photonic Crystal Nanocavity, Phys. Rev. Lett. 105, 123901 (2010)

N. Caselli et al., Deep-subwavelength imaging of both electric and magnetic localized optical fields by plasmonic campanile nanoantenna, Sci. Rep. 5, 9606 (2015)

K. Imura et al., Plasmon modes in single gold nanodiscs, Opt. Exp. 22, 12189 (2014)

Ratio of effort: Exp/Theo/Comp	Theo:	50%
	Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Parametric difference resonance in lasers

(1) Dr. F. Papoff, (2) Dr. Gordon Robb

Project Description:

It has been recently discovered that two oscillators appropriately coupled can be excited by a external force oscillating at a frequency equal to the difference between the resonance frequencies of the two oscillators. This has been proposed as a new mechanism to achieve lasing at frequencies much higher than the driving frequency used to pump energy into the lasers. In this project, we will instead look at using parametric difference resonances to synchronize lasers over a wide band of frequency, which can be useful in many applications, from metrology to to imaging of very fast processes.

Key References:

A. A. Svidzinsky et al., Quantum Amplification by Superradiant Emission of Radiation, PHYSICAL REVIEW X 3, 041001 (2013)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	40%
Comp:	60%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Computational Modelling of X-ray Free Electron Lasers

(1) Dr. Brian McNeil, (2) Dr. Gordon Robb

Project Description:

X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2].

The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level.

The supervisor of this project Dr Brian McNeil works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

Starting from the basic working equations that describe the FEL process, the student will gain an understanding of how an XFEL works. You will then use numerical methods to solve the simplest case. This will involve solving equations describing the electron trajectories through the combined undulator and light fields, while simultaneously solving the equation that describes how the light field is driven by the electrons. Initially a code like MATLAB can be used. The student may wish to then use a lower-level language like Fortran, C or Java (your choice), to solve the same or extended equations describing further effects (e.g. harmonic light generation) and then present the solutions in a meaningful way using available plotting packages.

The skills that you will learn are generic to a working theoretical/computational physicist and will prepare you well for a future career in this field. A good student should be able to take the analysis further and begin looking at more advanced topics. This will be like performing 'numerical experiments'. From these, it may be possible to predict new effects that can enhance or extend current XFEL performance.

Key Reference:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, **4**, 814, 2010
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	25%
Comp:	75%

Suitability: MPhys, BSc, BSc (Maths Physics)

Safety Training Requirements: *Normal office/computer user induction.*

The theory of X-ray Free electron Lasers

(1) Dr. Brian McNeil, (2) Dr. Gordon Robb

Project Description:

X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2].

The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level.

The supervisor of this project Dr Brian McNeil, works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

This project will involve the derivation of the working equations that describe the FEL process from the coupled Maxwell and Lorentz force equations. This will involve deriving equations that describe the trajectories of the relativistic electrons as they propagate through the undulating magnetic fields, how they consequently radiate light, how they then couple to this light, and how this coupling feeds back onto the electrons. Once derived, these non-linear equations can be analysed and simplified to obtain a set of coupled linear differential equations that can be solved analytically to obtain a solution.

The skills that you will learn are generic to a working theoretical physicist and will prepare you well for a future career in any theoretical field. A good student may be able to take this theoretical analysis further and begin looking at more advanced topics involving a degree of research into areas that have previously not been well explored, and perhaps even predicting new and useful practical ideas.

Key Reference:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
*[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, **4**, 814, 2010*
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Ratio of effort: Exp/Theo/Comp Exp: 0%
Theo: 80%
Comp: 20%

Suitability: MPhys BSc, BSc (Maths Physics)
Additional comments:
Safety Training Requirements: *Normal office/computer user induction.*

The scientific applications of X-ray Free Electron Lasers

(1) Dr. Brian McNeil (2) Dr. Gordon Robb

Project Description:

X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2].

The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level.

The supervisor of this project Dr Brian McNeil, works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

Starting from the basic working equations that describe the FEL process, the student will gain an understanding of how an XFEL works and the properties of the light they emit. You will then review the range of basic science that the output from XFELs is being applied to. This covers a wide range from the creation and studies of warm dense matter to the functioning of *in-vivo* organisms and processes. The student will identify the unique features of XFEL output, describe and explain the methods used to apply them in a range of experiments. They will also look forward to future potential application/experiments given an improvement in XFEL output or detection methods. This will require some analysis and numerical calculations to verify their feasibility.

A good student may be able to identify areas where significant advances would have an impact – for example, what if the XFEL were extended into the gamma range of the spectrum? Again, some analysis and numerics may be required to back up any conjectures made.

Key Reference:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, ***4****, 814, 2010*
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	50%
Comp:	30%

Suitability: BSc BSc (Phys with Teaching) BSc (Maths Physics)

***For MPhys students the project should be designed to last for two years**

Safety Training Requirements: *Normal office/computer user induction.*

Modelling a Hybrid Atom-Superconductor Quantum System

(1) Dr. Jonathan Pritchard, (2) Dr. Daniel Oi

Project Description:

Hybrid quantum systems combine disparate quantum technologies as a route to overcoming some of the challenges that prevent scalable quantum information processing. Coupling atoms to superconducting circuits using planar microwave resonators is a promising approach to obtaining fast processing, long term storage and optical coupling in a single device.

A key challenge for these systems is to reach the strong coupling regime whilst operating a finite temperature, where thermal occupation of the microwave resonator must be considered. The goal of this project is to explore the role of temperature in a coupled atom-superconductor system and whether it is possible to exploit strong coupling of the atom to the cavity mode to enable cooling of the cavity to permit high fidelity quantum operations at finite temperature.

The project will utilise the well documented QuTiP2 library for Python, which permits simple and efficient modelling of this complex system as well as a wide range of plotting and data visualisation tools. The open-ended nature of such a tool means students can later extend the project, for example to consider cavity-mediated interactions between pairs of atoms in the cavity field.

Key References: *Henschel et al,"Cavtiy QED with an ultracold ensemble on a chip: Prospects for strong magnetic coupling at finite temperatures" Phys Rev A **82,** 033810 (2010)*

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	50 %
Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: *Experience using Python would be beneficial but not essential.*

Additional comments:

Safety Training Requirements:

Programming a Gaussian-beam calculator with MATLAB

(1) Dr. Elmar Haller, (2) Prof. Dr Stefan Kuhr

Project Description:

The properties of Gaussian laser beams can be shaped by optical components, such as lenses, pin-holes, or wave plates and the propagation of the beam can be calculated analytically. For everyday lab-work it is extremely helpful to determine the expected shape and polarization of a laser beams before constructing the beam path on an optical table.

The goal of this project is to create a software program, which calculates the propagation of a Gaussian beam. The program should be written in the language MATLAB, and it should provide a simple interface for the user, which allows for a direct manipulation of the optical components with a computer mouse. The resulting program needs to be well documented and it will be published on the internet at MATLAB Central. The student will learn about the analytical description of Gaussian beams, the design of user interfaces, and the programming language MATLAB.

Ratio of effort: Exp/Theo/Comp	Exp:	5%
	Theo:	30%
	Comp:	65%

Suitability: MPhys, BSc, BSc Maths and Physics,

Additional comments: *The student should be familiar with basic programming and user interfaces (languages: Matlab).*

Safety Training Requirements: *None.*

3D-Printing of optics equipment in a laser laboratory

(1) Dr. Elmar Haller, (2) Prof. Dr Stefan Kuhr

Project Description:

Opto-mechanics, such as laser shutters, lens and mirror mounts, and other positioning elements are essential components in a laser laboratory. Even for small items typical costs are 10s to 100s of pounds. Over the last year an active community has formed to replace commercial components by self-made, 3D-printed alternatives, which can be directly produced and adopted by the end-user.

The goal of this project is to assess the possibly to create 3D-printed optics equipment. The project will start with the search for existing, open-source designs of components, and for printing-software. The student will design his/her own components with the CAD program Inventor. The new components need to be well documented and published on the internet. Finally, it is essential to test the components in the laboratory within an optical setup. Important test parameters are stiffness, thermal expansion, and the precision of the 3D printing process.

Ratio of effort: Exp/Theo/Comp	Exp:	50%
	Theo:	10%
	Comp:	40%

Suitability: MPhys, BSc, BSc Maths and Physics,

Additional comments: *The student should be familiar with basic programming and have an interest in computer aided design.*

Safety Training Requirements: *None.*

Topological band structures in optical lattices

(1) Prof. Andrew Daley, (2) Dr. Luca Tagliacozzo

Project Description:

Over the past fifteen years, experiments with ultracold atoms in optical lattices have developed to the point where they can be used as so-called "quantum simulators" of many-body physics that is usually associated with electrons in solid-state physics. In addition to addressing long-standing problems associated with theoretical condensed matter physics, this opens opportunities to explore novel physics in tailored lattice crystals (designed by interfering laser light).

An important recent development is the possibility to investigate topological effects, where the system exhibits properties that cannot be understood by looking at it solely locally. Such properties have been associated with many important new discoveries in condensed matter physics in the past decades, beginning with the quantum hall effect. In optical lattices, such systems can be engineered by introducing phases for the atomic motion that are non-zero when the atom returns to its original position.

In this project, we will compute the details involved in realising topological effects in a so-called Lieb lattice, calculating which parameter regimes are available for experiments currently under development and exploring what physics may be observable in such a setup. This will involve the computation of band structures in experimentally realisable lattices, and the resulting dynamics of interacting atoms moving in such bandstructures.

Key References:

Immanuel Bloch, Jean Dalibard and Sylvain Nascimbène, Nature Physics 8, 267 (2012)

F. Meinert, M. J. Mark, K. Lauber, A. J. Daley, and H.-C. Nägerl, Phys. Rev. Lett. 116, 205301 (2016)

M. Di Liberto, A. Hemmerich, C. Morais Smith, arXiv:1604.06055v1

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	40%
	Comp:	60%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: PH351, PH358

Additional comments: This project will involve a mixture of analytical and numerical calculations and will require students to have a particularly strong background in mathematics.

Safety Training Requirements: None

Quantum interference and boson sampler verification

(1) Prof. Andrew Daley, (2) Dr. Marco Piani

Project Description:

There has been a lot of recent interest in developing analogue quantum devices that can effectively perform calculations that are intractable to classical (existing) computers [1]. These include experiments with ultracold atoms in optical lattices, which can be used as "quantum simulators" of many-body physics that is usually associated with electrons in crystals, and boson samplers, a network of optical waveguides that produces samples from a distribution of outputs that would require exponentially difficult classical calculations to reproduce.

An exceptionally important question for all of these devices is how to verify that the output is correct when we are unable to compute the solution on a classical computer. Recently, we have shown how two quantum states for cold atoms in optical lattices may be interfered the therefore compared [2], and this has been realised in experiments [3]. In this project, we will generalise these ideas to the verification of boson samplers, determining a protocol to combine and compare outputs from boson samplers on the level of the whole quantum state at the output. This will involve understanding the content of the output of boson samplers [4], and the quantum interference processes that can be used to compare such outputs.

Key References:

[1] J. I. Cirac and P. Zoller, Nature Physics 8, 264 (2012)

[2] A. J. Daley, H. Pichler, J. Schachenmayer, and P. Zoller, Phys. Rev. Lett. 109, 020505 (2012)

[3] R. Islam et al., Nature 528, 77–83 (2015)

[4] M. A. Broome et al., Science 339, 794 (2013); J. B. Spring et al., Science 339, 798 (2013)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	65%
Comp:	35%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: PH351, PH358

Additional comments: This project will involve a mixture of analytical and numerical calculations and will require students to have a particularly strong background in mathematics.

Safety Training Requirements: None

Quantifying the entanglement of global quantum evolutions and measurements

(1) Dr Marco Piani, (2) Dr Daniel Oi

Project Description:

Entanglement is a very non-classical property of quantum systems composed by many parts. When such parts are entangled, global properties may dominate over individual properties, and may lead to puzzling quantum effects. With the advent of quantum information processing and the effort to tame quantum effects for quantum technologies, entanglement has acquired the status of resource, to be exploited to perform tasks that are impossible in its absence. In particular, entanglement is a precious resource that cannot be created or increased by a set of operations known as Local Operations aided by Classical Communication (LOCC), which is the most general class of manipulation of distributed quantum systems that distant parties can implement without being able to send each other quantum systems --- a natural and technologically motivated restriction. On the other hand, having at disposal initial entanglement to be "consumed" can allow parties to overcome the limit of LOCC. This project regards the quantification of the entanglement needed to implement global quantum operations, like global quantum measurements or global transformations. The student will learn concepts of quantum information theory, and about entanglement. The student will also learn about semidefinite programming optimization techniques, and employ them numerically when studying relevant examples.

Key References:

- M. A. Nielsen and I. L. Chuang, *Quantum computation and quantum information*. Cambridge University Press, 2010.
- J. Watrous, Lecture notes on *Theory of Quantum Information*, available at https://cs.uwaterloo.ca/~watrous/LectureNotes.html
- S. Bandyopadhyay et al., *Limitations on separable measurements by convex optimization*, arXiv:1408.6981 (and references therein)
- N. Yu, R. Duan, and M. Ying, *Distinguishability of quantum states by positive operator-valued measures with positive partial transpose*. IEEE Transactions on In- formation Theory, 60(4):2069–2079, 2014, arXiv:1209.4222 (and references therein)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	65%
Comp:	35%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Familiarity with basic concepts of quantum physics, with linear algebra and some basic matrix analysis, and with the use of Matlab

Additional comments: None

Safety Training Requirements: None

Quantifying correlations through the Operator Schmidt Decomposition

(1) Dr. Marco Piani, (2) Dr. Daniel Oi

Project Description:

Quantum systems, like photons or particles with spin, can be correlated to various degrees, going from actually being uncorrelated, to being entangled. Entanglement is a strong form of correlations, which is at the basis of many puzzling quantum phenomena as well as quantum technologies. The information about the state of a quantum system --- for example of a system composed of subsystems that may be correlated --- is encoded in the so-called density matrix. The proposed project is about studying --- and in particular, quantifying --- correlations between two quantum (sub)systems, using the so-called Operator Schmidt Decomposition of the density matrix of the total system. The Operator Schmidt Decomposition is a neat way to express the density matrix that emphasizes the presence of correlations between subsystems. The student will learn about the density matrix formalism, about quantum correlations (including entanglement), and about both analytical and numerical tools to study quantum correlations.

Key References:

- M. A. Nielsen and I. L. Chuang, "Quantum computation and quantum information", Cambridge University Press, 2010.
- J. Watrous, Lecture notes on Theory of Quantum Information, available at https://cs.uwaterloo.ca/~watrous/LectureNotes.html (retrieved on 26/08/2016)
- N. Johnston, "What the Operator-Schmidt Decomposition Tells Us About Entanglement", http://www.njohnston.ca/2014/06/what-the-operator-schmidt-decomposition-tells-us-about-entanglement/ (retrieved on 26/08/2016)

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	65%
Comp:	35%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: The student should be familiar with basic concepts of quantum physics, with linear algebra and some basic matrix analysis, with the use of Matlab and Mathematica

Additional comments: None

Safety Training Requirements: None

Quantification of the entanglement of identical particles

(1) Dr. Marco Piani, (2) Prof. Andrew Daley

Project Description:

Quantum systems can be correlated to various degrees, going from actually being uncorrelated, to being entangled. Entanglement is a strong form of correlations, which is at the basis of many puzzling quantum phenomena as well as quantum technologies. The treatment of entanglement, in particular its quantification, becomes delicate when one considers particles that are indistinguishable, like a same species of fermions (e.g., electrons) or bosons (e.g., photons). The present project is about the entanglement of indistinguishable particles and about an innovative approach to the quantification of the entanglement of indistinguishable particles. The student will learn about quantum entanglement, perform a literature review of the concept of entanglement for identical particles, and contribute to the numerical implementation of the new method to quantify entanglement for concrete, albeit theoretical, examples. The student will also learn about semidefinite programming optimization techniques, and employ them numerically when studying relevant examples.

Key References:

- M. A. Nielsen and I. L. Chuang, "Quantum computation and quantum information", Cambridge University Press, 2010.
- Malte Tichy, "Entanglement and interference of identical particles", PhD thesis, 2011, https://www.freidok.uni-freiburg.de/data/8233/

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	65%
Comp:	35%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: The student should be familiar with basic concepts of quantum physics, with linear algebra and some basic matrix analysis, and with the use of Matlab and Mathematica

Additional comments: None

Safety Training Requirements: None

Pattern formation with twisted beams

(1) Dr Alison M Yao, (2) TBC

Project Description:

In optics, the spontaneous breaking of the translational and rotational symmetries in the plane perpendicular to the direction of light propagation leads to pattern formation in the shape of hexagons, stripes, rhomboids and honeycombs. In this project we study transverse pattern formation for nonlinear crystals in optical cavities under the action of two pump waves [1]. As well as regular patterns, this system is ideal for the generation of rogue waves and optical turbulence [2]. In this project we see how the system is affected by using twisted optical waves (Laguerre-Gaussian modes) as the pump and/or injection.

Key References:

[1] G.-L. Oppo, A. M. Yao and D. Cuozzo, "Self-organization, Pattern Formation, Cavity Solitons and Rogue Waves in Singly Resonant Optical Parametric Oscillators", Phys. Rev. A 88, 043813 (2013).
[2] C. J. Gibson, A. M. Yao, and G.-L. Oppo, "Optical Rogue Waves in Vortex Turbulence", Phys. Rev. Lett. **116**, 043903 (2016).

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	30 %
Comp:	70 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None

Nonlinear Propagation of Structured Light

(1) Dr Alison M Yao, (2) TBC

Project Description:

Laser beams propagating in linear materials diverge during propagation. This diffraction can be compensated for by propagating through nonlinear materials that exhibit an intensity-dependent refractive index. Balancing the divergence and self-focusing results in a beam, known as a spatial soliton, that can propagate without changing shape. However, it is experimentally challenging to achieve this without suffering catastrophic beam collapse. Introducing saturation of the nonlinearity leads to an increase in stability by periodically modulating self-focusing effects first and filamentation later.

Laguerre-Gaussian (LG) modes are ring-like beams with an $\boldsymbol{l}$-fold helical phase structure that carry an orbital angular momentum (OAM). These are of interest due to their potential to carry an increased information content. Unfortunately these are seen to fragment during propagation in a Kerr medium to form $\boldsymbol{2l}$ filaments. Their stability can be increased, however, by using a superposition of LG modes with orthogonal polarisations. The resultant beam has a polarisation that is spatially structured and the aim of this project is to investigate how this polarisation structure, together with the OAM, affects the stability. The result will provide a novel approach to transport high-power light beams in nonlinear media with controllable distortions to their spatial structure and polarization properties.

Key References:

[1] W. J. Firth and D. Skryabin, Phys. Rev. Lett. **79**, 2450 (1997)

[2] A. S. Desyatnikov and Y. S. Kivshar, Phys. Rev. Lett. **87**, 033901 (2001) .

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	30 %
Comp:	70 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None

Non Resonant Optical Cavities

(1) Dr Nigel Langford, (2) Dr Alison Yao

Project Description:

Optical spectroscopy is a simple way of detecting pollutants in the atmosphere. In most cases the interaction between the absorbing species and the light is described by Beer's Law (I = Ioexp(-aL)) where L is the interaction length and a is the absorption coefficient. In many cases a is small and so to achieve a detectable change in I requires a long interaction length. One way of doing this is to contain the light in a non-resonant optical cavity whereby the mirrors of the cavity are arranged to allow the light to make multiple bounces. This project will involve modelling of the cavity by use of traditional beam tracing methods (ABCD Matrix approach) as well as using Huygens' Integral approach. The modelling will be done using MatLab.

Key Reference:

1. H. Kogelnik and T. Li, "Laser beams and resonators", Am J. Phys., Vol. 5, No. 10, pp.1550–67 (1966).
2. Kogelnik, H. and Li, T., Laser Beams and Resonators, Applied Optics, Vol. 5, pp. 1551-1552, 1966.
3. McManus, J. B., Kebabian P. L., & Zahniser M. S. Astigmatic mirror multipass absorption cells for long-path-length spectroscopy, Applied Optics, Vol. 33, pp.3336, 1995.
4. Arnaud, J.A. and Kogelnik, H., Gaussian Light Beams with General Astigmatism, Vol. 8, Issue 8, pp. 1687-1693, 1969.

Ratio of effort: Exp/Theo/Comp

Exp:	**0 %**
Theo:	**0%**
Comp:	**100 %**

Suitability: MPhys, BSc Physics, BSc Physics with Teaching, BSc Maths and Physics

Safety Training Requirements: Laser Safety

Resonant Optical Cavities

(1) Dr Nigel Langford, (2) Dr Alison Yao

Project Description:

Optical spectroscopy is a simple way of detecting pollutants in the atmosphere. In most cases the interaction between the absorbing species and the light is described by Beer's Law (I = Ioexp(-aL)) where L is the interaction length and a is the absorption coefficient. In many cases a is small and so to achieve a detectable change in I requires a long interaction length. One way of doing this is to contain the light in a resonant optical cavity whereby the mirrors of the cavity are arranged to allow the light to make multiple bounces. This project will involve modelling of the cavity by use of traditional beam tracing methods (ABCD Matrix approach) as well as using Huygens' Integral approach. The modelling will be done using MatLab.

Key Reference:

1. H. Kogelnik and T. Li, "Laser beams and resonators", Am J. Phys., Vol. 5, No. 10, pp.1550–67 (1966).
2. Kogelnik, H. and Li, T., Laser Beams and Resonators, Applied Optics, Vol. 5, pp. 1551-1552, 1966.
3. McManus, J. B., Kebabian P. L., & Zahniser M. S. Astigmatic mirror multipass absorption cells for long-path-length spectroscopy, Applied Optics, Vol. 33, pp.3336, 1995.
4. Arnaud, J.A. and Kogelnik, H., Gaussian Light Beams with General Astigmatism, Vol. 8, Issue 8, pp. 1687-1693, 1969.

Ratio of effort: Exp/Theo/Comp		
	Exp:	**0 %**
	Theo:	**0%**
	Comp:	**100 %**

Suitability: MPhys, BSc Physics, BSc Physics with Teaching, BSc Maths and Physics

Safety Training Requirements: Laser Safety

Plasmas Division

Simulation and measurement of two-dimensional periodic surface lattice

(1) Prof. Adrian W. Cross, (2) Dr. Craig W. Robertson

Project Description:

The main goal of the project is to study the interaction between two-dimensional (2D) periodic surface lattice (PSL) structures and electromagnetic waves. The primary objectives are: 1/ Theoretical study of electromagnetic wave propagation through a cylindrical 2D periodic surface lattice; 2/ Develop a CST Microwave Studio computer model of electromagnetic wave interaction with the 2D PSL; 3/ Experimental study of the transmission of electromagnetic radiation through the cylindrical 2D periodic surface lattice.

The properties of a periodic structure will be measured using a Vector Network Analyser. Experimental measurements will be compared with CST Microwave Studio simulations of the transmission of electromagnetic radiation through the structures**.**

Key Reference:

*[1] I.V. Konoplev, A.J. MacLachlan, C.W. Robertson, A.W. Cross and A.D.R. Phelps, 'Cylindrical periodic surface lattice as a metadielectric: Concept of a surface-field Cherenkov source of coherent radiation' Phys. Review A., **84**, art. 022902, 2011.*

*[2] I.V. Konoplev, A.J. MacLachlan, C.W. Robertson, A.W. Cross and A.D.R. Phelps, "Cylindrical, periodic surface lattice-Theory, dispersion analysis, and experiment, Applied Physics Letters, **101**. 121111, 2012.*

Ratio of effort: Exp/Theo/Comp	Exp:	20%
	Theo:	30%
	Comp:	50%

Suitability: PH550 M.Phys.

Additional comments:

Safety Training Requirements:

Design and simulation of a millimetre wave source based on a pseudospark produced electron beam

(1) Prof. Adrian W. Cross, (2) Dr. Huabi Yin

Project Description:

A project is proposed to design, simulate and numerically model a Backward Wave Oscillator (BWO) driven by a pseudospark (PS) electron beam. The BWO is based on the interaction between an electron beam and the negative spatial harmonic of a corrugated slow wave structure. The energy velocity in the slow-wave structure moves opposite to the phase velocity of the negative spatial harmonic. If the electron beam is synchronised with the negative spatial harmonic then the energy of the electron beam transfers to the field in the backward (with respect to the direction of beam propagation) direction [1].

A pseudospark (PS) is an axially symmetric, self-sustained, transient, low pressure (typically 50-500 mTorr) gas discharge in a hollow cathode/planar anode configuration, which operates on the low pressure side of the hollow cathode analog to the Paschen curve [2]. A useful property of this type of discharge is the formation of an electron beam during the breakdown process. During a PS discharge, low temperature plasma is formed as a copious source of electrons and can be regarded as a low work function surface that facilitates electron extraction [3]. Because of the special geometry and discharge mechanism, the electron beam from a PS discharge can propagate without an external magnetic guiding field due to the existence of an ion-focusing channel. The ion-focusing channel is formed due to the background gas ionization by the front of the electron beam itself. For generation of high frequency radiation in millimetre wave and sub-millimetre wave region this beam is ideal due to its small beam size, compactness and long lifetime. The project will involve the design of a millimetre wave BWO using analytical theory with the beam/wave interaction modelled using the numerical simulation code MAGIC.

Key Reference:

[1] S. E. Tsimring "Electron Beams and Microwave Vacuum Electronics", Wiley Series in Microwave and Optical Engineering, John Wiley and Sons Inc, ISBN-13-978-0-470-04816-0, (2007).

[2] H. Yin, A. W. Cross, W. He, A. D. R. Phelps, K. Ronald, D. Bowes, C.W. Roberson "Millimeter wave generation from a pseudospark-sourced electron beam". Phys. Plasmas 16 (2009).

[2] D. Bowes, H. Yin, W. He, A.W. Cross, K. Ronald, A.D.R. Phelps, D. Chen, P. Zhang, X. Chen and D. Li, "Visualization of a Pseudospark-Sourced Electron Beam", IEEE Transaction on Plasma Science, 42, 10, pp2826-2827, (2014).

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	30%
Comp:	50%

Suitability: PH450 BSc

Additional comments:

Safety Training Requirements:

Femtosecond chemistry with laser-plasma-accelerators

(1) Prof. Bernhard Hidding, (2) Dr. Grace Manahan

Project Description:

Femtochemistry is an important area of science which requires ultrashort, femtosecond particle and/or light pulses. Laser Wakefield Acceleration (LWFA), which is a trending topic worldwide and at Strathclyde can produce such pulses. The goal of this project is to understand how LWFA works, what kind of particle and light pulses can be produced on the one hand side, and on the other what the requirements are for modern ultrafast femtochemistry and which state-of-the-art accelerator systems (e.g. free-electron lasers) are used for this today. Based on these boundary conditions, suitable proof-of-concept experiments shall be designed. This involves also the selection of suitable systems both as regards relevance as well as regards feasibility of detection.

Key References: www.scapa.ac.uk http://silis.phys.strath.ac.uk/wp/ www.hybrids.desy.de
Laser-plasma accelerator based femtosecond high-energy radiation chemistry and biology, J Phys. 2012
Principles and applications of compact laser–plasma accelerators, nature Physics 2008

Ratio of effort: Exp/Theo/Comp

Exp:	10 %
Theo:	70 %
Comp:	30 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *None. Laser knowledge advantageous.*

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Coherent and incoherent combination of laser pulses

(1) Prof. Bernhard Hidding, (2) Dr. Grace Manahan

Project Description:

Laser Wakefield Acceleration (LWFA) is a trending topic worldwide, and Strathclyde has a leadership role based on its decade-long track record. State-of-the-art laser wakefield acceleration ultilises Ti:Sapphire laser pulses with a central wavelenth of 800 nm. This is mainly because in order to excite a strong plasma wave one needs laser pulses with gigantic powers of the order of tens of TW or more, and Ti:Sapphire is a strightforward medium to achieve that. An alternative method to achieve such high-power laser pulses is, instead of producing one laser pulse, to produce a number of weaker laser pulses and to combine those coherently or incoherently. Such low-power laser pulses may be produced by fiber lasers, which are much more energy efficient than single high-power-TW laser pulses.

The requirements and feasiblity of this method shall be analysed and compared with state-of-the-art LWFA. The most promising near-term application(s) shall be identified and a proof-of-concept experiment shall be designed.

Key References: *www.scapa.ac.uk* *http://silis.phys.strath.ac.uk/wp/* *www.hybrids.desy.de* *https://www.rp-photonics.com/coherent_beam_combining.html*

Plasma wakefields driven by an incoherent combination of laser pulses: A path towards high-average power laser-plasma accelerators, Benedetti 2014

Coherent addition of fiber-amplified ultrashort laser pulses, Seise et al. 2010

The future is fibre accelerators, Nature Photonics 2013

Ratio of effort: Exp/Theo/Comp

Exp:	10 %
Theo:	70 %
Comp:	30 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *None. Laser knowledge advantageous.*

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Mid-Infrared Laser Wakefield Acceleration

(1) Prof. Bernhard Hidding, (2) Dr. Grace Manahan

Project Description:

Laser Wakefield Acceleration (LWFA) is a trending topic worldwide, and Strathclyde has a leadership role based on its decade-long track record. State-of-the-art laser wakefield acceleration ultilises Ti:Sapphire laser pulses with a central wavelenth of 800 nm. This is mainly because in order to excite a strong plasma wave one needs laser pulses with gigantic powers of the order of tens of TW or more, and Ti:Sapphire is a strightforward medium to achieve that. However, there is a novel class of laser systems on the horizon which operates instead at mid-IR wavelengths up to CO_2-laser wavelength of 10 µm. This is a very different regime but has certain benefits, such as regards the production of ultralow emittance beams – which may have disruptive impact on photon science as well as high energy physics.

Fundamental differences of mid-IR LWFA when compared to state-of-the-art LWFA shall be analysed theoretically, e.g. as regards the ponderomotive potential, key electric fields, ionisation behaviour, dephasing and diffraction effects etc. Computational tools such as OOPIC shall be used to simulate basic LWFA effects, and impact on plasma wakefield accelerator strategy shall be discussed.

Key References: www.scapa.ac.uk http://silis.phys.strath.ac.uk/wp/ www.hybrids.desy.de
Modeling of laser wakefield acceleration at CO2 laser wavelengths, PRSTAB 2003
Two-Color Laser-Ionization Injection, PRL 2014
Ultra-low emittance beam generation using two-color ionization injection in a CO2 laser-driven plasma accelerator, arXiv 2015
Ultrahigh brightness bunches from hybrid plasma accelerators as drivers of 5th generation light sources, J. Phys. B 2014

Ratio of effort: Exp/Theo/Comp		
	Exp:	10 %
	Theo:	60 %
	Comp:	40 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *None. Laser knowledge advantageous.*

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Space Radiation Reproduction and Testing

(1) Prof. Bernhard Hidding, (2) Dr. Grace Manahan

Project Description:

Space radiation is a great danger to electronics and astronauts onboard space vessels. The spectral flux of space electrons, protons and ions for example in the radiation belts is inherently broadband, but this is a feature hard to mimic with conventional radiation sources. Using laser-plasma-accelerators such as those developed at Strathclyde, however, has the potential to reproduce important kinds of space radiation exactly. Thus could have transformative impact for space exploration, because better testing may lead to better performance of space missions. Various effects of radiation in space such as spacecraft charging, single event effects etc. shall be explored and the suitability of laser-plasma-based particle radiation to generate such effects shall be analyzed. In particular, the effect of secondaries which may be generated upon incidence of high energy particles shall be analysed. This requires detailed knowledge of stopping power and reactions in the matter (both electronics as well as biological systems shall be regarded). Such secondaries are currently shifting in the focus of the testing industry. A proof-of-concept experiment shall be designed which is suitable to demonstrate such secondary production and its effect on space electronics or for radiabiology.

Key References: www.scapa.ac.uk http://silis.phys.strath.ac.uk/wp/ www.hybrids.desy.de

Design Considerations for the use of laser-plasma-accelerators for advanced space radiation studies, T. Königstein, O. Karger, G. Pretzler, J.B. Rosenzweig, and B. Hidding, J. Plasma Physics, 2012

Laser-plasma-accelerators -- A novel, versatile tool for space radiation studies, B. Hidding, T. Königstein, O. Willi, J.B. Rosenzweig, K. Nakajima, and G. Pretzler. Nucl. Instr. Meth. A, Vol. 636, 1, 2011.

Ratio of effort: Exp/Theo/Comp

Exp:	10 %
Theo:	70 %
Comp:	30 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *None. Laser knowledge advantageous.*

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Beam-driven Plasma Wakefield Acceleration (PWFA)

(1) Prof. Bernhard Hidding, (2) Prof. Dino Jaroszynski

Project Description:

Electron beams can drive plasma waves for generation and acceleration of highest brightness electron beams, which is strongly desired for advanced free-electron lasers. Suitable electron beam drivers can be produced by conventional accelerators such as SLAC as well as by laser wakefield acceleration. PWFA is a highly trending field and will be studied in by means of particle-in-cell simulations as well as in experiments in which the electron bunch output from laser-plasma-accelerators in Strathclyde will be used for the first time for PWFA. One special additional feature is the development of the underdense photocathode (aka Trojan horse) concept [1-2].

Key Reference: [1] *B. Hidding, G. Pretzler, J.B. Rosenzweig, T. Königstein, D. Schiller, D.L. Bruhwiler, Ultracold Electron Bunch Generation via Plasma Photocathode Emission and Acceleration in a Beam-driven Plasma Blowout, Physical Review Letters 108, 035001, 2012 (4 pages) [2] Hybrid modeling of relativistic underdense plasma photocathode injectors*

Y. Xi, B. Hidding, D. Bruhwiler, G. Pretzler, and J. B. Rosenzweig, PRSTAB 16, Issue 3, 031303 (2013)

Ratio of effort: Exp/Theo/Comp	Exp:	40%
	Theo:	20%
	Comp:	40%

Suitability: MPhys, BSc, BSc (Phys with Teaching), BSc (Maths Physics)

Additional comments: *Knowledge in laser and plasma and accelerator physics is helpful but not mandatory. Anyone interested in taking up this project should contact the supervisors beforehand*.

Safety Training Requirements: *Contact the project supervisor for further advice*

Investigation of energy exchange in relativistically transparent laser-plasma interactions

(1) Prof. Paul McKenna, (2) Dr. Martin King

Project Description:

The energy exchange between the various induced fields and particle populations within laser-plasma interactions is important in various fields of physics such as astrophysics, fusion and laser-driven accelerators. During the interaction of an ultra-intense laser pulse with a solid target, particles can be accelerated to very high energies via multiple different acceleration mechanisms. In particular, ions can gain energy if the target becomes relativistically transparent to the laser (i.e. when the relativistically corrected electron density is reduced below the critical density of the laser).

This project will investigate the energy exchange mechanism from the laser pulse into the ions after relativistic transparency has occurred. This will involve numerical modelling through the use of particle-in-cell simulations along with some analytic analysis of the processes involved. MATLAB will also be used to perform the analysis of the numerical data.

Key References:

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	20%
Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

The effect of target composition on laser-driven ion acceleration

(1) Prof. Paul McKenna, (2) Dr. Martin King

Project Description:

Ion acceleration can be achieved through the interaction of an ultra-intense (>10^{20} Wcm^{-2}) laser pulse with a solid density target. This can have potential future applications in diverse fields such as medical oncology, astrophysics or fast-ignition inertial confinement fusion. The choice of target composition can greatly affect the underlying ion-acceleration mechanisms. It is therefore important to characterise this effect through the systematic variation of different target compositions. Of particular interest is comparing polymers of different carbon/proton ratios and single ion species with varying ion/electron ratios.

This project will therefore investigate the role of target composition on laser-driven ion-acceleration. This will involve numerical modelling through the use of particle-in-cell simulations as well as the use of MATLAB to analyse the resultant data.

Key References:

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	20%
Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Medical Radioisotope Production using a Laser-Plasma Wakefield Accelerator

(1) Dr. Mark Wiggins, (2) Prof. Dino Jaroszynski

Project Description:

Laser-plasma wakefield accelerators (LWFAs) are very compact laser-driven accelerators that have the potential to replace conventional accelerators in many applications. Reactors are usually used to produce medical radioisotopes (primarily Tc-99m), but their imminent decommissioning is threatening a world-wide shortage. Cyclotrons can be used but these are expensive. This project will explore how a LWFA can be used to produce radioisotopes for diagnostic imaging such as positron emission tomography (PET) or for in vivo targeted radiation therapy (alpha or beta particle emitters).

These applications cover a wide variety of biologically important isotopes such as C-11, O-15, Cu-62, Cu-64, Tc-99m and Ac-225 and the flexibility of the LWFA lends itself to be a potential source of many useful isotopes. Proof-of-principle studies are underway to demonstrate the LWFA as a viable driver for medical radioisotope production. A monoenergetic, high energy electron beam from a LWFA is used to produce gamma rays via bremsstrahlung from the electron beam as it interacts with a metallic converter. The gamma rays then interact with a secondary target to produce the desired radioisotope via photonuclear reactions.

This project involves the use of a Monte Carlo simulation code to model the nuclear reaction processes for a variety of the radioisotope scenarios with a view towards optimising the experimental setup. Favourable scaling towards single patient doses for future high repetition rate LWFAs will also be explored.

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	20%
	Comp:	80%

Suitability: MPhys, BSc, BSc (Phys with Teaching), BSc (Maths Physics)

Excitation of Heavy Atomic Species for ITER

(1) Prof. Nigel Badnell, (2) Prof. Bob Bingham (TBC)

Project Description:

The development of the ITER device for magnetic fusion requires the use of much heavier elements (Kr, Xe, W etc) than have traditionally been used, such as at the JET device.

Consequently, spectroscopic diagnostic modelling at ITER, which is already being simulated, requires atomic data where relativistic effects are likely much larger than have been seen before. The goal of the project is to assess the degree of importance of relativistic effects of relevance to ITER diagnostics. This will entail computational calculations of atomic data with varying degrees of treatments of relativistic effects viz. non-relativistic vs relativistic wavefunctions, the importance of the Breit interaction and the validity of its Pauli approximation at `low'-charge.

Key Reference: *http://www.iter.org/*

Ratio of Experiment/Theory/Computation:

Exp:	0 %
Theo:	30 %
Comp:	70 %

Suitable for: MPhys

Additional Comments: *Familiarity with Unix (e.g. Linux) working environment and good computing skills in general.*

Safety Training Requirements:

Atomic Processes for Astrophysical Plasmas

(1) Prof. Nigel Badnell, (2) TBC

Project Description:

Collisions of electrons and photons with atoms, ions and molecules play a fundamental role in unfolding our understanding of the origin and evolution of the Universe. Knowledge of atomic collision processes permits investigations of past and present states of galaxies, gas clouds, stars and other objects via spectroscopy. In particular, the state of matter in each object the distribution of temperature and density, chemical composition, flow velocities, and the like may be determined. This kind of information is deduced from the spectra of the objects through diagnostic analysis in which models incorporating the full physics of the object confront the observations. It is these models which we seek to support.

In recent years, a wealth of XUV satellite spectra of solar (SOHO, Hinode/EIS, STEREO, SDO) and astrophysical (Chandra, XMMNewton, HST, FUSE) plasmas of the most varied sources (e.g. the solar corona, stellar atmospheres, supernova remnants, AGN, comets) have shown the richness in spectral lines and the potential for plasma diagnostics.

The project aim is to support atomic physics calculations needed to keep pace with observational capability, in order to enhance the scientific returns from these costly missions.

http://www.apapnetwork.org/

Key Reference: *Foster et al "The Challenges of Plasma Modeling: Current Status and Future Plans" Space Sci. Rev. v157 13554 (2010) http://link.springer.com/article/10.1007/s1121401097321*

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	30%
Comp:	70%

Suitability: MPhys, BSc, BSc (Maths Physics)

Additional comments: *Familiarity with Unix (e.g. Linux) working environment and computing skills will be helpful.*

Safety Training Requirements: *N/A*

Stochastic Particle Heating of Charged Particles by Plasma Waves

(1) Dr. Bengt Eliasson, (2) Dr. Kevin Ronald

Project Description:

Plasmas are ubiquitous in space and laboratory. The Earth is surrounded by a plasma layer, the so-called ionosphere, which shields us from radiation and energetic particles from the sun, and in the laboratory, plasmas are artificially created and studied with application to magnetic confinement fusion and basic research. A plasma is an ionised gas in which there are free electrons and ions so that the gas is electrically conducting. The Earth's ionosphere is magnetized by the geomagnetic field, and in the laboratory, an external magnetic field is used to confine the plasma and prevent it from escaping to the walls. The acceleration of charged particles by electromagnetic waves can lead to chaotic motion of the particles and a rapid heating of the magnetised plasma due to the complicated motion of the particles. This is important for heating of particles in the laboratory, in magnetic confinement fusion devices, in the solar corona, in the Earth's ionosphere, etc., where collisions between particles are relatively rare. Stochastic heating is therefore different from Ohmic heating which is due to collisions between particles.

The project involves at building a numerical model for stochastic heating of charged particles (electrons and/or ions) in magnetized plasmas by using test-particle simulations, and to use the numerical model to study some different cases where stochastic heating takes place. A theoretical derivation and understanding of the mathematical models is also part of the project.

Key Reference: *J. M. McChesney, R. A. Stern, and P. M. Bellan (1987) Observation of fast stochastic ion heating by drift waves, Phys. Rev. Lett. 59, 1436-1439.*

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	50%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: *Experience in simulations using Matlab (or any other programming language) and good theoretical skills are beneficial.*

Safety Training Requirements:

Simulations of magnetic turbulence in plasma

(1) Bengt Eliasson, (2) Kevin Ronald

Project Description:

Plasmas are ubiquitous in space and laboratory. The Earth is surrounded by a plasma layer, the so-called ionosphere, which shields us from radiation and energetic particles from the sun, and in the laboratory, plasmas are artificially created and studied with application to magnetic confinement fusion and basic research. A plasma is an ionised gas in which there are free electrons and ions so that the gas is electrically conducting. An outstanding problem in science is the generation of magnetic field in the Cosmos, and the generation of magnetic fields are also observed in laser-plasma interactions. Plasmas are inherently nonlinear systems, and often show unpredictable and turbulent behaviour.

The project involves at building a numerical model for fluid turbulence of electrons in plasmas and magnetic field generation due to temperature and density gradients. A theoretical derivation and understanding of the mathematical models is also part of the project.

Key Reference: B. Eliasson, P. K. Shukla, and V. P. Pavlenko (2009), Dynamics of nonlinearly interacting magnetic electron drift vortex modes in a nonuniform plasma, Physics of Plasmas 16, 042306, doi:10.1063/1.3103785.

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	50%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: Experience in simulations using Matlab (or any other programming language) and good theoretical skills are beneficial.

Safety Training Requirements:

Design of a Brewster Window for a W-band Gyro-TWA

(1) Dr. Wenlong He, (2) Dr. Liang Zhang

Project Description:

A W-band gyrotron-travelling wave amplifier (gyro-TWA) based on a helically corrugated waveguide and a cusp electron gun is currently being studied. It is predicted to achieve an output power of 5 kW over a wide frequency band of 90 - 100 GHz. For an amplifier the microwave window, which separates the high vacuum side from the atmospheric pressure outside must couple in or out the microwave power with minimum absorption or reflection, and is one of the critical components for the successful operation of the gyro-TWA.

In this project, a Brewster-type microwave window will be studied using analytical theory. Numerical simulations Brewster-type microwave window will be carried out using CST Microwave Studio. A corrugated waveguide that maintains the Gaussian-like HE mode required for the Brewster window will also be designed and simulated. The design goals of the Brewster window are 10% bandwidth at a centre frequency of 95 GHz, small insertion loss and a reflection of less than -20 dB for the operating band. If the design meets the requirement, the Brewster window will be manufactured and measured using a Vector Network Analyser (VNA).

Key References:

[1] Wenlong He, Craig R. Donaldson, Liang Zhang, Kevin Ronald, Paul McElhinney and Adrian W. Cross, "High Power Wideband Gyrotron Backward Wave Oscillator Operating towards the Terahertz Region", Physical Review Letters, 110(16):165101, 04, 2013.

[2] Paul McElhinney, Craig R. Donaldson, Liang Zhang and Wenlong He, "A High Directivity Broadband Corrugated Horn for W-band Gyro-devices", IEEE Transactions on Antennas and Propagation, vol. 61, no. 3, pp. 1453-1456, 2013.

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	30%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments:

Safety Training Requirements: *High voltages will **not** be used and X-ray emission will **not** be generated during this project although a risk assessment will need to be completed in semester 1.*

Design and Measurement of a Mode Converter for a Microwave Amplifier

(1) Dr. Wenlong He, (2) Dr. Craig Donaldson

Project Description:

A microwave amplifier in the form of a gyrotron traveling wave amplifier is being studied at the University of Strathclyde. The amplifier uses the interaction between a rotating electron beam and a low power microwave signal to amplify the microwaves to high power over a wide bandwidth. In order to have the correct interaction a low power microwave signal needs to go through a mode converter to change from a $TE_{1,1}$ mode to a $TE_{3,1}$ mode.

In this project, a mode converter will be studied using analytical theory. Numerical simulations will be carried out using CST Microwave Studio. This converter is a four-fold helical corrugated waveguide. Initially this will be studied and measured using a vector network analyser (VNA), at X-band frequencies ~9 GHz.

In year 2 of the project the converter will be scaled down in size to operate at a much higher frequency in the W-band, at ~ 94 GHz. In both applications the converter will have to operate over the amplifiers bandwidth range of 10GHz and have a high conversion efficiency whilst maintaining a low reflection coefficient.

Key Reference: *He W., Donaldson C.R, Zhang L., Ronald K., McElhinney P., and Cross A.W., "High power wideband gyrotron backward wave oscillator towards the terahertz region", Phys. Rev. Letts, 110, art 165101, (2013).*

Ratio of effort: Exp/Theo/Comp	Exp:	25%
	Theo:	25%
	Comp:	50%

Suitability: MPhys

Additional comments:

Safety Training Requirements: *High voltages and X-ray emission will **not** be required for this project although a risk assessment will need to be completed in semester 1.*

Simulations of the Demonstration of Ionisation Cooling Experiment

(1) Dr. Alan Young, (2) Dr. Kevin Ronald

Project Description:

Due to their greater mass than electrons (approximately 200 times greater) and their decay mechanism, muons are very appealing for the study of fundamental particle physics, either through a muon collider or a neutrino factory. An important step in realising this potential are the development of techniques to improve the quality of muon beams and ionisation cooling has been identified as an attractive method for achieving this. Ionisation cooling uses the interaction of the muons with low Z absorbers to reduce the momentum spread while RF cavities are used to maintain the energy. Such a mechanism is very rapid, this is critical as with a mean lifetime of 2.2µs it is essential that the muons are rapidly cooled and accelerated to relativistic velocities to extend their lifetime. The international Muon Ionisation Cooling Experiment (MICE) aims to demonstrate this effect for the first time. Current models of the MICE experiment have assumed certain levels of RF gradient and field structure in the cavities. This project will aim to test the sensitivity of ionisation cooling to these parameters.

Key Reference: *Adams D. et al, 2013, 'Characterisation of the muon beams for the Muon Ionisation Cooling Experiment' Euro. Phys. J. C,* ***73,*** *art. 2582*

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	20%
Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Additional comments:

Safety Training Requirements:

High-Power Microwave Sources

(1) Dr. Phil MacInnes, (2) Dr. Kevin Ronald

Project Description:

High-power microwave sources, developed for a range of applications, are of significant interest, both in industry and the academia, with new sources showing increases in achievable output frequency and power capacity. In particular this project will investigate sources based on free electron physics whereby the kinetic energy in an electron beam provides the free energy to excite a powerful electromagnetic wave.

The aim of this project is to perform a design study, investigating the current state of the art of a particular class of high power microwave source. This would involve understanding the theoretical principles underpinning the operation of the source(s) and include a review of published results. Numerical simulation, both of the passive components and the active device, will be used to evaluate the potential output power, operating frequency, bandwidth and the dependence of these performance characteristics on the adjustment of various control parameters in a given design.

Over the course of the project the student will have the opportunity to gain experience working with a range of numerical-simulation codes and their applicability to different stages in source design. The student will also have the opportunity to develop skills working with the numerical solver package MatLab – some pre-existing experience with MatLab would be beneficial but is not required. Similarly there is access to Maple / Excel etc.

It is unlikely that the project will include experimental work. However, should promising results arise from the simulations early on, there is some scope for manufacture and passive testing of parts. In this case the experimental component would be unlikely to exceed 10% of the total work.

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	30-40%
	Comp:	60-70%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Additional comments:

Safety Training Requirements:

Numerical simulation of cyclotron maser amplifiers

(1) Dr. Kevin Ronald, (2) Dr. Alan Young

Project Description:

Applications including communications, RaDAR, industrial heating, fundamental physics research (both particle and plasma physics) and medicine require the amplification of electromagnetic wave signals to levels far in excess of that possible with solid state electronics. Free electron techniques are vital to addressing these needs. Typically an electron beam is accelerated to a high level of kinetic energy, and microwave signals are amplified as they induce a deceleration of the particles. Using the interaction of an EM wave with a gyrating particle beam having a large component of perpendicular velocity has been shown to offer some two orders of magnitude improvement in peak and average power capacity. This project will investigate cyclotron maser amplifiers using a multi-dimensional Finite-Difference Time-Domain method to self consistently model the evolution of the EM fields and particles.

Key References:

He W. et al, 2013, Phys. Rev. Lett., **110**, art 165101
Bratman V.L. et al, 2000, Phys. Rev. Lett., **84**, pp2746-2749
Denisov G.G. et al, 1998, Phys. Rev. Lett., **81**, pp5680-5683
Denisov G.G. et al, 1998, IEEE Trans. Plasma Science, **26**, pp508-518
Cooke S.J. et al, 1996, Phys. Rev. Lett., **77**, pp2320-2323
Lawson W., 2005, IEEE Trans. Plasma Science, **33**, pp858-865
Blank M., 2000, IEEE Trans. Plasma Science, 28, pp706-711

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	10-20 %
Comp:	80-90 %

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: prerequisite PH352, recommended PH452

Additional comments:

Safety Training Requirements: Review and adherence to guidelines for use of computer workstations/VDUs.

Simulation of Langmuir probes and sheaths in plasma

(1) Dr. Kevin Ronald, (2) Dr. David Speirs

Project Description:

Langmuir and other forms of electrostatic probes have been well known as important local diagnostics for plasma properties since the earliest days of plasma physics and gas discharge research. Such probes are often used to determine electron temperature and both ion and electron density. They also provide insight into the electron energy distribution. In practice the interpretation of such probe results is difficult and depends on the experience of the experimenter. Modern computational techniques allow insight into probe behaviour extending beyond the constraints previously imposed to ensure analytical solutions were tractable. In particular in strongly magnetised plasma the constraint of the Lorentz forces makes them particularly difficult to interpret, forcing the use of other less local and more complex diagnostics. The project will aim to set up and validate an electrostatic model of a probe immersed in plasma in at least 2 spatial dimensions. The system will be allowed to evolve and the resulting plasma properties and probe fluxes analysed and compared to Langmuir probe and/or Bohm sheath theory to understand the validity of the simulation. The project may be extended to consider the impact of applying a magnetic field to the plasma to see the modification in the probe IV responses as a result of the gyrating motion of the particles and associated an-isotropy in the plasma parameters.

Key References:

Langmuir I., 1929, Phys. Rev., **33**, 954
Huddleston R.H. and Leonard S.L. (Eds.), 1965 'Plasma Diagnostic Techniques', Academic Press, London
Hutchinson I.H., 1990, 'Principles of Plasma Diagnostics', Cambridge University Press, Cambridge
Tarakanov V.P. and Shustin E.G., 2015, Vacuum, **113**, 59
McConville S.L. et al, 2011, Plasma Phys. Control. Fusion, **53**, art 124020

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	20-30 %
Comp:	70-80 %

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: prerequisite PH352, recommended PH452

Additional comments:

Safety Training Requirements: Review and adherence to guidelines for use of computer workstations/VDUs.

Nonlinear Vacuum Electrodynamics

(1) Prof. Dino Jaroszynski, (2) Dr. Adam Noble, Dr. Samuel Yoffe

Project Description:

An important characteristic of Maxwell's equations in vacuum is that they are linear. In certain material media, by contrast, interactions with the particles comprising the medium can induce nonlinearities. Due to the presence of virtual electron-positron pairs, the quantum vacuum can itself behave like an exotic medium, in which nonlinear interactions can modify the propagation of light. Similar phenomena are predicted in the low energy limit of more speculative branches of physics, such as string theory.

This project will explore some of the consequences of nonlinear vacuum theories of electrodynamics, such as the refractive index of strong electric and magnetic fields, birefringence, and light-by-light scattering. Prospects for detecting such phenomena at upcoming laser facilities will also be considered.

Key Reference:

Limits on nonlinear electrodynamics, M Fouché, R Battesti and C Rizzo, Phys. Rev. D **93**, 093020 (2016).

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	At least 70%
Comp:	Up to 30%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: This challenging project will suit an ambitious student with strong mathematical skills, who enjoys exploring technical and conceptual questions. Anyone interested in pursuing this project should contact the supervisors beforehand.

Radiation Reaction

(1) Prof. Dino Jaroszynski, (2) Dr. Adam Noble, Dr. Samuel Yoffe

Project Description:

The nature of electromagnetic radiation reaction – how an electron interacts with the radiation it emits – is one of the oldest open questions in physics. The "standard" description exhibits unphysical behaviour (self-acceleration, violation of causality), and proposed alternatives remain contentious. With the advent of a new generation of laser facilities operating at unprecedented intensities, it is more important than ever to properly understand radiation reaction.

This project will explore the difficulties involved in the theoretical description of radiation reaction, and some of the attempts to overcome them. It will also investigate how additional effects, for example due to spin and quantum mechanics, might affect radiation reaction in the context of high-power lasers.

Key References:

Aspects of electromagnetic radiation reaction in strong fields, DA Burton and A Noble, Contemp. Phys. **55**, 110 (2014).

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	At least 50%
Comp:	Up to 50%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: This challenging project will suit an ambitious student with strong mathematical skills, who enjoys exploring technical and conceptual questions. Anyone interested in pursuing this project should contact the supervisors beforehand.

Placeholder Title

(1) Prof. Dino Jaroszynski, (2) ??

Project Description:

Key References:

Ratio of effort: Exp/Theo/Comp

Exp:	??%
Theo:	??%
Comp:	??

Suitability:

Additional comments:

Ion Channel Laser with Large Oscillation Amplitude

(1) Dr Bernhard Ersfeld, (2) Prof. Dino Jaroszynski

Project Description:

The ion channel laser (ICL) is a proposed device for generating coherent radiation, similar to the free-electron laser (FEL), but much more compact. In the FEL, a relativistic electron beam radiates due to periodic deflection by the magnetic field of an undulator, whereas in the ICL electrons oscillate in the electrostatic field of a channel in plasma from which background electrons have been expelled (by an intense laser pulse or a relativistic particle beam). As an important difference, an efficient ICL requires oscillation amplitudes in excess of the electron beam width, which reduces the overlap with the emitted radiation.

The project offers the opportunity to investigate, analytically and numerically, effects of such large oscillation amplitudes, like harmonic generation and correlations between longitudinal and transverse electron motion.

Key References: B. Ersfeld et al., "The ion channel free-electron laser with varying betatron amplitude", New Journal of Physics **16** (9), 093025 (2014), and literature on free-electron lasers

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	50 %
Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Knowledge in the following areas would be advantageous: wave propagation, Fourier theory; computer programming (C or similar).

Additional comments: Anyone interested in taking up this project should contact the supervisors beforehand.

Safety Training Requirements: None

Intense Laser Pulse Filamentation in Near Critical Density Plasmas

(1) Dr. Ross Gray, (2) Dr. Bruno Gonzalez-Izquierdo

Project Description:

At the focus of the most intense laser systems in the world, peak laser intensities routinely exceed 10^{20} W/cm^2. When interacting with matter, this extreme electromagnetic field strips electrons from atoms and produces some of the strongest accelerating fields ever measured in the lab. In the last two decades, significant progress has been made in exploiting these exceptional accelerating fields to develop compact laser driven, plasma based, particle accelerators to be used both as tools for new science but also for applications such as proton oncology and nuclear fusion. A major challenge to the development of these applications, however, arises in the propagation of these intense pulses through dense plasmas. Small modulations in the plasma density or laser intensity profile are reinforced and grow beyond control, leading to beam breakup and the destruction of the pulse uniformity. Understanding and controlling the growth of this laser filamentation is therefore of great interest to the development of the field.

The main objective of the project is to investigate the growth of this laser filamentation for a range of laser and plasma conditions using the state of the art plasma simulation code EPOCH and analysis tool such as MATLAB.

Key References: R.J Gray *et al.*, New Journal of Physics 16 (11), 113075 (2014)

Ratio of effort: Exp/Theo/Comp		
	Exp:	%
	Theo: 20	%
	Comp:80	%

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: PH452 Topics in Physics (Recommended but not required)

Additional comments: None

Safety Training Requirements: None

Self-phase Modulation of Relativistically intense laser pulses in near critical density plasmas

(1) Dr. Ross Gray, (2) Dr. Martin King

Project Description:

By focusing petawatt-scale pulses of laser light to intensities exceeding 10^{18} W/cm^2 matter is rapidly ionised and heated to temperatures in excess of >10^9 K on timescales of 10's of femtoseconds. Under these conditions the resulting plasma evolves into an exotic state of matter called a *relativistic plasma*, as electrons are accelerated to velocities approaching the speed of light. Using this type of matter we are able to observe Einstein's special theory of relativity at work in the laboratory and in simulations. The changing behaviour of the electrons in the plasma as they gain mass due to their relativistic velocity can have profound effects on the propagating laser pulse. This opens the possibility to exploit these effects for so called *relativistic optics*.

The main objective of this project is to investigate the optical phenomena of *relativistic self-phase modulation* for intense laser pulses for a range of laser and plasma conditions. With a particular focus on pulse spectral broadening and on self-compression. The work will be conducted using the state of the art plasma simulation code EPOCH and analysis tools such as MATLAB.

Key References:

Ratio of effort: Exp/Theo/Comp	Exp:	%
	Theo:20	%
	Comp:80	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

PH452 Topics in Physics (Recommended but not required)

Additional comments: None

Safety Training Requirements: None

Plasma optical modulators for intense lasers

(1) Prof. Zhengming Sheng, (2) Dr. Feiyu Li

Project Description:

Optical modulators are key components for manipulating optical signals, which are widely used in scientific and industrial applications. For example, high-speed compact electro-optic modulators (EOMs) are essential for data communications. EOMs can alter the fundamental characteristics (that is, amplitude, frequency, phase and polarization) of a light beam in a controllable manner, by making use of electro-optic effects to change the refractive index of a material when an external radio-frequency electric field driver is applied. Normal EOMS can only apply for low light intensity due to the low optical damage threshold. Recently, we have proposed a plasma-based optical modulator [1], which can directly modulate high power lasers with intensity to produce an extremely broad spectrum with ultra-broad bandwidth.

The main task of this project is to investigate the effect of plasma density inhomogeneity along the laser propagation on frequency modulation. The student may also explore the effect of a plasma channel on frequency modulation to see the modulation limit. The student will use a one-dimensional and/or two-dimensional particle-in-cell (PIC) code to study this problem.

Key References:

[1] L.L. Yu, Y. Zhao, L.J. Qian, M. Chen, S.M. Weng, Z.M. Sheng, D.A. Jaroszynski, W.B. Mori, and J. Zhang, “Plasma optical modulators for intense lasers”, Nature Comm. 7,11893 (2016).

Ratio of effort: Exp/Theo/Comp

Exp:	0	%
Theo:	20	%
Comp:	80	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Some basic knowledge on computer programming such as C, C++, or Fortran and software for visualisation such as MATLAB would be helpful, but not essential.

Additional comments: No

Safety Training Requirements: No

Compact X-ray sources from nonlinear Thomson scattering with intense lasers

(1) Prof. Zhengming Sheng , (2) Dr. Feiyu Li

Project Description:

X-ray sources are widely used in scientific research, industry, and medicine. Well-known X-ray sources include X-ray tube, synchrotron radiation, X-ray free electron lasers, etc. With the advent of ultrashort high power, one can obtain compact X-ray sources in various new ways.

This project aims to develop a theory model together with corresponding numerical simulation to study the production of ultrashort X-ray sources from nonlinear Thomson scattering. In particular, an all-optical scheme will be considered, in which electrons will be first accelerated by an intense laser pulse and subsequently they are used to scatter the second intense laser pulse (or two intense lasers) for X-ray generation. In this project, the student will focus on the scattering processes. By the end of the project, the student will become familiar with the laser acceleration of a test electron in vacuum and familiar with the calculation of temporal and angular distributions of the X-ray radiations from the scattering of an energetic electron from intense laser pulses.

Key References:

1. W.-M. Wang, Z.M. Sheng et al., Phys. Rev. ST-AB 13, 071301 (2010).
2. S. Corde et al., Rev. Mod. Phys. 85, 1-48 (2013).
3. K. Ta Phuoca et al., Eur. Phys. J. D 33, 301–306 (2005).
4. S. P. Goreslavskii et al., Laser Physics 9, 1039–1044 (1999).
5. Y. Y. Lau et al., Phys. Plasmas 10, 2155-2162 (2003).

Ratio of effort: Exp/Theo/Comp

Exp:	0	%
Theo:	20	%
Comp:	80	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Some basic knowledge on computer programming either with C, C++, or Fortran, or MATLAB for simulation and visualisation is essential.

Additional comments: No.

Safety Training Requirements: No.

High harmonics and attosecond radiation from laser interaction with a solid target

(1) Prof. Zhengming Sheng, (2) Dr. Feiyu Li

Project Description:

Recently with the development of chirped pulse amplification (CPA) technology, one can produce ultrashort and high intensity laser pulses. Such laser pulses can push electrons to relativistic quiver motion, and thereby produce X-ray sources via various schemes.

One scheme is based upon intense laser solid interaction. It is found that free electrons at the solid surface can be driven into relativistic oscillations in the incident laser fields. As a result, high harmonics of the laser pulse will be produced. When the solid target is very thin such as a few nano-meters, the high harmonics generation enters a new regime called coherent synchrotron radiation, where attosecond (1 attosecond=10-15s) light pulses may be produced. In this project, the student will use some well-developed numerical simulation tool---a particle-in-cell code, to investigate high harmonics generation in different regimes or conditions.

Key References:

1. R. Lichters, J. Meyer-ter-Vehn, & A. Pukhov, Phys. Plasmas 3, 3425 (1996).
2. H.-C. Wu, Z.-M. Sheng et al., Phys. Rev. E 75, 016407 (2007).
3. S. Cousens, B. Reville, B. Dromey, and M. Zepf, Phys. Rev. Lett. 116, 083901 (2016).
3. U. Wagner et al., Phys. Rev. E 70, 026401 (2004).
4. M. Tatarakis et al., Nature (London) 398, 489 (2002).

Ratio of effort: Exp/Theo/Comp			
	Exp:	0	%
	Theo:	20	%
	Comp:	80	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Some basic knowledge on computer programming such as C, C++, or Fortran and software for visualisation such as MATLAB would be helpful, but not essential.

Additional comments: No.

Safety Training Requirements: No.

Institute of Photonics

Neurophotonic Systems for Interfacing with the Retina

(1) Dr. Keith Mathieson, (2) Dr. Niall McAlinden

Project Description

Optical coherence tomography (OCT) [1] is an interferometric technique that detects backscattered photons that are then used to create a 3D image of neural tissue, such as the retina. It has become commonplace in ophthalmology clinics where it is used to diagnose diseases of the retina. However, many diseases affect the functional (electrical signalling) behaviour of the retina and leave the structure unaffected. There is some evidence that optical techniques can be used to measure this loss of function [2]. During this project the student will be able to work on an OCT system that has been combined with electrophysiological recording equipment that monitors the electrical behaviour of the retinal output cells. The analysis of these OCT images and subsequent correlation with the electrical recordings will be able to show whether OCT techniques have the sensitivity required to measure the small refractive index changes that occur during neural signalling in the retina. The project will require analysis of large datasets and experience with programming would be an advantage.

Key Reference:

[1] "Cellular and Functional Optical Coherence Tomography of the Human Retina", W. Drexler, DOI:10.1167/iovs.07-0895 Investigative Ophthalmology & Visual Science, ***48****, 12 (2007)*

[2] "In vivo imaging of intrinsic optical signals in chicken retina with functional optical coherence tomography" Moayed et al., Optics Letters ***36****, 23 (2011)*

Ratio of effort: Exp/Theo/Comp

	Exp:	40%
	Theo:	10%
	Comp:	50%

Suitability: MPhys, BSc

Additional comments:

Safety Training Requirements: *Laser Safety Training*

Photonic Neurons: Spiking information processing with lasers

(1) Dr. Antonio Hurtado, (2) Prof. Thorsten Ackemann

Project Description:

Neuromorphic photonics aims at emulating the brain's powerful computational capabilities for novel paradigms in ultrafast information processing. Biological neurons respond by firing spikes when stimulated. Semiconductor lasers can also produce neuronal dynamical responses similar to those observed in biological neurons but several orders of magnitude faster. This feature makes them ideal candidates for the use in novel neuro-inspired systems for all-optical information processing.

This project will analyse the emulation of different spiking regimes in Vertical Cavity Surface Emitting Lasers (VCSELs) under the arrival of induced perturbations into the devices. The project will also look at the application of VCSELs for neuro-inspired information processing tasks such as the development of spiking all-optical logic gates, digital-to-spiking signal format conversion and the propagation of the generated spiking patterns between interconnected VCSELs.

Key References:

- *A. Hurtado et al. "Investigation of vertical cavity surface emitting laser dynamics for neuromorphic photonic systems", in Applied Physics Letters, 100, 103703 (2012)*
- *B. Shastri et al, "Photonic Spike Processing: Ultrafast Laser Neurons and an Integrated Photonic Network", in IEEE Photonics Society Newsletter. Research Highlights (Jun 2014)*

For further information contact Dr A. Hurtado at antonio.hurtado@strath.ac.uk.

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	15%
Comp:	15%

Suitability: MPhys BSc

Additional comments: *Basic knowledge in optics and lasers is desirable but not essential. Attendance to PH455 is also recommended.*

Safety Training Requirements: *Laser safety*

Modelling non-linear processes in compact waveguides

(1) Dr. Michael Strain, (2) Prof. Gian Luca Oppo

Project Description:

Waveguides with sub-micron cross-sectional dimensions have proven extremely successful in non-linear optical applications, making them useful tools for quantum optics experiments, telecommunications systems and biosensors. By using materials with high refractive index, such as silicon, light can be confined into ultra-small volumes, producing extremely high local field intensities. If these materials also exhibit an optical non-linearity, i.e. their susceptibility\refractive index is a function of the strength of the optical field, then a wide array of devices can be designed. For example, ultra-fast photonic switches can be created that are triggered using optical pulses (i.e. without the need for electronics) with potential applications in optical signal processing. Non-linear processes can also create new wavelengths of light in a device, for example allowing a signal input at □1 to be broadcast on a wide range of new wavelengths, simply by propagating through a non-linear device. Finally, these devices can take a single laser wavelength input and, through self-phase modulation, generate a supercontinuum of light.

It is not only the refractive index of the material that exhibits non-linear behaviour with respect to the intensity of light propagating within it. The material loss (due to carrier absorption and two photon absorption events) is also a non-linear function of intensity. In order to predict the behaviour of these waveguides, accurate models of the light-matter interaction must be designed including non-linear index and loss functions.

In this project the student will use numerical tools to model the non-linear behaviour of nanowire waveguides in a variety of materials. This analysis will then underpin further calculation of these effects in nanowire waveguides, with particular reference to self-phase modulation and four wave mixing processes. The student will write customised simulation codes to probe the behaviour of these waveguides and compare their results with experimental demonstrations.

Key Reference:

1. *Q. Lin, O. J. Painter, and G. P. Agrawal, "Nonlinear optical phenomena in silicon waveguides: modeling and applications.," Opt. Express, vol. 15, no. 25, pp. 16604–44, Dec. 2007.*
2. *J. Leuthold, C. Koos, & W. Freude, "Nonlinear silicon photonics," Nature Photonics, 4(8), 535–544, 2010.*
3. *A.C. Turner, M.A. Foster, A.L. Gaeta, M. Lipson, "Ultra-low power parametric frequency conversion in a silicon microring resonator," Optics express, 16, (7), p. 4881-7, 2008.*

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	50%
Comp:	50%

Suitability: MPhys, BSc

Additional comments: *Some previous experience of Matlab would be beneficial but not essential.*

Safety Training Requirements: *N/A*

Measurement of non-linear processes in silicon photonic waveguide arrays

(1): Dr. Michael Strain, (2): Dr. Gian Luca Oppo

Project Description:

Coupled arrays of planar optical waveguides are a useful system for experimentally modelling the behaviour of more difficult to engineer physical systems such as Bose-Einstein condensates. By using non-linear optical materials to create these waveguides, complex intensity dependent effects can also be studied, such as soliton or light bullet formation. Silicon photonics is a well-established material platform for telecommunications systems, and is now finding significant application in quantum optics experiments. Waveguide cross-sections are in the order of 500x220 nanometres allowing the light field to be very strongly confined to an extremely small area. This confinement in turn increases the light-matter interaction, producing strong non-linear effects in both the refractive index and the associated waveguide loss.

Arrays of silicon photonic waveguides with varying amounts of propagation length and coupling between elements in the array have been designed and fabricated. This project will involve the measurement of these optical waveguide arrays in both the linear and non-linear optical regimes. The student will develop skills in the alignment of sub-micron waveguide devices to custom fibre optic components. The waveguide arrays will be imaged using a state of the art near-IR camera to allow characterisation of the distribution of light across the array as a function of input power. These results will give an insight into the interaction of light travelling in coupled systems and how it can be controlled using the input signal intensity.

The student will develop experience of automated laboratory systems using LabView control, fibre optics based measurement systems and silicon photonic device measurements. The project will also involve the post-processing of image data using Matlab. This work will detail the limits of current state-of-the-art silicon photonics as a tool for quantum and non-linear optics. The student will produce data sets to compare with theoretical models.

Key References:

1. *Q. Lin, O. J. Painter, and G. P. Agrawal, "Nonlinear optical phenomena in silicon waveguides: modeling and applications.," Opt. Express, vol. 15, no. 25, pp. 16604–44, Dec. 2007.*
2. *J. Leuthold, C. Koos, & W. Freude, "Nonlinear silicon photonics," Nature Photonics, 4(8), 535–544, 2010.*
3. *Y. Lahini, A. Avidan, F. Pozzi, M. Sorel, R. Morandotti, D. N. Christodoulides, and Y. Silberberg, "Anderson localization and nonlinearity in one-dimensional disordered photonic lattices," Phys. Rev. Lett., vol. 100, no. 1, pp. 1–4, 2008.*

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	10%
Comp:	20%

Suitability: MPhys BSc

Additional comments: Some previous experience of Matlab would be beneficial but not essential.

Safety Training Requirements: Laser safety course

Project Title: Placeholder 1

(1) Dr Alan Kemp, (2)

Project Description:

Key References:

Ratio of effort: Exp/Theo/Comp

Exp:	%
Theo:	%
Comp:	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Project Title: Placeholder 2

(1) Dr Alan Kemp, (2)

Project Description:

Key References:

Ratio of effort: Exp/Theo/Comp

Exp:	%
Theo:	%
Comp:	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Bio Photonics

Super-wide field of view two dimensional cell imaging

(1) Prof. Gail McConnell, (2) Lee McCann

Project Description:

Optical microscopy is a routine tool in biomedical research, enabling cell imaging to study structure and function that can inform about disease diagnosis and treatment. However, the small field of view of a standard microscope, which is a few mm, does not readily support imaging of multi-well plates that are used as standard in pharmacological studies, e.g. in vitro wound scratch assay. Some new microscopy methods, including light sheet and the Mesolens, have increased the field of view but not to the >10mm scale required. This project will involve the design and development of an optical imaging system capable of imaging wide fields (>10mm) with cellular, or sub-cellular, resolution.

We propose using a lens system usually applied in machine vision together with an appropriate photodetector (camera, scanner) to image firstly tissue phantom specimens and then fixed cell specimens showing wounds between 0 and 2 mm wide. This will enable characterisation of the optical system (e.g. contrast, resolution etc.) and inform further optimisation before applying the imaging system to live cell specimens, where the wound will close over time when treated with appropriate pharmacological interventions. The project will therefore involve optical design, imaging at the macroscopic and microscopic levels, working with biological specimens (and learning to prepare biological specimens), and image analysis methods.

Key References: 0.5 gigapixel microscopy using a flatbed scanner, Guoan Zheng, Xiaoze Ou, & Changhuei Yang. Biomedical Optics Express Vol. 5, No. 1 (2014).

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	10%
Comp:	20%

Suitability: BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements: Online laser safety awareness course

Quantification and measurement of marine microbial populations using the Mesolens

(1) Prof. Gail McConnell, (2) Dr. David McKee

Project Description:

The Mesolens is a giant microscope objective designed for computer data acquisition rather than the human eye. It arose from a realization in the early days of confocal microscopy that confocal images could not be obtained of large specimens, because the available low magnification objectives had too poor a resolution in depth. We have created a Mesolens with an unprecedented numerical aperture of nearly 0.5 at a magnification of 4x. This results in a field size of 6 mm, with a working distance of 3 mm, and the possibility to resolve sub-cellular detail throughout this large volume in x, y and z.

The aim of this project is to explore the application of the Mesolens to study populations of marine organisms. Specifically, the project will entail (a) culture and maintenance of organisms, (b) optical mesoscopic imaging and (c) image interpretation and data analysis. The main focus of the project will be on image processing: handling the massive data files produced by the system, segmenting around objects of interest and applying / optimising basic particle identification techniques to facilitate taxonomic discrimination

Key References:

G. McConnell et al, "A novel optical microscope for imaging large embryos and tissue volumes with sub-cellular resolution throughout", eLife (accepted).

Ratio of effort: Exp/Theo/Comp	Exp:	30 %
	Theo:	10 %
	Comp:	60 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments: Good computing skills a benefit.

Safety Training Requirements: Laser Basic Awareness training course.

In vivo optical imaging of microplastics in marine organisms

(1) Prof. Gail McConnell, (2) Dr. David McKee

Project Description:

Microplastics, such as the small beads often used in cosmetic and cleaning products, are found in the aquatic and marine environments and have the potential to be hazardous to life e.g. through transfer of attached pathogens. However, little is known about how microplastics are taken up by protozoa (which are food for higher organisms), in what quantity they are present, and even in what quantity they may be present in the food that we eat.

The aim of this project is to prepare marine organisms with known concentrations of microparticles and perform in vivo imaging to determine the quantity, rate, and location of uptake. Specifically this project will involve (a) culture and maintenance of organisms, (b) brightfield and fluorescence time-lapse microscopy, and (c) image interpretation and data analysis.

Key References:

Ratio of effort: Exp/Theo/Comp		
	Exp:	70 %
	Theo:	10 %
	Comp:	20 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements: Laser Basic Awareness training course.

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Allocated Projects (Fifth Year students)

Project Name	*Supervisors*	*Student Name*

Appendices

Safety induction training record for Undergraduate students undertaking project work

This form **MUST** be completed by student and supervisor and returned **before** student enters a laboratory and by 31st October 2016 at the **latest.**

1) I have read and understood the '*Local rules for the Safe Use of Lasers*' (available from https://moss.strath.ac.uk/physics/Safety/Laser%20Information/Local%20Rules/130222_LocalRulesLaserSafety_Append.doc) ❑

N/A ❑

Others: ……………………………………………………………………………

……………………………………………………………………………………

2) I have attended the following safety training lectures:

Physics Laser Safety ❑ **N/A** ❑

Others: ……………………………………………………………………………..

……………………………………………………………………………………

3) I have received an induction in the use of the local safety systems and access controls in rooms:

……………………………………………………………………………………

4) I have received an induction in operating the following devices and/or instrumentation (e.g. laser)

…………………………………………………………………………………..

…………………………………………………………………………………..

5) I received an induction in the following techniques:

Laser beam alignment procedures ❑ **N/A** ❑

Others: ……………………………………………………………………

……………………………………………………………………

Signature of student: .... Date: ....

Name (print): ....

Signature of supervisor: .... Date: ....

Name (print) ....

Please return this completed form to Students Office, JA 8.31

<u>Project allocation request form 2016/17 (1 of *2 Pages*)</u>

(To be returned by the student to Students Office JA 8.31 by 4pm 23/09/2016)

- **Top 3 choices** must be discussed with prospective supervisor and signed off
- **Choices 4-10** will be referred to in the event the first 3 choices have already been allocated
- Where there several requests for the same project, it will be decided by 3rd year class rank
- Project availability is subject to supervisor discretion
- Allocations will be announced on Thursday 29th September 2016

Student Name	
Student Number	

Project title:		
Supervisor's signature: **Supervisor's name:**		**This project has been discussed by us, and we have agreed that it is appropriate for the student to undertake the work.**
Student's signature:		
Preference (1,2, or 3):		**For student to choose on completion of the form**

Project title:		
Supervisor's signature: **Supervisor's name:**		**This project has been discussed by us, and we have agreed that it is appropriate for the student to undertake the work.**
Student's signature:		
Preference (1,2, or 3):		**For student to choose on completion of the form**

Project title:		
Supervisor's signature: **Supervisor's name:**		**This project has been discussed by us, and we have agreed that it is appropriate for the student to undertake the work.**
Student's signature:		
Preference (1,2, or 3):		**For student to choose on completion of the form**

Project allocation request form 2016/17 (2 of *2 Pages*)

Project Choice 4 **Title and First Supervisor**	
Project Choice 5 **Title and First Supervisor**	
Project Choice 6 **Title and First Supervisor**	
Project Choice 7 **Title and First Supervisor**	
Project Choice 8 **Title and First Supervisor**	
Project Choice 9 **Title and First Supervisor**	
Project Choice 10 **Title and First Supervisor**	

Project Timetables

PH450

Taken in 4^{th} year by MPhys and BSc Physics
Optional for BSc Physics with Teaching and BSc Mathematics and Physics students

- **12th September 2016**. Project booklet available to students

Students will receive project handbook with project request page.

- **12th – 23rd September 2016**. Students choose projects

Students should visit supervisors and draw up a shortlist in order of preference. Preferences 1 to 3 must be signed and dated by both the student and the supervisor and submitted to the student office, JA8.31.

- **12 noon 23rd September 2016**. Deadline for submission of Project choice form to JA8.31

- **29th September 2016**. Official start of Projects

Project allocations announced at 12 noon through Myplace. Students who have been unsuccessful in getting their choice of project will receive an updated booklet for a second round.

- **14th October 2016**. Literature review complete

Students submit literature survey and a risk assessment for project. The literature review will usually take the form of the Final Report's introductory chapter.

- **31st October 2016**. Completed safety form to be returned to JA 8.31 by this date

- **2nd December 2016**. Progress report to be returned by students to JA 8.31 by this date

- **15th & 22nd February 2017.** Project Talks 1-5 pm in parallel Sessions

Each student will be given a 15-minute slot. The expectation is that students will talk about their project for 10 minutes and then be questioned by the audience for 5 minutes.

- **31st March 2017** at Noon. Project reports submitted

Project reports to be submitted as PDF format through MyPlace and then passed through Turnitin for plagiarism detection. In preparing the report, please be aware that supervisors can advise on up to 10 pages of material, to help with the style of writing and content, but not to correct physics.

- **Week beginning 17th April 2017.** Viva Week

Each viva will be about 35 minutes long, with 5 minutes for the student to outline their project work and 30 minutes of questions about project content.

Project Information for Continuing 5th Year Students

PH 550

To Insert

Plagiarism

Plagiarism most commonly involves the passing off of another person's work as your own and is regarded as a form of academic dishonesty. Plagiarism more often than not involves the copying of another person's work, be it a figure, text, experimental data or homework for example and not acknowledging the source of the work. Plagiarism can be avoided by suitable referencing.

For more details on plagiarism please see the University Handbook and follow this link http://www.strath.ac.uk/media/ps/cs/gmap/plagiarism/plagiarism_student_booklet.pdf for guidelines on plagiarism. If you are unsure of any aspect of this, please contact the department. The department will make extensive use of software capable of detecting plagiarism. The Department will use the anti-plagiarism software Turnitin (https://turnitin.com/static/index.php) to check for plagiarism. Any student caught plagiarising another person's work may be reported to the University Disciplinary committee.

Index of Project Titles