DEPARTMENT OF PHYSICS

PH450

4th Year Research Projects

2019/20

Table of Contents

Health and Safety

- The department has a duty to provide such information, instruction, training and supervision as is necessary to ensure the health, safety and welfare of students whilst undertaking coursework, which may include practical classes, project work, fieldwork, use of workshops outside normal hours, etc.
- All proposed undergraduate project work will be risk assessed for development, construction and operational phases, before work commences. Assessments may need to include a general risk assessment, plus other specific assessments, for example a COSHH assessment etc. These risk assessments will be overseen and signed by the member of staff initiating the work but they are encouraged to include the student in the process, for training purposes.
- An Undergraduate safety induction training record is required to be completed for each project student (no exceptions). Please ensure that the appropriate training is completed and the form returned to Shirley Wylie before the project work begins. (see Appendix)
- At a minimum, ***all students must attend a building safety induction session*** regardless of project.
- Departments will record the means of delivery of the health and safety programme for each course, each year.

Mr John Gillan,
Department Safety Officer

Preface

The 4th Year and 5th Year projects are an integral part of the training that you will receive as a Physicist. The projects are the ideal opportunity for you to further develop your critical thinking skills as you plan for the project, analyse the data that you generate and compare your work with that of others. Whether the project you undertake is experimental, computational or theoretical in nature, this will give you the chance to focus on and explore a specific idea or concept in great depth. You have the potential to become well versed in the area you are exploring. The project also allows you to pull together the knowledge that you have gained from the other areas of the teaching provided by the department be it 1st year introductory concepts or through to advanced 4th year teaching.

Many students are reluctant to pick a computational project, thinking that they will be required to write and build the computer programmes necessary to run the project. For the majority of computational projects this is not the case. Normally, the staff offering computational projects will have written programs to simulate given aspects of Physics and will require you to alter variables or input into the program to understand their effect and the Physics of the project's topic. To this end, this is no different from the type of work you would do in an experimental project: you modify an experimental parameter and then look at the effect of that variation.

Once you have selected your project, work hard and enjoy the project. Make sure that you talk to your supervisor regularly and also Post-Docs in their group or PhD students they are supervising. You will find that they are a source of information that can help with your learning in the project.

Assessment

The PH450 Project mark will comprise of the following assessment:

- 10% Talk Mark
- 50% Project Report Mark
- 20% Supervisor Mark
- 20% Viva Mark

The Project Report and the Viva will be assessed by the supervisor and at least one other independent marker. Only a single mark will be returned for the course (you will not be given an individual breakdown) as per departmental policy. You may ask your supervisor for informal feedback on any aspect of the project.

Please be familiar with the University Policy on plagiarism (more detail is available in the Appendix).

Project Timetable

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

Semester 1

16th September 2019 (Welcome Week Wk 0) *Project Induction Week*

Students will have had received Project Handbook prior to the Welcome Week. Students will attend project information and safety briefings (details on MyPlace TBA). General Safety Briefings ***compulsory for all students***.

16th – 20th September 2019 (Wk 0) *Students choose preferred projects*

Students visit supervisors to discuss projects, obtain signatures, and draw up a shortlist[1].

23rd September 2019 at Noon (Wk 1) *Submission deadline of Project request form.*

Signed forms to be handed in to the Student Office JA8.31.

27th September 2019 (Wk 1) *Official start of Projects*

Project allocations announced through Myplace. Students unsuccessful in getting one of their shortlisted projects will receive an updated list for a second round.

21st October 2019 at Noon (Wk 5) *Literature review complete, report due.*

Students submit literature survey via MyPlace (PDF).

28th October 2019 (Wk 6) *Safety induction record form*

To be submitted by students to Student Office JA8.31 by this date.

Semester 2

13th January 2020 (Wk 0) *Progress Report Due*

Students should submit a progress report via MyPlace (PDF).

19th & 26th February 2020 (Wks 5&6) *Project Talks 1-5 pm in parallel sessions*

Each student has a 15-minute slot: 10 minutes for students to present their project and 5 minutes for audience questions and discussion. Slides to be uploaded to MyPlace (PDF/PPT) prior to talk.

16th March 2020 (Wk 9) *Sample 10 pages for Feedback Due*

Students may submit a sample of 10 pages of the report for feedback from their supervisor.

6th April 2020 (Spring Break) at Noon *Project reports Due*

Project reports submitted by students as PDF format (40MB max file size) through MyPlace.

20th April to 22nd May 2020 (Exam Period) *Vivas*

[1] Staff Contact List https://www.strath.ac.uk/staff/?department=Physics

Plasmas Division

Nonlinear waves in plasmas

(1) Dr Adam Noble, (2) Prof Dino Jaroszynski

Project Description:

One of the most noteworthy features of plasmas is the vast array of wave phenomena they can support. The properties of these waves will depend on the conditions of the plasma (density, temperature, magnetic fields...) as well as the polarisation of the wave and which component of the plasma (light electrons or heavy ions) is oscillating. Plasma waves are usually analysed in the linear limit, but as they are driven to higher amplitudes a rich suite of phenomena is unveiled.

This project will explore the range of waves that can propagate in plasma, and how nonlinear behaviour can lead to important effects such as wavebreaking, particle trapping and soliton-formation. It will also address the significance of these phenomena for ongoing endeavours to accelerate particles in plasma.

Key Reference:

Theory of Wave Motion of an Electron Plasma, AI Akhiezer and RV Polovin, Sov. Phys. JETP **3**, 696 (1956).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: This project will suit mathematically minded students with an interest in widely applicable theoretical techniques. Anyone interested in pursuing this project should contact the supervisors beforehand.

Safety Training Requirements: None.

A coherent synchrotron source based on a laser-plasma wakefield accelerator

(1) Dr. Antoine Maitrallain, (2) Prof. Dino Jaroszynski

Project Description:

Laser wakefield acceleration in plasma (1) is a new scheme to accelerate particles, which enables bunch properties hitherto not achievable with conventional accelerators. Moreover, this type of accelerator can sustain accelerating fields 3-4 orders of magnitude higher than in a conventional RF accelerator, hence reducing the footprint of facilities substantially, which provides a unique source of electrons and electromagnetic radiation. Beams from laser wakefield accelerators have mono-energetic energy spectra at relatively high-energy and durations of approximately one femtosecond (10^{-15}s). Taking advantage of these extremely short bunches it is possible to directly produce coherent radiation using an undulator (2), which provides a unique compact femtosecond source of XUV coherent radiation. The project will involve theoretical and numerical calculations (using software packages and purpose written routines) to study the evolution of the electron bunch properties during its propagation through the undulator and the characteristics of the radiation emitted. The project could also have an experimental aspect in the SCAPA laboratory, using the 40 TW laser system. Due to the significant reduction in size and cost of the accelerator, radiation sources obtained from this facility will be of interest for many applications. This is a paradigm shifting technology, which provides the student with an opportunity to work at the forefront of scientific advances.

Key papers:

1. Esarey E, Schroeder CB, Leemans WP. Physics of laser-driven plasma-based electron accelerators. Rev Mod Phys. 2009 Aug 27;81(3):1229–85.

2. Schlenvoigt H-P, Haupt K, Debus A, Budde F, Jäckel O, Pfotenhauer S, et al. A compact synchrotron radiation source driven by a laser-plasma wakefield accelerator. Nat Phys. 2008 Feb;4(2):130–3.

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

Suitability (delete not applicable ones): Appl. Phys./ Adv. Phys.

Additional comments: n/a

Safety Training Requirements: laser safety training will be provided for experimental work

Plasma Gratings as Optical Elements with High Damage Thresholds for Ultrashort, Extremely Intense Laser Pulses

(1) Prof. Dino Jaroszynski, (2) Dr. Gregory Vieux, (3) George Holt

Project Description:

Next-generation laser facilities will produce pulses with peak power in the hundreds of petawatt range, delivering intensities in the region of 10^{24} W/cm^2. Such intensities will enable the experimental study of new regimes of fundamental physics, and drive the development of new technologies such as novel particle accelerators delivering particles and photon sources with extremely high energies beyond the physical limits of conventional technologies. A challenging and limiting aspect in the design of these facilities is the low damage threshold of their solid state optical components. Such components must be able to withstand the extreme irradiance of the ultra-high power laser pulse. It is suggested to develop plasma-based, optical elements because plasma does not have a damage threshold. A transient plasma photonic crystal (TPPC) can be generated by colliding two laser beams in a plasma. A TPPC would allow for time-dependent laser beam manipulation due to the temporal nature of the structure.

This project offers the opportunity to numerically investigate the formation and properties of plasma grating structures by utilising advanced particle-in-cell simulation codes deployed on local and national supercomputing facilities. Real experimental data will also be available for analysis and comparison after being generated on the Gemini laser at the UK's Central Laser Facility (CLF) during August – October 2019.

Key References:

[1] Lehmann, G., & Spatschek, K. H. (2016). Transient Plasma Photonic Crystals for High-Power Lasers. Physical Review Letters, 116(22), 225002. https://doi.org/10.1103/PhysRevLett.116.225002

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: Familiarity with Python/MATLAB and Linux is desirable but not necessary. Some prior knowledge of laser and plasma physics would be useful.

Additional comments: An ambitious student who is looking to gain experience using world-class computing facilities, improve their data analysis and visualisation skills and has a strong ability to grasp difficult and new concepts would be well-suited to this project. Interested persons should first contact the project supervisors.

Safety Training Requirements: None

Simulation and measurement of two-dimensional periodic surface lattice

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

Project Description:

The main goal of the project is to study the electron beam electromagnetic wave interaction within a two-dimensional (2D) periodic surface lattice (PSL) structure. A theoretical study of electromagnetic wave propagation through a cylindrical 2D periodic surface lattice will be carried out. A CST Microwave Studio computer model of the electron beam-electromagnetic wave interaction within the 2D PSL will be developed. The results from the CST Microwave Studio model will be compared to experimental measurements.

Key Reference:

[1] A.J. (MacLachlan, C.W. Robertson, A.W. Cross, A.D.R. Phelps, "Volume and surface mode coupling experiments in periodic surface structures for use in mm-THz high power radiation sources", AIP ADVANCES, 8 105115 (2018) DOI: 10.1063/1.5020542

[2] A.J. (MacLachlan, C.W. Robertson, I.V. Konoplev, A.W. Cross, A.D.R. Phelps, K. Ronald, "Resonant Excitation of Volume and Surface Fields on Complex Electrodynamic Surfaces", Physical Review Applied, 11, 11, 034034, March 2019
DOI: 10.1103/PhysRevApplied.11.034034

[3] A.J. (MacLachlan, C.W Robertson, K. Ronald, A.W. Cross and A.D.R. Phelps, "Mode coupling in periodic surface lattice and metamaterial structures for mm-wave and THz applications", SN Applied Sciences, 1, Nos 6, Article Number: 613
DOI: 10.1007/s42452-019-0596-z

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 BSc and MPhys

Additional comments:

Safety Training Requirements: Part 1 and Part 2 of Safety Induction Course

Design, simulation and experiments of an Extended Interaction Oscillator based on a pseudospark sourced sheet electron beam

(1) Prof Adrian W. Cross, (2) Dr Liang Zhang

Project Description:

A project is proposed to design, simulate, construct and measure the millimetre output radiation generated by a planar Extended Interaction Klystron Oscillator (EIKO) that uses a pseudospark-sourced sheet electron beam.

High frequency (365GHz) radiation sources are used in a number of diverse applications such as the study of the fundamental properties of materials, security and medical imaging, magnetic resonance spectroscopy and chemical sensing. The power that can be generated from ‘bench top’ free electron radiation sources in the hundreds of GHz to THz frequency range has been limited by the fact that as the frequency is increased, the size of the slow wave interaction region has to be reduced in order to prevent the maser becoming overmoded which results in a loss of the temporal or spatial coherence of the output radiation. As the frequency increases it becomes increasingly difficult (if not impossible) using conventional thermionic cathodes to focus and form high current density, high quality electron beams through the small size interaction region of the THz maser. A pseudospark plasma cathode can overcome current density limitations imposed by thermionic emission as well as being able to generate a sheet electron beam without the need to use an external magnetic field.

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. 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. 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, long lifetime and ability to form sheet electron beams.

The project will involve the design, simulation and construction of a psuedospark-sourced sheet electron beam to power a planar Extended Interaction Klystron Oscillator (EIKO) which is extended in one direction as compared to conventional EIKOs based on a cylindrical electron beam. Millimetre wave radiation for the planar EIKO will be measured and compared to the results of analytical theory and numerical simulations.

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:	30%
Theo:	30%
Comp:	40%

Suitability: PH450 BSc and MPhys

Safety Training Requirements: Part 1 and Part 2 of Safety Induction Course

Design, simulation and experiments of a microwave undulator

(1) Prof Adrian W. Cross, (2) Dr Liang Zhang

Project Description:

In a free electron laser (FEL) [1,2], the relativistic electron beam passes through a transverse periodic magnetic field to generate short-wavelength radiation. An undulator that is able to create such a magnetic field is important for FEL operation. In literature, the conventional permanent magnet undulators (PMUs) play a dominant role. The periodic magnetic field can also be generated by an electromagnetic wave. Such types of undulator are known as RF undulators or microwave undulators (MU), depending on the wavelength.

A microwave undulator (MU) that is an alternative to the permanent magnet undulators in a free electron laser (FEL) will be investigated. A microwave undulator cavity operating at ~37 GHz will be modelled using the 3D electromagnetic code CST microwave studio. The microwave undulator cavity will be designed and constructed with its properties measured using a Vector Network Analyser. The goal of the project will be to compare theory and simulation of the electromagnetic fields in the microwave undulator with measurement of electromagnetic wave propagation through the structure.

Key References:

[1] D. A. G. Deacon, L. R. Elias, J. M. J. Madey, G. J. Ramian, H. A. Schwettman, and T. I. Smith, "First Operation of a Free-Electron Laser," Phys. Rev. Lett., vol. 38, no. 16, pp. 892-894, April 1977. DOI: 10.1103/PhysRevLett.38.892
[2] Z. Huang and K.-J. Kim, "Review of x-ray free-electron laser theory," Physical Review Special Topics - Accelerators and Beams, vol. 10, no. 3, p. 034801, March 2007. DOI: 10.1103/PhysRevSTAB.10.034801

Ratio of effort: Exp/Theo/Comp	Exp:	30%
	Theo:	30%
	Comp:	40%

Suitability: BSc

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Beam-driven Plasma Wakefield Acceleration (PWFA)

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

Project Description:

Electron beams can drive strong plasma waves which can sustain electric fields up to the Teravolt-per-meter scale. This is three or four orders of magnitude larger than state-of-the-art accelerators and may in turn allow to realize ultracompact high energy accelerators on the cm- instead of the km-scale. Particle beams are highly suitable for plasma acceleration, and this possibly transformative approach is mushrooming worldwide and has already spread to large labs such as CERN or SLAC. In addition to shrinking down the size of particle accelerators, at Strathclyde we have developed novel methods which are highly promising to also allow to increase the obtainable electron beam quality of plasma accelerators by orders of magnitude. In particular, the so called “Trojan Horse” plasma photocathode method [1-3] may allow to increase the electron beam brightness to orders of magnitude better than even those obtainable at the best state-of-the-art accelerators. Such an increase in beam quality is highly desirable for key applications such as for advanced light sources, e.g. undulator synchrotron sources [4] or even hard x-ray free-electron lasers.

Suitable intense electron beam drivers to excite the plasma wave in a process called plasma wakefield acceleration (PWFA) can be produced by large conventional accelerators such as at SLAC as well as by laser wakefield acceleration (LWFA). PWFA is a trending R&D field and will be studied in by means of particle-in-cell simulations, theory as well as in experiments in which the electron bunch output from laser-plasma-accelerators at Strathclyde and the Scottish Centre for the Application of Plasma-based Accelerators (SCAPA) will be used for the first time for PWFA.

Key References:

[1] Ultracold Electron Bunch Generation via Plasma Photocathode Emission and Acceleration in a Beam-driven Plasma Blowout, B. Hidding et al., Physical Review Letters 108, 035001, 2012
[2] Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams, G.G. Manahan, F.A. Habib et al., Nature Communications 8, 15705 (2017)
[3] http://www.eupraxia-project.eu/the-brightest-electron-beams-of-the-world.html
[4] A compact synchrotron radiation source driven by a laser-plasma wakefield accelerator, H.P. Schlenvoigt et al., Nature Physics 4, 130-133 (2008)

Ratio of effort: Exp/Theo/Comp

Exp:	0-30%
Theo:	20-50%
Comp:	40-60%

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

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: This project is open to more than one student.

Safety Training Requirements: Laser and radiological safety training will be provided, if required.

Electron beam physics and transport modelling

(1) Prof Bernhard Hidding, (2) Dr Brian McNeil

Project Description:

Electron beams, either produced by conventional radiofrequency- or plasma-based accelerators, are fundamental drivers of scientific progress: electron accelerators are required for high energy physics as well as most advanced imaging devices such as free-electron lasers and other light sources, and many more applications in natural, material and life sciences [1]. Fundamental building blocks of accelerators are transport and beam conditioning elements which are typically based on ensembles of electromagnets or permanent magnets. Examples are magnetic chicanes e.g. for bunch compression, or quadrupole triplets for focusing of particle beams.

State-of-the-art accelerators push the boundaries of what is possible to generate in terms e.g. of electron beam current, emittance or brightness. In this project, transport and conditioning of intense electron beams will be explored and modelled. Theoretical fundamentals include topics such as Twiss parameters, Hill's equation, or phase space [2]. Computational tools such as elegant and SDDS [3] and/or Astra [4] will be used to describe and explore a transport beamline element. The student(s) will learn fundamental beam physics aspects and their computation, which is an indispensable part of any accelerator application. For example, beam transport elements for novel undulator-based light sources such as (hard) x-ray free-electron lasers will be calculated.

Key References:

[1] EuCARD – Applications of Accelerators, 2017 http://iiaglobal.com/wp-content/uploads/2017/07/EuCARD-Applications-of-Accelerators-2017.pdf
[2] Fundamentals of Beam Physics, J.B. Rosenzweig, Oxford University Press
[3] Overview of elegant and SDDS http://www.aps.anl.gov/Accelerator_Systems_Division/Accelerator_Operations_Physics/elegant.html
[4] ASTRA http://www.desy.de/~mpyflo/

Ratio of effort: Exp/Theo/Comp

Exp:	0-30%
Theo:	20-50%
Comp:	50-80%

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

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: This project is open to more than one student.

Safety Training Requirements: None required.

Monte Carlo Modelling of Particle Beam-Matter Interaction

(1) Prof Bernhard Hidding, (2) Dr Mark Wiggins

Project Description:

Electron, proton and ion beams are important tools in the context of radiation damage and therapy in bio-systems, for space and aviation electronics or for shielding issues in context of nuclear reactors, fusion and particle accelerators in general. Various electromagnetic and nuclear processes are involved and will be explored and modelled. Key concepts are cross section, Mean Free Path, ionization track, Linear Energy Transfer, Bethe-Bloch equation, Bragg peak, scattering, straggling, bremsstrahlung, pair production etc. [1].

The Monte Carlo code Geant [2], which is a standard code in high-energy physics and related research incorporates all of the above mentioned (and many more) effects will be used to model the interaction of particle beams with matter. The tasks involve modelling of monoenergetic to broadband electron, proton and ion beams with finite divergence, interacting with slab/voxelized structures composed of different materials, extraction of deposited total ionizing and non-ionizing dose in a 3d volume, and implementation of more complex, realistic structures generated in CAD tools. This setup will then be used to understand and predict the depth-dose deposition and transmitted flux of various experimentally relevant setups. The project amalgamates various general key physics processes with the design of next generation accelerator applications for natural, material and life sciences.

Key References:

[1] Tavernier, S., Experimental Techniques in Nuclear and Particle Physics: Interaction of Particles in Matter, Springer, 2009
[2] Geant Monte Carlo Code http://geant4.cern.ch/

Ratio of effort: Exp/Theo/Comp

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

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

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: This project is open to more than one student.

Safety Training Requirements: None required.

Space Radiation Reproduction and Testing

(1) Prof Bernhard Hidding, (2) Dr Mark Wiggins

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 (van-Allen belts) is inherently broadband, which is a feature hard to mimic with conventional radiation sources. Using laser-plasma-accelerators such as those developed at the Scottish Centre of the Application of Plasma-based Accelerators (SCAPA), 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 radiation hardness assurance community. A proof-of-concept experiment shall be designed which is suitable to demonstrate such secondary production and its effect on space electronics or for radiobiology.

Key References:

[1] Laser-plasma-based Space Radiation Reproduction in the Laboratory, B. Hidding et al., *Scientific Reports* 7, 42354 (2017)
[2] http://www.bbc.co.uk/news/uk-scotland-39845085
[3] http://www.bbc.co.uk/news/av/uk-scotland-39876170/powerful-laser-to-make-space-exploration-safer
[4] http://physicsworld.com/cws/article/news/2017/may/12/space-radiation-brought-down-to-earth
[5] Strathclyde Centre for Doctoral Training PPALS http://ppals.phys.strath.ac.uk/
[6] http://radecs2017.com/Radecs2017/index.php
[7] http://www.nsrec.com/

Ratio of effort: Exp/Theo/Comp

Exp:	0-20%
Theo:	20-50%
Comp:	30-60%

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

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: This project is open to more than one student.

Safety Training Requirements: Laser and radiological safety training will be provided, if required.

Radiation reaction effects in ultra-intense laser-foil interactions

(1) Prof. Paul McKenna, (2) Dr Remi Capdessus

Project Description:

Upcoming international laser facilities, such as the Extreme Light Infrastructure (ELI) and APOLLON will produce record laser intensities, in excess of 10^{23} Wcm^{-2}. When these ultra-intense laser pulses interact with thin metal foils, they ionize the target, producing a plasma. The ions within this plasma are subsequently accelerated to high energies. It is predicted that next-generation laser facilities will produce ions with energies of hundreds of MeVs, which have important applications in oncology and fast ignition fusion. At ultra-high intensities however, QED effects strongly influence the plasma dynamics and resulting ion beam properties. For example, electrons oscillating in the laser fields can acquire relativistic velocities, causing them to radiate away energy via synchrotron radiation. This energy loss can be interpreted in the classical framework as a recoil force acting on the electrons, known as the radiation reaction (RR) force.

Building on recent results on the effects of the RR force on plasma dynamics and radiation distribution during interactions with thin (50-500 nm) foils ([1], [2]), this project aims to investigate the effects of laser polarisation on the plasma energy partition and probe RR effects in the transition region between thin and thick foil ion acceleration mechanisms. This will involve running 1D and 2D Particle-In-Cell (PIC) code simulations and using Matlab to analyse the results, in order to investigate key aspects of the laser-plasma interaction. Whilst the project will be primarily simulation driven, there is the potential to develop an analytical model to describe any relevant simulation results.

Key References:

[1] Capdessus, R. and McKenna, P., 2015. Influence of radiation reaction force on ultra-intense laser-driven ion acceleration. *Physical Review E*, *91*(5), p.053105
[2] Duff, M.J., et al., 2018. Modelling the effects of the radiation reaction force on the interaction of thin foils with ultra-intense laser fields. *Plasma Physics and Controlled Fusion*, *60*(6), p.064006
[3] Tamburini, M., et al., 2010. Radiation reaction effects on radiation pressure acceleration. *New Journal of Physics*, *12*(12), p.123005

Ratio of effort: Exp/Theo/Comp

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

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

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Plasma instabilities in intense laser-foil interactions

(1)Dr. Martin King, (2) Dr. Ross Gray, (3) Prof Paul McKenna

Project description:

The interaction of an ultra-intense (>10^{20} W/cm^2) laser pulse with an ultrathin (nanometre scale) foil results in ionisation and the acceleration of high currents of energetic electrons and ions. Various types of instabilities can occur during the acceleration of these particles. Studies have shown that, for the thinnest targets, Rayleigh-Taylor-like instability develops at the laser plasma interface, and that plasma expansion of micron-thick targets is subject to the Weibel instability. Both of these processes result in filamentary structures in the electrostatic fields and thus are detrimental to laser-driven ion acceleration.

The proposed project will investigate the onset of instabilities in intense laser-foil interactions. It involves processing and analysing data from an experiment performed using the Gemini high power laser at the Central Laser Facility, STFC Rutherford Appleton Laboratory, Oxfordshire. The project will evolve to include simulating the onset of instabilities in laser-plasma interactions using a particle-in-cell code running on a high performance computer.

Key References:

[1] G. G. Scott *et al.*, "Diagnosis of Weibel instability evolution in the rear surface density scale lengths of laser solid interaction via proton acceleration" *New Journal of Physics*, 19, 043010 (2017).
[2] R. J. Gray *et al.*, "Laser pulse propagation and enhanced energy coupling to fast electrons in dense plasma gradients" *New Journal of Physics*, 16, 093027 (2014).
[3] B. Gonzalez-Izquierdo *et al.*, “Optically controlled dense current structures driven by relativistic plasma-aperture induced diffraction.” *Nature Physics*, 12, 505-512 (2016)

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	10%
	Comp:	90%

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

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Laser-driven ion acceleration from ultrathin foils undergoing relativistic self-induced transparency

(1) Dr. Robbie Wilson, (2) Dr. Ross Gray, (3) Prof Paul McKenna

Project Description:

The potential to produce compact sources of energetic (hundreds of MeV/nucleon) ions with unique beam properties, including short temporal duration, motivates an intense international research activity in high power laser-driven ion acceleration. These enabling sources are being applied for radiographic density diagnosis with micron-scale resolution, for probing highly transient electric and magnetic fields in plasmas with picosecond resolution, for the isochoric heating of matter and for probing radiation-induced processes in matter. Societal applications, such as in biomedicine (for example hadron therapy) and fusion energy have also been proposed. Some of the applications require higher ion energies than presently achieved, and many require high laser-to-ion energy conversion efficiency, as well as spectral and beam divergence control.

Efforts to increase the maximum ion energy have largely focused on the development of novel acceleration mechanisms involving ultrathin (tens-to-hundreds of nanometres) foil targets. The proposed project aims to characterise the spatial-intensity and energy distributions of beams of high energy protons accelerated during intense laser pulse interactions with ultrathin foils undergoing relativistic self-induced transparency. It involves processing and analysing data from an experiment performed earlier this year using the VULCAN high power laser facility at the Rutherford Appleton Laboratory, UK. The project may evolve to include simulating laser-driven ion acceleration using a particle-in-cell code.

Key References:

[1] A. Higginson *et al*., Near-100 MeV protons via a laser-driven transparency-enhanced hybrid acceleration scheme. Nature Communications, 9, 724 (2018)

[1] H. Padda, *et al*., "Intra-pulse transition between ion acceleration mechanisms in intense laser-foil interactions." Physics of Plasma, 23, 063116 (2016).

[2] H.W. Powell, et al., "Proton acceleration enhanced by a plasma jet in expanding foils undergoing relativistic transparency." New Joural of Physics, 17, 103033 (2015).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Atomic Processes for Astrophysical Plasmas

(1) Prof Nigel Badnell, (2) Dr Junjie Mao

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. There is room for up to two students to work on complementary aspects of this project.*

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:

Scattering of Relativistic Electrons off Electromagnetic Ion Cyclotron Waves

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

Project Description:

Relativistic electrons with energies in the MeV range and protons in the 100 MeV range are mirror trapped in dipole field of the Earth in the van Allen radiation belts. The trapping is due to the conserved magnetic moment of the charged particles. High-energy particles are detrimental to the electronics on board spacecraft and satellites, and there is an effort to find ways to clean the radiation belts of relativistic electrons and ions by perturbing the gyro-motion of the particles so that they fall within a loss-cone and are absorbed by the neutral gas of the lower ionosphere. Obeying a certain resonance condition the particles can interact with the electromagnetic waves leading to pitch angle scattering into the loss cone. Low frequency electromagnetic waves occur naturally due to solar storms, and are also produced due to man-made transmitters. Laboratory experiments have also been carried out to study pitch-angle scattering of mirror-contained particles by low-frequency electromagnetic waves. The project involves carrying out test-particle simulations to study the scattering of relativistic electrons by electromagnetic ion cyclotron waves near the ion cyclotron resonance in a diverging magnetic field, and comparing the results with theoretical expressions of pitch angle diffusion. The programming language is likely to be Matlab or similar high level language.

Key References:

[1] B. Eliasson and K. Papadopoulos: Pitch angle scattering of relativistic electrons near EMIC resonances in diverging magnetic fields. Plasma Physics and Controlled Fusion **59**(10), 104003, doi:10.1088/1361-6587/aa8100 (2017).
[2] Summers, D., and R. M. Thorne (2003), Relativistic electron pitch-angle scattering by electromagnetic ion cyclotron waves during geomagnetic storms, *J. Geophys. Res.*, 108, 1143, doi:10.1029/2002JA009489, A4.
[3] Van Compernolle B, Bortnik J, Pribyl P, Gekelman W, Nakamoto M, Tao X and Thorne R M 2014 Direct detection of resonant electron pitch angle scattering by whistler waves in a laboratory plasma Phys. Rev. Lett. 112 145006
[4] Vincena S, Gekelman W and Maggs J 2001 Shear Alfvén waves in a magnetic beach and the roles of electron and ion damping Phys. Plasmas 8 3884–96
[5] Öztürk M K 2016 Trajectories of charged particles trapped in Earth's magnetic field Am. J. Phys. 80 420–8
[6] Stix T H 1960 Absorption of plasma waves Phys. Fluids 3 19–32

Ratio of effort: Exp/Theo/Comp

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

Suitability: MSc in Applied/Advanced Physics

Recommended Classes/Pre-requisites: PH355 Physics Skills, PH352, EM and Quantum Physics, PH452 and PH560 Plasma Physics, good theoretical and numerical skills.

Safety Training Requirements: Induction TIC building, use of computer workstations.

Development of field-pickup diagnostics for high-power microwave signal analysis

(1) Dr Philip MacInnes (2) Dr Kevin Ronald

Project description:

When working with sources that generate high-power microwave signals, determination of the operating mode (i.e. the dominant EM field pattern), especially in over-moded systems, is of utmost importance. One means of achieving this is to extend the output "waveguide" from the source some distance and terminate it in an absorbing load, with a series of calibrated pick-up probes located at specific locations in the intervening space. By comparing the magnitude and phase of the AC signals recorded by the probes one may then ascertain the operating mode, operating frequency and a good estimate of the output power.

This project aims to develop a set of field-probes (D-dot or B-dot) suitable for implementation in measuring the output power / mode / frequency (etc.) of a high-power microwave source operating in the X-band (8-12GHz). There is potential in this project for the probe design to be progressed to manufacture of a prototype, with some initial testing of performance performed at low/moderate power. In this regard the project would be best suited to students with a strong experimental skill set / interest in applied physics.

Key References:

Huiskamp T. et al., 2016, IEEE Sensors Journal, 16(10), pp. 3792 - 3801

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

Suitability: MPhys, BSc, BSc Maths and Physics

Pre-requisites: PH352, recommended: PH452

Additional comments:

Safety Training Requirements: The project is based in the TIC building; all users must complete the relevant induction materials before working in TIC. Students must also review and adhere to the guidelines for use of computer workstations / VDUs. Should the project proceed to experiments, the experiments will be supervised, and the student will be provided with an induction to good practice in high power microwave experiments.

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:

Design and measurement of an input coupler for a microwave amplifier

(1) Dr. Craig R. Donaldson, (2) Dr. Colin G. Whyte

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. To feed the microwaves from a solid-state low power source into the evacuated experiment requires some junction, in the form of an input coupler.

In this project, an input coupler will be studied using analytical theory. Numerical simulations, and geometry optimisation, will be carried out using CST Microwave Studio. A vector network analyser (VNA), at W-band frequencies 90-100 GHz, will be used to measure the microwave properties of the optimised input coupler.

New challenges arise when operating at higher frequencies. Therefore, in year two the project focus will be to design an input coupler for application over 360-384 GHz.

In both frequency ranges the input coupler will be designed in order to reduce its reflection coefficient and keep a high transmission whilst operating over a wide bandwidth.

Key Reference: W. He, C.R. Donaldson, L. Zhang, et al., "High power wideband gyrotron backward wave oscillator towards the terahertz region", Phys. Rev. Lett, 110, 165101, (2013).

Ratio of effort: Exp/Theo/Comp

Exp:	15%
Theo:	25%
Comp:	60%

Suitability: MPhys

Additional comments:

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

Radiation Reaction

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

Nonlinear Vacuum Electrodynamics

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

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

Semi-automated characterisation of laser-driven proton beams

(1) Dr Ross Gray (2) Dr Robbie Wilson

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. These electrons set up exceptionally strong (TV/m) electric fields which then act to accelerate the ions in the plasma to high energies over distances significantly shorter than conventional particle accelerators. In recent years there has been a great deal of interest in developing these new ions sources for applications including cancer therapy and nuclear fusion [1].

For the most intense laser systems, an electronic based ion detection system placed close to the interaction point would not survive the extremely high flux of particles or the strong electromagnetic pulse (EMP) that is generated near the plasma. As a result a self-exposing radiochromic dosimetry film is typically used [2]. A key challenge therefore exists in rapidly characterising the spatial and spectral properties of the resulting ion beam of by making measurements of this film.

We have developed a prototype film scanner which employs a novel multi-exposure algorithm to enable a high dynamic range measurement. In this project we will aim to fully characterise the scanner performance with reference data and then develop a robust semi-automated analysis program which can characterise the spatial and spectral properties of a given ion beam. This aspect of the project will involve the use of Python and MATLAB, making use of image processing, statistical and machine learning approaches for data analysis.

In the second part of the project, building on the earlier developments, we will aim to analyse and characterise new ion beam data resulting from a recent high power laser-plasma experiment. In this stage we will seek to apply existing physics models to the data as well as insights gained from large scale plasma simulations.

Key References:

[1] H. Daido *et al.*, Rep. Prog. Phys. **75** 056401 (2012)
[2] F. Nurnberg *et al.*, Rev. Sci. Instrum. 80, 033301 (2009)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

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

Additional comments:

Safety Training Requirements: none

Attosecond radiation from laser interaction with a solid target

(1) Zhengming Sheng, (2) Weimin Wang

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^{-15}s) 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, in particular, when the incident laser pulses are in few cycle duration.

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

Recommended Classes/Pre-requisites: Laser and Optics, Classical Electrodynamics, 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.

Terahertz radiations driven by two-colour lasers in gas

(1) Zhengming Sheng , (2) Weimin Wang

Project Description

Terahertz (THz) radiations are electromagnetic waves located in the frequency band between microwaves and visible light waves. The oscillation and rotation frequencies of many organic molecules are located in this band, implying broad applications of THz technology in biology, medicine, material sciences. Currently, one of the key challenges for the applications of this technology is the generation of THz sources.

This project aims to investigate a type of THz sources driven by short intense laser pulses in gas targets. It is found that when the laser power is high enough, field ionisation of atoms can lead to the formation of transient electron currents, which can produce few-cycle THz radiation. The students will use a model to calculate the ionisation currents when the driving lasers have two frequencies components. The objective is to optimise the laser and gas parameters for most efficient THz radiation generation. By the end of the project, the student will become familiar with this scheme of THz radiation generation.

Key References

L. Zhang et al. Observation of terahertz radiation via the two-color laser scheme with uncommon frequency ratios. Phys. Rev. Lett. 119, 235001 (2017).
Z. Zhang et al. Controllable terahertz radiation from a linear-dipole array formed by a two-color laser filament in air. Phys. Rev. Lett. 117, 243901 (2016).
Z. Zhang et al., Manipulation of polarizations for broadband terahertz waves emitted from laser plasma filaments, Nature Photonics 12, 554 (2018).
M. Chen, A. Pukhov, X.-Y. Peng, and O.Willi, Phys. Rev. E 78, 046406 (2008).
H.-C. Wu, J. Meyer-ter-Vehn, and Z.-M. Sheng, New J. Phys. 10, 043001 (2008).
W.-M. Wang, Z.-M. Sheng, H.-C. Wu, M. Chen, C. Li, J. Zhang, and K. Mima, Opt. Express 16, 16999 (2008).

Ratio of effort: Exp/Theo/Comp

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

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

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

Additional comments: No.

Safety Training Requirements: No.

Laser pulse compression towards the single cycle regime in plasma

(1) Zhengming Sheng, (2) Weimin Wang

Project Description:

High intensity ultrashort laser pulses can be found broad application, such as attosecond X-ray generation [1], terahertz generation [2] and electron acceleration [3], etc. Currently even though the shortest optical laser pulses obtained in laboratory already approach single cycles, the pulse power or intensity is weak. This is due to the limited frequency bandwidth of amplification media. For example, Ti: Sapphire crystals usually can only the amplification of shortest pulse lasers over a few cycles. Plasma as a nonlinear optical medium may be used to compress an intense laser pulse of a few cycle to single cycle [4,5,6].

The main task of this project is to compare different schemes [4,5,6] of laser pulse compression in plasma and explore the limit of these schemes. The student will use a one-dimensional particle-in-cell (PIC) code to numerically test different schemes of laser pulse compression in plasma.

Key References:

[1] https://phys.org/news/2017-10-world-shortest-laser-pulse.html
[2] H.-C. Wu, J. Meyer-ter-Vehn, and Z.-M. Sheng, New J. Phys. 10, 043001 (2008).
[3] K. Schmid, L. Veisz et al., Phys. Rev. Lett. 102, 124801 (2009).
[4] H. Y. Wang et al., Phys. Rev. Lett. 107, 265002 (2011).
[5] O. Shorokhov et al., Phys. Rev. Lett. 91, 265002 (2003).
[6] Z. M. Sheng et al., Phys. Rev. E 62, 7258 (2000).

Ratio of effort: Exp/Theo/Comp

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

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

Recommended Classes/Pre-requisites: Laser and Optics, Classical Electrodynamics, 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

Nanoscience Division

Engineering semiconductor defects for quantum electronics

(1) Dr Alessandro Rossi, (2) Prof. Robert Martin

Project Description:

The ability to introduce alien atomic species into microscopic regions of a semiconductor material, a technique widely known as doping, has been the cornerstone for the build-up of modern integrated electronics. In fact, this is how the electrical conductivity of semiconductors is locally controlled through ion implantation. However, during the implantation process, high energy collisions between these dopants and the semiconductor target can generate significant crystal damage. Although this may be a problem for the reliability of electronic chips, it has been shown that some atomic defects have very interesting physical properties and lend themselves to the realisation of quantum devices [1].

In particular, the atomic defects created by the implantation of C atoms in silicon carbide (SiC) are spin-active and luminescent. They have been exploited in a diverse range of quantum devices, such as quantum magnetometers, quantum thermometers, single-photon emitters, as well as to encode quantum bits of information [2].

In this project, the student will be involved in designing SiC-based quantum devices. In order to improve the reliability and yield of these electronic systems, an optimisation of the implantation process will be carried out. This mainly computational project will make use of Monte-Carlo simulations [3] to tune the implantation parameters and achieve desirable defect concentrations, localisation and patterning. The main expected outcome of the project is the definition of a set of process specifications to be submitted to an ion implantation facility for real sample manufacturing.

Key References:

[1] M. Atature et al., Nature Reviews Materials 3, 38 (2018)
[2] A. Lohrmann et al., Rep. Prog. Phys. 80, 034502 (2017)
[3] http://www.srim.org/

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: PH258 and PH358

Additional comments: None.

Safety Training Requirements: None.

Investigation of β-Gallium Oxide semiconductors for power electronics applications

(1) Dr Naresh Kumar, (2) Prof. Rob Martin

Project Description:

Gallium oxide (Ga_2O_3) is an emerging material for power electronics devices with capabilities beyond existing technologies due to its large bandgap (≈ 5 eV). Among the five different polymorphs of Ga_2O_3, the β phase (Monoclinic crystal system) is the stable form under normal conditions and has been the most widely researched and developed.

This project will explore the structural and optical properties of β-Ga_2O_3 layers, produced using edge-defined film-fed growth (EFG) and hydride vapour phase epitaxy (HVPE) methods [1,2]. A range of techniques will be employed to resolve crystal orientation, image surface morphology, and to study optical emission and absorption. The project will employ scanning electron microscopy for crystal orientation and surface morphology as well as studies of photoluminescence (PL) using UV lasers and high power UV lamps for optical emission. The absorption properties will be investigated by photoluminescence excitation (PLE). Temperature dependent (20 – 300 K) PL and PLE will also be performed for a detailed understanding of defect related transitions.

The objective of the project is to correlate the structural and optical properties of the Ga_2O_3 layers, evaluate the quality of layers grown by different growth methods and their suitability for various power electronic devices.

Key References:

[1] "A review of Ga_2O_3 materials, processing, and devices", S. J. Pearton et al., Applied Physics Reviews 5, 011301 (2018).
[2] "High-quality β-Ga_2O_3 single crystals grown by edge-defined film-fed growth", A. Kuramata et al, Japanese Journal of Applied Physics 55 1202A2 (2016).

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

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

Recommended Classes/Pre-requisites: PH453 Topics in Solid State Physics, PH355 Physics Skills.

Additional comments: Involves working with lasers and high-power UV light sources.

Safety Training Requirements: Laser and radiological safety training, technology innovation centre safety induction will be needed.

Investigation of spectral characteristics of UV LEDs

(1) Dr Jochen Bruckbauer, (2) Prof. Robert W. Martin, Dr Carol Trager-Cowan

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 [1]. Recently, LEDs emitting in the ultraviolet (UV) region became attractive for water purification, sterilisation and medical applications due to their compactness and robustness. 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 [2]. Although, blue/white LEDs are extremely successful their counterparts in the UV, also based on III-nitride semiconductors, still suffer from several challenges and research is ongoing to improve their performance [3].

Requirements for LEDs for most applications is that their emission wavelength should not change when the light intensity is changed and that their emission properties should remain constant during the course of their lifetime. Nitride-based LEDs (UV to blue/green) have the disadvantage of having in-built electric fields affecting device performance. Changing the drive current changes these electric fields, which then results in a small shift in the emission wavelength. The aim of this project is to investigate the impact of drive current on optical properties of a range of UV LEDs with different emission wavelengths. For this the emission from UV LEDs will be measured to investigate emission parameters, such as wavelength, intensity and relative LED efficiency. The project will also consider the effect of heating of the devices.

Key References:

[1] E. Fred Schubert: Light-Emitting Diodes, 2nd Ed., Cambridge University Press
[2] https://www.nobelprize.org/nobel_prizes/physics/laureates/2014/
[3] M. Kneissl *et al.*, *Nat. Photonics* **13**, 233 (2019)

Ratio of effort: Exp/Theo/Comp

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

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

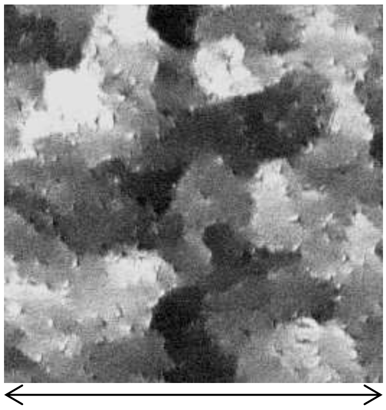
Recommended Classes/Pre-requisites: *PH453 Semiconductor Physics and Devices course*

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)*

Investigating sub-grain structure and dislocations in nitride semiconductor thin films

(1) Dr Carol Trager-Cowan, (2) Dr Jochen Bruckbauer



Project Description:

Nitride semiconductor thin films, which are used to make blue, green and UV-LEDs and high frequency transistors, are nominally single crystal. However if they are imaged with microscopic techniques with sufficient sensitivity to detect small tilts and rotations, it is possible to reveal that they contain sub-grains, rotated or tilted with respect to each other, by a fraction of a degree. For example the adjacent figure shows an image acquired from an AlGaN thin film where the different grey scales reveal sub-grains of different orientations. The small features on the boundaries of the sub-grains are defects (dislocations) which can form as a result of the relative misorientations of the sub-grains. Such defects limit device performance; e.g., lead to the generation of heat rather than light in LEDs, induce electrical shorts and limit device lifetime.

The image was acquired in a scanning electron microscope (SEM) using the technique of electron channelling (diffraction) contrast imaging (ECCI). ECCI micrographs may be produced when a sample is placed so that a plane or planes are at, or close to, the Bragg angle with respect to the incident electron beam. Any crystallographic misorientations, or change in lattice constant due to local strain, will produce a variation in contrast in the resultant ECCI image. Extremely small changes in orientation and strain are detectable, revealing sub-grains with low angle tilt and rotation boundaries and enabling extended defects such as dislocations to be imaged.

If the plane selected to diffract the incoming beam is not distorted due to the presence of a defect such as a sub-grain boundary or a dislocation, then that defect will be invisible in the ECCI image. Therefore, to reveal all the sub-grains and dislocations, a number of ECCI image need to be acquired over a range of diffraction conditions.

The aim of the project is to use ECCI to study the relationship between sub-grains and dislocations for a set of AlGaN thin films exhibiting different dislocation densities. A series of ECCI images will be acquired from each AlGaN thin film so that all sub-grains and dislocations are revealed. Image analysis tools will then be used to align and combine the ECCI images into a single image showing all sub-grains and dislocations in a single image. Image analysis tools will then be used to determine sub-grain size and the number of dislocations around the sub-grain, to investigate the relationship between sub-grain size and dislocation density. Ultimately can we answer the question: to minimise the dislocation density, is it better to grow AlGaN thin films so they have a small number of large grains, or a larger number of small grains?

Key References:

[1] http://ssd.phys.strath.ac.uk/. In particular: http://ssd.phys.strath.ac.uk/techniques/scanning-electron-microscopy/electron-channelling-contrast-imaging-ecci/

Ratio of effort: Exp/Theo/Comp

Exp:	30%
Theo:	40%
Comp:	30%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH453 Topics in Solid State Physics, PH454 Topics in Nanoscience

Safety Training Requirements: None.

Investigation of polytypism in nitride semiconductors

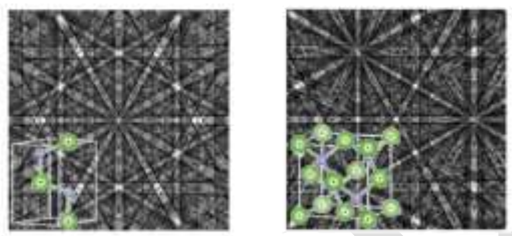
(1) Dr Carol Trager-Cowan, (2) Dr Jochen Bruckbauer, (3) Dr Gergely Ferenczi

Project Description:

GaN semiconductor thin films, which are the basis of blue, green and UV-LEDs, are usually grown with the thermodynamically stable wurtzite (2H) crystal structure; however, they can also be grown with the zincblende (3C) crystal structure. The zincblende crystal structure has advantages for the production of more efficient LEDs, particularly in the green region of the spectrum [1]. Certain growth conditions result in GaN thin films containing both crystal structures (polytypes). In this project the student will investigate GaN thin films which contain both the 2H and 3C polytypes using the scanning electron microscopy technique of electron backscatter diffraction (EBSD).

The scanning electron microscope (SEM) is a very powerful tool for investigating and imaging a wide range of material properties spanning topography, structure, composition and light emission. SEMs are extensively used for imaging topography, by monitoring the intensity of secondary electrons as a focussed electron beam, with an energy in the range of 100 eV to 30 keV, is rastered over the surface of a sample. Less well known is the technique of electron backscatter diffraction (EBSD) [2-6] which exploits diffraction to provide information on crystal structure and crystal misorientation. EBSD provides information on the structural properties of materials rapidly and non-destructively with a spatial resolution of tens of nanometres.

In EBSD the sample is tilted at around 70° to the normal of the incident electron beam. The impinging electrons are scattered inelastically through high angles forming a diverging source of electrons which can be diffracted. The resultant electron backscatter diffraction pattern (EBSP) consists of a large number of overlapping bands, known as Kikuchi bands, which are closely related to a 2-D projection of the crystal structure. See adjacent figure for example simulated EBSPs for wurtzite and zincblende GaN respectively. The interpretation of the EBSPs allows the crystal structure of the sample to be identified.



EBSP wurtzite GaN   EBSP zincblende GaN

Key References:

[1] M Frentrup et al, J. Phys. D: Appl. Phys. **50** 433002 (2017).
[2] A. J. Schwartz et al, Electron Backscatter Diffraction in Materials Science (Springer, 2009).
[3] A. J. Wilkinson and P. B. Hirsch, Micron **28** 279 (1997).
[4] A. J. Wilkinson and T. B. Britton, Mater. Today **15** 366 (2012).
[5] C. Trager-Cowan et al., Phys. Rev. B. **75** 085301 (2007)
[6] http://ssd.phys.strath.ac.uk/

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH453 Topics in Solid State Physics, PH454 Topics in Nanoscience

Additional comments: This project is open to more than one student.

Safety Training Requirements: None.

Ga_2O_3 solar-blind detectors and the quest for the optimal electrical contacts

(1) Dr Fabien Massabuau, (2) Dr Paul Edwards

Project Description:

Solar-blind photodetectors are sensitive to ultraviolet (UV) radiation with a wavelength shorter than 280 nm. These could be employed for flame detection, biological and chemical sensing, or non-line-of-sight communication systems. With a bandgap of 5 eV, Ga_2O_3 is a promising candidate for solar-blind detector applications.

We have recently demonstrated that low temperature atomic layer deposition could be used to synthesise crystalline Ga_2O_3 films and the suitability of the materials for solar-blind detection has been proven. Despite promising first results, various aspects of the device need to be improved – *e.g.* increasing grain size, reducing point defect density, improving carrier transfer at contacts. Semiconductor-metal contacts are of vital importance for the performance and reliability of semiconductor devices, yet the conditions leading to low resistivity ohmic contacts are still unexplored for this material. In this project we will tackle the conditions for optimal electrical contact and their impact on solar-blind detection performance.

The student will be expected to operate a probe station to record I-V characteristics of the contact structures. If time allows the measurements will be performed in dark and under UV light illumination.

Key References:

[1] "α-Ga_2O_3 grown by low temperature atomic layer deposition on sapphire", J. Roberts et al., J. Cryst. Growth 487, 23 (2018)
[2] "Investigation of Different Metals as Ohmic Contacts to b-Ga2O3: Comparison and Analysis of Electrical Behavior, Morphology, and Other Physical Properties", Y. Yao et al., J. Electron. Mater. 46, 2053 (2017)

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: PH453 Topics in Solid State Physics (recommended but not compulsory)

Additional comments: The project may involve working a UV light source.

Safety Training Requirements: Laser and radiological safety training will be provided.

Investigation of Gallium Oxide semiconductors for UV applications

(1) Prof Rob Martin, (2) Dr Fabien Massabuau

Project Description:

Gallium Oxide (Ga_2O_3) has recently become a material of interest for applications in electronics and in ultra-violet (UV) devices, either detectors or emitters. For example, photodetectors that are sensitive to UV radiation with a wavelength shorter than 280 nm but not to the Sun's emission (so-called solar blind detectors) have a range of applications in sensing and communications. The bandgap of Ga_2O_3 is in the region of 5 eV, making it a possible material for such devices. This project will explore the optical properties of Ga_2O_3 layers, which have recently been produced using low temperature atomic layer deposition [1]. A range of techniques will be employed to see what can be learnt about emission from the layers, both near the bandgap and also from longer wavelength defect-related transitions, as well as their optical absorption. The project will cover photoluminescence (PL) using UV lasers and high power UV lamps as wavelength-tunable excitation sources, with sample temperature (15 – 300K) being an additional variable. The absorption properties will be investigated by photoluminescence excitation (PLE) and photocurrent spectroscopy, with the latter monitoring current flowing between electrical contacts prepared on the sample surface. Reference [2] is a recent paper describing PL and PLE measurements (Figs 4 & 5) on a different crystal phase of Ga_2O_3.

The aim of the project will be to gain as much information as possible on the optical properties and quality of the studied Ga_2O_3 layers, as well as their suitability for the range of possible device applications.

Key References:

[1] "α-Ga_2O_3 grown by low temperature atomic layer deposition on sapphire", J. Roberts et al., J. Cryst. Growth 487, 23 (2018)
[2] "Structural and optical properties of pulsed-laser deposited crystalline β-Ga2O3 thin films on silicon", Y. Berencén et al., Semicond. Sci. Technol. 34, 035001 (2019)

Ratio of effort: Exp/Theo/Comp

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

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

Recommended Classes/Pre-requisites: PH453 Topics in Solid State Physics, PH355 Physics Skills.

Additional comments: Involves working with lasers and high-power UV light sources.

Safety Training Requirements: Laser and radiological safety training will be needed.

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.

Computational Methods in Single-Molecule Localization Microscopy

(1) Dr Sebastian van de Linde, (2) Dr Oliver Henrich

Project Description:

Super-resolution microscopy methods have the ability to overcome the classical diffraction limit of light microscopy and thus have opened the door for the study of finer cellular ultrastructure as evidenced by the Nobel Prize awarded for this work in 2014.

A very powerful variant is single-molecule localization microscopy (SMLM) that achieves a lateral resolution down to 20 nm. SMLM is a wide-field based imaging technique utilizing photoswitchable fluorophores, i.e. molecules that exhibit a transition between non-fluorescent off- and fluorescent on-states. Image generation is based on the acquisition and processing of a series of images, each of them containing different subsets of stochastically activated fluorophores.

With the aid of sensitive cameras, fluorophores are detected as diffraction limited spots as they are convolved with the point spread function (PSF) of the microscope. By fitting a two-dimensional Gaussian function to its emission profile, the centre of the molecule can be determined with nanometre precision. Finally, a super-resolution image is generated by merging all single-molecule coordinates into a single image.

Objectives of this project are an introduction to state-of-the-art SMLM software packages and image processing. Depending on progress and interest of the student software routines for (i) simulating fluorophore blinking for advanced multi-channel SMLM and/or (ii) analysis of multi-channel imaging SMLM data will be developed.

Key References:

C. G. Galbraith and J. A. Galbraith. Super-resolution microscopy at a glance. *J. Cell Sci.* **124**, 1607 (2011)

S. van de Linde. Single-molecule localization microscopy analysis with ImageJ. *J. Phys. D: Appl. Phys*. **52**, 203002 (2019)

S. Wolter, M. Schuettpelz, M. Tscherepanow, S. van de Linde, M. Heilemann, M. Sauer. Real-time computation of subdiffraction-resolution fluorescence images. *J. Microsc.* **237**, 12 (2010)

A. Small and S. Stahlheber. Fluorophore localization algorithms for super-resolution microscopy. *Nat. Methods* **11**, 267 (2014)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: Experience of programming is strongly advised.

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

Evaluating Spot-Finding Methods

(1) Dr Sebastian van de Linde, (2) Dr Daniel Oi

Project Description:

Finding the centre of a spot in an image is surprisingly useful in many applications, both on the Earth an in space. Distributing quantum encryption keys (QKD) from space will allow secure communication on a global scale. Strathclyde is working with collaborators both in the UK and overseas to build and fly our own quantum satellites. A crucial element of SatQKD is the pointing system that allows quantum signals to be sent from space to a ground-based optical receiver, that is a CCD or COMS camera. The detected light appears as 2D photon distribution on the camera, which can be further analysed to extract the position of the object.

Such position extraction is also the key part of super-resolution microscopy, allowing the ability to probe the structure of biological systems at small scales previously thought impossible. This project will look at how we can best process images to extract spot positions. In particular, the ability to localise objects with high precision will be explored. The influence of camera parameters such as fill-factor and pixel response function on systematic and random errors in spot finding, along with finding optimum values for spot size and algorithm tuning parameters will be researched. Further a study of the trade-off between computational complexity versus accuracy and robustness of different spot finding methods such intensity weighting and Gaussian fitting will be performed.

Although the project is mainly computational, at a later stage of the project experimental data of fluorescent spots originating from high-end laser microscopes will be measured for comparison.

Key References:

A. Small and S. Stahlheber, Fluorophore localization algorithms for super-resolution microscopy, *Nat. Methods*, **11**, 267 (2014)

Oi DK, Ling A, Vallone G, Villoresi P, Greenland S, Kerr E, Macdonald M, Weinfurter H, Kuiper H, Charbon E, Ursin R. CubeSat quantum communications mission. *EPJ Quantum Technology*. 2017 Dec 1;4(1):6.

Ratio of effort: Exp/Theo/Comp		
	Exp:	5%
	Theo:	20%
	Comp:	75%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: Experience in programming and data analysis is recommended.

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

Computing the inverse square law

(1) Dr Ben Hourahine, (2) Dr Oliver Henrich

Project Description:

Interactions proportional to $1/r^2$ occur in gravitational, electrostatic and electromagnetic interactions, where r is the separation between bodies. The slow decrease of this function with distance causes major challenges when there are large numbers of interacting objects. Every possible pair of particles in the system contributes to the total interaction, so for N particles there are N^2 contributions.

One of the major computational breakthroughs in the 20th Century [1] was to realise that instead of considering each pair of particles, at larger distances only the net contributions from groups of particles matters. This leads to methods that evaluate a total of either $N \log N$ interactions [2], or even better only N [3] terms. This has enabled simulations of up to $\approx 10^{12}$ particles on large supercomputers for application in cosmology or materials and bio-science.

This project will investigate using these smarter ways to calculate the forces between interacting particles, and see if it is possible to use $< N$ terms in evaluating their interactions.

Key References:

[1] B. A. Cipra (May 16, 2000). "The Best of the 20th Century: Editors Name Top 10 Algorithms". SIAM News. Society for Industrial and Applied Mathematics. 33 (4): 2.
[2] J. Barnes and P. Hut. "A Hierarchical O(N log N) Force-Calculation Algorithm". Nature 324, 446–449 (1986).
[3] J. Carrier, L. Greengard, and V. Rokhlin. A Fast Adaptive Multipole Algorithm for Particle Simulations. SIAM J. Sci. and Stat. Comput. 9, 669–686 (1988).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH456 Topics In Computational And Complex Systems In Physics

Additional comments: This project is open to more than one student.

Safety Training Requirements: N/A

Optical Modes and Multiple Scattering

(1) Dr Ben Hourahine, (2) Dr Francesco Papoff

Project Description:

It has recently been shown that the optical properties of most nano-particles can be understood as arising from the modes of the particle. These are, like the standing acoustic waves of an organ pipe or the wavefunctions of a quantum mechanical particle in a box, distinct solutions of the appropriate wave equations (here, Maxwell's equations). However, if a second particle is brought close by, how
does this affect these modes?

Light will then "bounce" between these two particles (multiple scattering), leading to a new set of optical modes which describe the whole composite system. This project will theoretically and computationally study the transition between the isolated and coupled modes of two glass particles as they approach each other.

Key Reference (if applicable):

F. Papoff, B. Hourahine, Geometrical Mie theory for resonances in nanoparticles of any shape, Optics Express, 19, 21432 (2011)

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: This project is open to more than one student.

Optics Division

Characterization of optically pumped quantum well and quantum dot vertical-cavity structures

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

Project Description:

The research field of spintronics aims at utilizing the carrier spin for applications in addition to the number of carriers as usual in electronics and semiconductor photonics. However, electrical injection of spin polarized carriers is still limited to cryogenic temperatures or low temperatures in combination with a large magnetic field. At room temperature, optical pumping provides a convenient alternative to electrical injection since carrier spin and photon spin are coupled by angular momentum selection rules. III-V semiconductor gain media in vertical-cavity structures possess the necessary isotropy in the plane of the gain medium to investigate spin dependent effects. Most work centred on relatively low gain structures in vertical-cavity surface-emitting lasers (VCSEL) with quantum well gain media.

This project will look at high gain quantum well samples for external-cavity use (VECSELs) and VCSEL structures containing quantum dots, zero dimensional semiconductors with quantum confinement in all directions. The measurements will start with analyzing the polarization properties of the photoluminescence in dependence on the polarization ellipticity of the optical pump field. Polarization dependent gain will be measured afterwards via a tunable laser. The final aim of the project is to achieve lasing.

Key Reference:

[1] Bhattacharya et al., Quantum dot polarized light sources, Semicond. Sci. Technol. 26 (2011) 014002
[2] Hoevel et al., Appl. Phys. Lett. 92, 041118 (2008)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

Additional comments: The student is required to attend PH445 and PH453 to obtain the necessary background. The project demands the engagement with tedious and careful optical alignment.

Safety Training Requirements: laser

Photon statistics of small lasers

(1) Prof Thorsten Ackemann, (2) Dr Konstantinos Lagoudakis

Project Description:

There is an increasing drive to miniaturize lasers to reduce footprint, costs and energy consumption to satisfy the ever increasing demand on bandwidth in telecom and Datacom driven by the rapid growth of internet traffic [1]. "Microlasers" have dimensions of a few micrometres and "nanolasers" go below a mircometres down to the restrictions given by the wavelength. An important consequence of making lasers smaller and smaller is that the ration b of the spontaneous emission going into the lasing mode larger and larger and the laser threshold smears out. At b=1 one talks about the "thresholdless laser" [1]. This has also important consequences on the photon statistics of the laser and how coherence emerges. Abrupt spikes of emission have been seen in the output of small lasers with the intensity auto-correlation g(2) showing bunching reminiscent of thermal light [1-4]. The project will look at the output and noise characteristics of single-mode vertical-cavity surface emitting lasers (VCSEL) as an important example for microlasers [5]. The transition through threshold will be measured and the intensity output will be analysed via histograms, RF-spectra and autocorrelation.

Key References:

[1] Martin T. Hill and Malte C. Gather, "Advances in small lasers", Nature Photon. 8, 908 (2014)
[2] T. Wang, G.P. Puccioni, G.L. Lippi, "Photon bursts at lasing onset and modeling issues in mesoscale devices", arXiv:1905.08639v1
[3] T. Wang, D. Aktas, O. Alibart, E. Picholle, G.P. Puccioni, S. Tanzilli, and G.L. Lippi, "Nontrivial photon statistics in small scale lasers", arXiv:1710.02052v1
[4] TAO WANG, GAOFENG WANG, GIAN PIERO PUCCIONI, AND GIAN LUCA LIPPI, "Exploration of VCSEL ultra-low biasing scheme for pulse generation", J. Opt. Soc. B 36, 799 (2019)
[5] S. P. Hegarty et al., " Size dependence of transverse mode structure in oxide-confined vertical-cavity diodes", Appl. Phys. Lett. 73, 596 (1998)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites: PH455 Photonics, PH453 solid state

Additional comments: The students needs to be willing to do tedious optical alignment.

Safety Training Requirements: Laser.

Grating magneto-optical trap modelling

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

Project Description:

Magneto-optical traps are ubiquitous in many atomic physics experiments, providing a dense source of ultracold atoms which can be utilised to obtain ultra-precise measurements [1]. However, such traps require six input laser beams and thereby suffer from optical complexity which can inhibit portable applications. We have pioneered the use of grating magneto-optical traps to circumvent this problem [2-5].

In this project you will model the acceleration in both forms of magneto-optical trap to see how the atom number collected scales with laser input power. An ideal extension of this project will be to compare your theoretical results to the lab experiments.

Key References:

[1] E. L. Raab, M. Prentiss, A. Cable, S. Chu, and D. E. Pritchard, *Trapping of Neutral Sodium Atoms with Radiation Pressure*, Phys. Rev. Lett. 59, 2631 (1987).

[2] M. Vangeleyn, P.F. Griffin, E. Riis and A.S. Arnold, *Single-laser, one beam, tetrahedral magneto-optical trap*, Opt. Express **17**, 13601 (2009).

[3] M. Vangeleyn, P.F. Griffin, E. Riis, and A.S. Arnold, *Laser cooling with a single laser beam and a planar diffractor*, Opt. Lett. **35**, 3453 (2010).

[4] C.C. Nshii *et al.*, *A surface-patterned chip as a strong source of ultracold atoms for quantum technologies*, Nature Nanotech. **8**, 321 (2013).

[5] J.P. McGilligan, P.F. Griffin, E. Riis, A.S. Arnold, *Phase-space properties of magneto-optical traps utilising micro-fabricated gratings*, Opt. Express **23**, 8948 (2015).

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	20%
Comp:	60%

Suitability: MPhys only

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments:

Safety Training Requirements: Laser safety training will be provided.

Digital feedback for control of quantum optics experiments

(1) Dr Paul Griffin, (2) Dr Oliver Burrow

Project Description:

Quantum optics experiments require precise control of experimental parameters, including the frequency and power of lasers, magnetic fields, and piezo-electrics controllers. Typically, much of this has been achieved through active feedback using home-built analogue electronics. These circuits are custom designed for specific applications and often require finetuning due to variation of component values

The Red Pitaya [1] is an affordable field-programmable gate array (FPGA) board with fast analog inputs and outputs. This makes it useful in the laboratory, in particular as a digital feedback controller. The aim of this project is to design, test, and implement a versatile digital feedback system to minimise fluctuations in a quantum optics experiment.

Within this project you will get experience of laser systems and digital electronics.

Key References:

[1] https://www.redpitaya.com
[2] “PyRPL (Python Red Pitaya Lockbox) — An open-source software package for FPGA-controlled quantum optics experiments,” L. Neuhaus et al., 2017 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich, Germany, 2017. http://dx.doi.org/0.1109/CLEOE-EQEC.2017.8087380

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

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

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: The project is suitable for a student with interests in lasers, electronics and control theory. The successful candidate will work closely with PhD students, postdocs, and academics within EQOP.

Safety Training Requirements: Laser safety training is required and will be provided.

Propagation of orbital-angular momentum beams through a scattering medium

(1) Dr Paul Griffin, (2) Dr David McKee

Project Description:

Light with an electric-field pattern. in 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 will use spatial light modulators (SLMs) as a rapid and robust method of generation of such light beams from standard laser systems. The project will examine how such beams propagate and how their subsequent detection can be used for measurement of physically interesting properties, such as measurement of particles and turbulence in water and in air

Key References:

[1] "A.M. Yao, and M.J. Padgett, "Orbital angular momentum: origins, behaviour and applications", Advances in Optics and Photonics, 3 (2). p.161, (2011)

[2] Wikipedia key topics: "Orbital angular momentum of light," "Transmissometer", "Mie scattering"

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: This project is suitable primarily for a student with a strong interest in experimental physics.

Safety Training Requirements: Laser safety training will be provided.

Building A 3D Airborne Fluxgate Magnetometer for Geomagnetic Field Measurements

(1) Dr Terry Dyer, (2) Prof Erling Riis

Project Description:

Magnetometry can provide a wealth of information about the environment around us – from solar storms, the human heartbeat, to underground mineral deposits. State-of-the-art research-grade magnetometers provide very precise measurements but with the drawbacks of cost and complexity.

Low cost fluxgate magnetometers are coming available as commercial off-the-shelf products [1]. Featuring ~1.5 nT/sqrt(Hz) sensitivity at 1 kHz, these offer the possibility of making low-cost, low-power DC and AC geomagnetic field measurements at the mm scale.

In this project the student will develop a portable battery-operated system to record geomagnetic field data from three orthogonally-mounted sensors, in addition to position from a GPS sensor [2]. The data will be uploaded periodically to a cloud server via cellular or WiFi connection [3] for data analysis.

Key References:

[1] V Petrucha and D Novotny, Journal of Electrical Engineering, **69** 418–421 (2018).

[2[https://www.adafruit.com/product/2542

[3] https://www.espressif.com/en/products/hardware/esp32/overview

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics,

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments: The project requires the use of microcontrollers, such as an Arduino, and the interfacing with computers. The successful candidate(s) will be eager to demonstrate these skills and to apply them rapidly to the project. There is room for up to two students to work on complementary aspects of this project.

Safety Training Requirements: Safety training will be provided.

Atomic Physics Game Design for Outreach Activities

(1) Dr Stuart Ingleby, (2) Dr Paul Griffin and Dr Gordon Robb

Project Description:

Atomic physics and quantum technologies, such as optically pumped magnetometers, atomic clocks and rotation sensors, are increasingly important in real-world applications [1]. It is important to communicate effectively with the public on the advantages, operation and scientific basis of these technologies. However, the underlying physics is not always intuitively easy to understand. In this project you will develop a console-type game allowing members of the public to play with the atomic system and visualise how the sensor works.

A physics-based game should have several advantages over other demonstration activities. We have observed that people engage much more with things that they can interact directly with, and the graphical interface of a game can be used to visualise the system physics more readily than a model or image display. By using robust, durable controllers, a game can be made suitable for visitors of all ages, including schoolchildren. Your game should meet the following criteria:

- Accurately represent the physics of the atomic sensor system (e.g. the precession of alkali atoms in an optically pumped magnetometer).
- Have simple, intuitive controls that can be learned in a few seconds.
- Have an attractive and polished graphical appearance suitable for display on monitors of varying sizes.
- Run on a portable computer, such as a Raspberry Pi.

Key References:

[1] Roadmap on quantum optical systems, R Dumke *et al.*, J. Opt. **18** 093001 (2016)

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: PH355 Physics Skills

Additional comments:

Safety Training Requirements:

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.

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 < ~1μK , 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*

Creation and control of continuous-mode optical superposition qubits

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

Project Description:

The creation and coherent control of qubits, the quantum version of the bit, is a fundamental task in quantum information processing. The no-cloning theorem [1], a fundamental result of quantum mechanics, forbids the perfect creation of a state that is orthogonal to an unknown quantum state (i.e. the implementation of a NOT gate). In contrast we can in principle realize a perfect orthogonalizer even if we only know some limited preliminary information about the input state, most notably if we know its expectation value with respect to a particular operator [2].

A coherent state is a quantum state of the electromagnetic field that can represent a laser pulse and therefore can be easily generated and manipulated. Recent work [3][4][5] proved the ability to create the state orthogonal to an unknown coherent state, based on the sole knowledge of the coherent state's mean photon number. An arbitrary superposition of the coherent state and its orthogonal counterpart can also be created, such for example the so called Schrödinger cat state [6].

The aim of this project is to investigate how this tool can be generalized and used in optical quantum information processing to create and control optical qubits composed of a superposition of a coherent state and its orthogonal counterpart. The project will be comprised of two parts. The first will focus on a theoretical investigation based on standard quantum optical tools, possibly aided with some simulation. In the second part, the findings of the first part will be used to design an experiment.

Key References:

[1] W. Wootters, and W. Zurek, A single quantum cannot be cloned, Nature 299, 802-803 (1982).
[2] M. R. Vanner, M. Aspelmeyer, and M. S. Kim, Quantum State Orthogonalization and a Toolset for Quantum Optomechanical Phonon Control, Phys.Rev. Lett 110, 010504 (2013).
[3] A.S. Coelho, L.S. Costanzo, A. Zavatta, C. Hughes, M.S. Kim, and M. Bellini, Universal continuous-variable state orthogonalizer and qubit generator, Phys. Rev. Lett., 116, 110501 (2016)
[4] A. Zavatta, V. Parigi, M. S. Kim, H. Jeong, & M. Bellini, Experimental demonstration of the bosonic commutation relation via superpositions of quantum operations on thermal light fields. Phys. Rev. Lett. 103, 140406 (2009)
[5] A. Zavatta, S. Viciani, and M. Bellini, Single- photon excitation of a coherent state: Catch- ing the elementary step of stimulated light emission, Phys. Rev. A 72, 023820 (2005).
[6] E. Schrödinger, Die gegenwärtige Situation in der Quantenmechanik, Naturwissenschaften 23, 807-812 (1935).

Ratio of effort: Exp/Theo/Comp

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

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

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Coherent Perfect Amplification of Light

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

Project Description:

Absorption and emission of light are governed fundamentally by the rules of both quantum and classical physics. Classical physics provides the optical mode structure and quantum provides the absorption/emission probabilities and hence the light intensities.

In the most striking form of coherent perfect absorption [1] an absorbing medium of subwavelength thickness is rendered transparent or perhaps fully absorbing, merely by changing the mode of the incoming radiation. Precursors to this effect were suggested nearly 20 years ago in quantum optics in a body of work that examined the quantum properties of lossy beam splitters [2-4].

The optical mode structure of amplifying subwavelength films is similar to that of absorbers [5-6]. This project will model such devices and find the spectral and perhaps the quantum properties of the light that they can emit.

The project will begin with a study of the mode structure of slab devices, investigating the thin limit for both attenuating and amplifying media. The output light modes will be calculated and the possibility of basing a laser light source on such structures will be investigated.

Key References:

[1] J. Zhang, K.F. MacDonald and N.I. Zheludev, *Controlling light-with-light without nonlinearity*, Light: Science & Applications (2012) **1**, e18; doi:10.1038/lsa.2012.18, and references therein.
[2] R. Matloob et al., *Electromagnetic Field Quantisation in Absorbing Dielectrics*, Phys. Rev. A **52**, 4823 (1995).
[3] S.M. Barnett et al., *Quantum Optics of Lossy Beam Splitters*, Phys. Rev. A **57**, 2134 (1998).
[4] J. Jeffers, *Interference and the Lossless Lossy Beam Splitter*, J. Mod. Opt. **47**, 1819-1824 (2000).
[5] R. Matloob et al., *Electromagnetic Field Quantisation in Amplifying Dielectrics*, Phys. Rev. A **55**, 1623 (1997).
[6] J. Jeffers et al., *Canonical Quantum Theory of Light Propagation in Amplifying Media*, Optics Communications **131**, 66-71 (1996).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: High marks in 3rd Year Quantum Physics, Electromagnetism. Computational Physics.

Additional comments: A good level of mathematics will be required. Matlab programming.

Safety Training Requirements . N/A

Two-Photon Young's Beamsplitters for Communication

(1) Prof John Jeffers, (2) TBC

Project Description:

Young's slits are the classic optical experiment that shows that light can in some circumstances be described by waves. On the other hand, two photon interference is the classic quantum optical experiment that shows that light can be described as bosonic particles. This project will examine a hybrid of these two experiments, in which two parties each send an independent photon to separate beam splitters (slits) and nonlocal quantum interference should force joint detections in particular spatial locations. The locations may allow the establishment of a secret key between two parties.

This project requires the student to be proficient with the mathematics of linear superposition and with quantum mechanics. A good mark in the 3rd year quantum course is essential to undertaking this project, especial the quantum theory of the harmonic oscillator.

Key References:

H. Fearn and R. Loudon, Optics Communications 64, 485, 1987 C.K. Hong, Z.Y. Ou and L. Mandel, Physical Review Letters 59, 2044, 1987

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites: Quantum optics theory, programming, quantum information theory.

Additional comments:

Safety Training Requirements:

Coherent absorption in boson-sampling networks

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

Absorption and emission of light are governed fundamentally by the rules of both quantum and classical physics. Classical physics provides the optical mode structure and quantum provides the absorption/emission probabilities and hence the light intensities.

In the most striking form of coherent perfect absorption [1] an absorbing medium of subwavelength thickness is rendered transparent or perhaps fully absorbing, merely by changing the mode of the incoming radiation. Precursors to this effect were suggested nearly 20 years ago in quantum optics in a body of work that examined the quantum properties of lossy beam splitters [2-4].

Lossy beam splitters in the form of couplers are used in optical networks, but the impact of coherent absorption has not been studied in these systems. Such networks have been used as boson samplers, which have been suggested as early places to look for quantum supremacy, where quantum processing has an advantage over classical.

The project will begin with a study of the loss and phase structure of reflection and transmission coefficients. Then simulations will be performed with classical light to determine overall mode-dependent loss. Finally, multiple single-mode inputs will be studied for as large a network as computation speed allows.

Key References:

[1] J. Zhang, K.F. MacDonald and N.I. Zheludev, *Controlling light-with-light without nonlinearity*, Light: Science & Applications (2012) **1**, e18; doi:10.1038/lsa.2012.18, and references therein.
[2] R. Matloob et al., *Electromagnetic Field Quantisation in Absorbing Dielectrics*, Phys. Rev. A **52**, 4823 (1995).
[3] S.M. Barnett et al., *Quantum Optics of Lossy Beam Splitters*, Phys. Rev. A **57**, 2134 (1998).
[4] J. Jeffers, *Interference and the Lossless Lossy Beam Splitter*, J. Mod. Opt. **47**, 1819-1824 (2000).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: High marks in 3rd Year Quantum Physics, Electromagnetism. Computational Physics.

Additional comments: A good level of mathematics will be required. Matlab or Python programming.

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.*

‘Cool’ simulations of atomic qubits

(1) Jonathan Pritchard

Project Description:

Quantum information processing with neutral atoms offers an exciting and scalable platform for performing both digital quantum computation and quantum simulation, with controllable long-range interactions mediated by highly excited Rydberg levels. A key advantage of neutral atoms is the ability to cool and trap large numbers of qubits, with experiments demonstrating deterministically loaded arrays of arbitrary geometry.

A dominant limitation in the performance of atom qubits to date arises from finite temperature effects, with atomic motion limiting coherence for atoms confined within microscopic dipole traps. This can be overcome using the technique of resolved-sideband cooling, as used for trapped-ion qubits, to cool atoms to the motional ground state of the harmonic potential by performing coherent operations between motional quantum states [1].

The project will utilise the well documented QuTiP library for Python, in addition to the Alkali Rydberg Calculator (ARC), to develop numerical models of motional cooling in microscopic dipole traps [2] to simulate a new experimental platform being built at Strathclyde to trap over 100 atomic qubits. This will then be used to benchmark quantum gate fidelities using techniques including randomised benchmarking to develop protocols for characterising experiments.

Students will also have the opportunity to test these models against experimental realisations over the course of the project.

Key References:

[1] D. Leibfried *et al.*, *Quantum dynamics of single trapped ions*, Rev. Mod. Phys. **75**, 281 (2003)

[2] A. M. Kaufman, B. J. Lester, and C. A. Regal, *Cooling a Single Atom in an Optical Tweezer to Its Quantum Ground State*, Phys. Rev. X **2**, 041014 (2012)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: We recommend taking PH462 Topics In Quantum Optics and PH459 Topics in Atomic and Molecular Physic alongside this module.

Additional comments:

Safety Training Requirements:

Magnetic states with long-range interactions

(1) Prof Andrew Daley, (2) Dr Jorge Yago

Project Description:

Magnetic phenomena have been explored over many years, and discussions of the transitions to magnetically ordered states (e.g., with Ferromagnetic or Antiferromagnetic ordering in the Ising model) are commonplace in Solid State Physics Classes. Recently, experiments with atoms excited to Rydberg levels with high principle quantum number (>20) have opened new opportunities to look at systems with unusual magnetic interactions – for example, interactions that switch between ferromagnetic and antiferromagnetic as a function of distance between spins. This leads to important open questions regarding what type of order is produced under different conditions, and also how to prepare and measure these types of magnetic order in experiments.

In this project, we will explore the magnetic ordering expected in these unusual long-range Ising models, and develop understanding as to what happens for quantum systems when we also consider transverse Ising models. We will analyse basic properties of models that account for interactions in real experiments, and explore the low-temperature behaviour with analytical and numerical calculations.

A feature of the numerical calculations for longitudinal spin models will be classical monte-carlo calculations based around Markov chains, which make it possible to explore the statistical mechanics of these states.

Key References:

[1] Peter Schauß et al., Nature 491, 87 (2012)
[2] Hendrik Weimer et al., Nature Physics 6, 382 - 388 (2010)
[3] Shannon Whitlock et al 2017 J. Phys. B: At. Mol. Opt. Phys. 50 074001 (2017)

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: There are separate models that can be studied here, and there are also different numerical approaches for quantum and classical models. This project will involve a mixture of analytical and numerical calculations, and requires a strong background in statistical mechanics.

Safety Training Requirements: None

Quantum transport in superconducting wires and cold atoms

(1) Prof Andrew Daley, (2) Dr François Damanet

Project Description:

Both in nanoelectronics and in experiments with ultracold atoms, there have been substantial developments over the past few years in the ability to engineer laboratory experiments, so that the quantum mechanical behaviour of electrons and of collections of atoms can be explored in a variety of novel scenarios that bring out a range of surprising and also useful aspects of quantum mechanical motion. In particular, the connection between these experimental platforms has been growing, as experiments with ultracold gases have been developed that mimic the physics of electrons in nanowires. A key milestone was reached with the observation of quantised conductance and transport with interacting particles in a quantum wire in the group of Tilman Esslinger in Zurich [1]. These experiments involved the engineering of optical traps for fermionic ultra-cold atoms: deep traps were produced to represent reservoirs or leads, and were coupled with narrow geometries that represented nanowires.

In this project, we will look at novel transport scenarios which could be explored in such experiments, in order to set a roadmap for future developments also in nanoelectronics. We will particularly explore the dynamics of particles in traps of unusual engineered geometries [2], which allow for so-called topological properties through quantum interference. We will separately investigate the effects of strong interactions on such quantum transport dynamics.

Key References:

[1] "Observation of Quantised conductance in neutral matter", S. Krinner et al., Nature **517**, 64 (2015)
[2] "Quantum Emitters in Two-Dimensional Structured Reservoirs in the Nonperturbative Regime", A. González-Tudela and J. I. Cirac, Physical Review Letters **119**, 143602 (2017)

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: PH352, PH359, PH358

Additional comments: There are separate geometries and interaction types that can be studied here, each of which are likely to have markedly different phenomena associated with them. There are also aspects of the project that can be adapted to be more computationally focussed, or more focussed on analytical calculations. As a result, there is room for two students to take on distinct but synergistic aspects of this project, with separate second supervisors. This project requires a mixture of analytical and numerical calculations, and requires a strong background in quantum mechanics and statistical mechanics.

Safety Training Requirements: No specific requirements.

Scattering of light beams carrying angular momentum

(1) Dr Francesco Papoff, (2) Dr Alison Yao

Project Description:

Beams of light with angular momentum have many interesting properties: for instance, when they interact with small particles, their angular momentum can be transfer and the particles rotate, an effect that can be used to create micro and nano engines. To model these beams, one normally uses the paraxial approximation that does not describe properly the relation between the beam's polarization and amplitude. This approximation is good in many cases, but fails when the light beams are tightly focused. Exact solutions of Maxwell's equations that describe exactly light beams have been recently published [1] . In this project we will combine these exact solutions with Mie theory [2] to investigate the scattering of light with angular momentum from micro and nano spheres.

Key References:

[1] "Closed-form bases for the description of monochromatic, strongly focused, electromagnetic fields", N.J. More and M.A. Alonso, Onimous et al., J. Opt. Soc. Am. A, 26, 2211 (2009)
[2] "Lorenz-Mie scattering of focused light via complex focus fields: An analytic treatment", R. Gutiérrez-Cuevas, N. J. Moore, and M. A. Alonso, Phys. Rev. A 97, 053848 (2018)

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: PH355 Physics Skills

Additional comments: This project requires a good understanding of electromagnetism. More than one student may be accommodated on this project.

Safety Training Requirements: None.

Nonlinear Propagation of Fully Structured Light

(1) Dr Alison Yao (2) Dr Duncan McArthur

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 beams are known as fully-structured beams as they have an intensity, phase and polarisation that are spatially structured. The aim of this project is to investigate how this structuring affects the stability of the beams during nonlinear propagation. 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] F. Bouchard et al., *Polarization Shaping for Control of Nonlinear Propagation*, Phys. Rev. Lett. **117**, 233903 (2016)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH352 Quantum Physics & Electromagnetism

Additional comments: This project requires a good level of mathematical ability and preferably some programming experience.

Safety Training Requirements: N/A.

Pattern formation with twisted beams

(1) Dr Alison 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:	20%
Comp:	80%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH352 Quantum Physics & Electromagnetism

Additional comments: This project requires a good level of mathematical ability and preferably some programming experience.

Safety Training Requirements: N/A.

Scattering of twisted light by chiral molecules

(1) Dr Robert Cameron (2) Dr Alison Yao

Project Description:

The words “chiral” and “chirality” were introduced by Lord Kelvin to describe anything that differs from its mirror image; a human hand is an example of something that is chiral and has chirality. Chirality is particularly important in chemistry and biology, as the molecules that comprise living things are chiral and their chirality is inherent to their behaviour.

Circularly polarised light is often used to study chiral molecules [1]; the interaction between a circularly polarised beam of light and a chiral molecule differs depending on whether the polarisation is left- or right-handed. In this purely theoretical research project you will investigate the scattering of linearly polarised light with helical phase fronts, i.e. light carrying orbital angular momentum (OAM) [2], by a chiral molecule.

There are three objectives:

1. Learn about chiral molecules and light with helical phase fronts.
2. Calculate the relevant scattering rates. This will require you to develop a basic understanding of multipolar expansions, molecular polarisabilities and scattering calculations.
3. Determine whether the scattering rate differs for left- and right-handed helical phase fronts.

Key References:

[1] Laurence D. Barron, *Molecular Light Scattering and Optical Activity* (2004)

[2] Alison M. Yao and Miles J. Padgett, *Adv. Opt. Photon.* **3**, 161–204 (2011)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH352 Quantum Physics & Electromagnetism

Additional comments: This project requires a good knowledge of electromagnetism and a high level of mathematical ability.

Safety Training Requirements: N/A.

Nonlinear Optical Loop Mirrors Based on 3 X 3 fibre optic couplers

(1) Dr Nigel Langford (2) Dr A Yao

Project Description:

The optical fibre is an ideal system for studying non-linear processes such as self-phase and cross-phase modulation because the fibre can guide light over very long distances with low loss [1]. The light in an optical fibre is guided in the core of the fibre and by placing the cores of two fibres close together a fibre coupler can be formed which is the fibre analogue of a beam splitter. The most common form of fibre coupler is the 2 x 2 coupler and if the two output ends of the couplet are joined together it is possible to build the fibre equivalent of a mirror [2]. By exploiting the Kerr optical non-linearity it is possible to make a loop mirror where the strength of the signal reflected by the loop mirror depends on the intensity of the light coupled into the loop mirror [3]. Unlike a bulk optics beam splitter where there are 2 inputs and two output optical fibres offer the potential to make N X N couplers. In this project you will model a non-linear loop mirror using a 3 X 3 fibre coupler and compare the response of this device with that based on a 2 X 2 fibre coupler.

Key References:

[1] Agrawal, Govind (2006). *Nonlinear Fiber Optics* (4th ed.). Academic Press. ISBN 978-0-12-369516-1

[2] D B Mortimore, "Fiber loop reflectors,"*J Lightwave Technol,* vol 6, no 7, pp 1217-1224, July 1988

[3] "N. J. Doran and D. Wood, "Nonlinear-optical loop mirror", Opt. Lett. 13 (1), 56 (1988)

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH 455 Topics in Photonics

Additional comments: This project is available for up to 2 students. Students should be comfortable with programming in MatLab or C.

Safety Training Requirements: Computer workstation.

Astigmatic mirror multipass absorption cells for long path length spectroscopy

(1) Dr Nigel Langford

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 References:

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:	10%
Comp:	90%

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

Recommended Classes/Pre-requisites: PH 455 Topics in Photonics

Additional comments: This project is available for up to 2 students. Students should be comfortable with programming in MatLab or C.

Safety Training Requirements: Computer workstation.

Characterising Digital Camera Sensors

(1) Dr Daniel Oi, (2) (TBA)

Project Description:

Electro-optic sensors are important components, from photography, machine vision, autonomous vehicle guidance, and scientific data gathering. In this project, the student will characterise the electro-optical performance of a consumer digital camera. Parameters of interest include sensitivity, noise, dark-current, spectral response, and full-well capacity. The student will learn the basic operating principles of CCDs and CMOS imagers and the physics of digital camera sensors.

Key Reference:

Janesick JR. Photon transfer. San Jose: SPIE press; 2007 Aug 14.

Ratio of effort: Exp/Theo/Comp

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

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

Pre-requisites: Computational skills, Matlab.

Additional comments:

Safety Training Requirements:

Gauge Theories of Gravity

(1) Dr James Gaunt, (2) Dr Daniel Oi

Project Description:

The two great pillars of modern theoretical physics are undoubtedly General Relativity and Quantum Field Theory. Individually, these theories have had enormous success. General relativity has successfully and accurately made predictions of large scale physics, with the most recent verification being the discovery of gravitational waves. On the other hand quantum field theory, or more specifically gauge theories, have had huge successes in the form of the Standard Model of Particle Physics and most recently the discovery of the Higgs boson. It is well known however that in regimes in which this two theories overlap, for example in black holes, these theories are incompatible. A consistent theory of quantum field theory and gravity is more commonly known as quantum gravity and is arguably the holy grail of modern theoretical physics.

This project will aim to study general relativity as a gauge theory and its successes in doing so. The initial parts of the project will involve the study of the so called Palatini, or tetrad, formalism of general relativity with the intention of arriving at Einstein-Cartan gravity [1,2]. From here, there are many possible avenues we could explore. One of which is that of exploring the relation of 2+1D Einstein-Cartan gravity theories to the so called Topological Field Theories, or more specifically Chern-Simons Theories [3]. Another avenue is to study the full 3+1D form of General Relativity and its relation to MacDowell-Mansouri gravity [2]. Along the way we will study the necessary differential geometry, algebra and topology needed to understand and formalise the above constructions.

Key References:

[1] "Spacetime and geometry: An introduction to general relativity", Sean M. Carroll, Cambridge University Press, (2019).
[2] “MacDowell-Mansouri gravity and Cartan geometry,'' D. K. Wise, Class. Quant. Grav., 155010, doi:10.1088/0264-9381/27/15/155010, (2010).
[3] “2+1 dimensional gravity as an exactly solvable system”, E. Witten., Nucl. Phys. B311, 46-78, (1988).
[4] “Modern Differential Geometry for Physicists”, C. J. Isham, World Scientific, River Edge, NJ, (1999).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH457 Topics in Theoretical Physics recommended. Students may need to independently learn material e.g. PH557 Advanced Topics in Theoretical Physics.

Additional comments: This project will be particularly suited to students who are comfortable with formal mathematics and theoretical physics. More than one student could work on this project.

Safety Training Requirements: None

Institute of Photonics

Quantum applications of Semiconductor Disk Lasers

(1) Dr Jennifer Hastie, (2) Dr Paulo Hisao Moriya

Project Description:

Semiconductor disk lasers (SDLs), also referred to as Vertical-External-Cavity Surface-Emitting Lasers (VECSELs), thanks to their unique combination of low noise, narrow linewidth, wavelength flexibility and high power (see e.g. [1]), are emerging as suitable light sources for a wide range of applications. In particular, high performance lasers are essential for the cooling and manipulation of ultra-cold atoms, which are used as a platform to enable the development of quantum sensors [2]. This kind of technology is expected to create devices (such as GPS, gravimeters and clocks) that will outperform the existing classical systems [3].

The Institute of Photonics has pioneered the sample design and the development of high performance lasers based on such technology with emission wavelength in different parts of the electromagnetic spectrum [1,4]. For example, our group has developed high power and ultra-narrow-linewidth SDLs with emission at novel wavelengths for neutral Strontium optical clocks [5]. The resulting laser system has reduced size, weight, power and cost (SWaP-C) but increased optical power when compared to commercial laser systems.

In this project, the selected student will work with SDLs currently being developed at the Institute of Photonics for quantum technologies. The research will include (but it is not limited to): laser cavity design; laser cavity engineering; laser performance characterisation and optimisation (including intensity and frequency noise); passive techniques for laser performance stabilisation; active laser frequency stabilisation techniques; design and optimisation of intracavity linear and nonlinear optical processes; design and characterisation of custom optical devices and opto-mechanical tools.

Key References:

[1] S. Calvez *et al.*, "SDLs for the generation of visible and ultraviolet radiation," *Laser & Phot Rev* **3**, 407 (2009).
[2] L. Fallani and A. Kastberg, "Cold atoms: A field enabled by light", *Europhysics Letters* **110**, 5 (2015).
[3] UK National Quantum Technology Hub in Sensors and Metrology: https://www.quantumsensors.org/ .
[4] R. Casula *et al.*, "Cascaded crystalline Raman lasers for extended wavelength coverage", *Optica* **5**, 1406 (2018).
[5] D. Paboeuf and J. E. Hastie, "Tunable narrow linewidth AlGaInP semiconductor disk laser for Sr atom cooling applications," *Appl. Opt.* **55**, 4980 (2016).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys and BSc

Recommended Classes/Pre-requisites: PH455 Topics in Photonics

Additional comments: This project is open to one student.

Safety Training Requirements: Laser safety training will be provided.

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 Semiconductor Lasers (SLs) under the arrival of induced perturbations into the devices. The experimental work will be performed with devices operating at 1310 and 1550nm, the most commonly used wavelengths in optical telecommunication systems, thus making our neuro-inspired photonics platform totally compatible with actual present optical networks. The project will also look at the application of SLs 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 SLs.

Key References:

[1] J. Robertson, T. Deng, J. Javaloyes, A. Hurtado, "Controlled inhibition of spiking dynamics in VCSELs for neuromorphic photonics: theory and experiments", in Optics Letters, 42, 1560 (2017)
[2] A. Hurtado and J. Javaloyes "Controllable spiking patterns in long-wavelength vertical cavity surface emitting lasers for neuromorphic photonic systems", in Applied Physics Letters, 107, 241103 (2015)
[3] P.R. Prucnal et al, "Recent progress in semiconductor excitable lasers for photonic spike processing", in Advances in Optics and Photonics, 8, 228 (2016)

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

Spectroscopy of Dy-doped crystals for mid-IR laser applications

(1) Dr. Vasili Savitski, (2) Prof. Alan Kemp

Project Description:

High-energy narrow-linewidth differential absorption LIDAR (DIAL) systems are widely used for remote gas pollution sensing of industrial and waste disposal sites. These systems are based on laser sources emitting in 3-5 μm spectral range, corresponding to absorption lines of many "greenhouse" gases. Dy doped fluorides and lead halide crystals are characterised with emission in the mid-IR spectral range and absorption bands at the wavelengths suitable for direct diode laser pumping. These features make them attractive for building new diode-pumped laser sources emitting in the wavelength range of 3-5 μm.

In this project systematic spectroscopic study of a range of Dy doped flourides and lead halides in mid-IR will be carried out. Laser related parameters of the crystals (emission cross section, radiative lifetimes, quantum efficiencies, cross-relaxation and upconversion processes) will be evaluated to underpin the efficient laser pumping schemes and oscillation regimes in these crystals.

Key References:

[1] F. Innocenti, R. Robinson, T. Gardiner, A. Finlayson, and A. Connor, "Differential Absorption Lidar (DIAL) Measurements of Landfill Methane Emissions," Remote Sensing 9, 953 (2017).
[2] B. M. Walsh, H. R. Lee, and N. P. Barnes, "Mid infrared lasers for remote sensing applications," Journal of Luminescence 169, 400-405 (2016)

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

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites: PH455 Topics in Photonics

Additional comments:

Safety Training Requirements: Laser safety training required

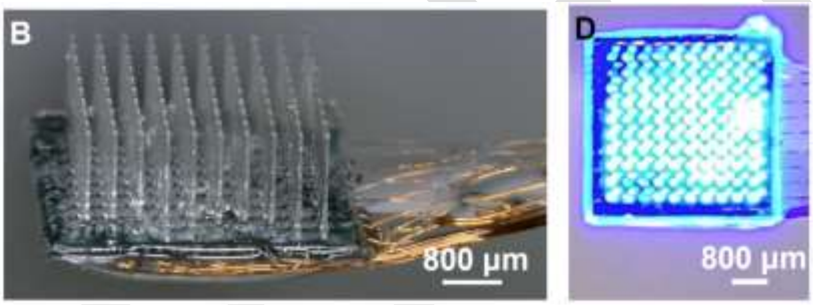
Mapping brain activity: A multi-channel fiber photometry device

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

Project Description:

Fiber photometry is an increasingly popular tool used by neuroscientists to record activity from genetically defined neural populations. In its simplest form, an excitation light source is coupled to a multi-mode fiber optic which is implanted into the brain [1]. The returning fluorescent signal (which can be correlated to neural activity) returns through the same fiber and can be detected. Multi-channel fiber photometry can simultaneously monitor neural activities in several brain regions at once, and can be used to discover how neurons in connected brain regions coordinate their activity to produce behaviour. Multi-channel fiber photometry is, however, extremely challenging, as it requires the implantation of several bulky multi-mode fibers and the resulting light sources and detection optics [2].

For this project the student will be testing a potential new multi-channel fiber photometry device based on a neual implant device [3] (see figure below). The device will be characterised to assess, the excitation light throughput, the illumination volume from individual sites and the collection efficiency. This will be done using an agar brain phantom. The students will gain optical alignment and imaging skills. Optical modelling using Zemax may also play a role in this project.



Key References:

1. Pisanello, M., et al., *The Three-Dimensional Signal Collection Field for Fiber Photometry in Brain Tissue.* Frontiers in Neuroscience, 2019. **13**(82).
2. Guo, Q., et al., *Multi-channel fiber photometry for population neuronal activity recording.* Biomedical optics express, 2015. **6**(10): p. 3919-3931.
3. Boutte, R.W., et al., *Utah optrode array customization using stereotactic brain atlases and 3-D CAD modeling for optogenetic neocortical interrogation in small rodents and nonhuman primates.* Neurophotonics, 2017. **4**(4): p. 041502-041502.

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements: Laser safety course

Understanding how to exploit diamond in solid-state lasers

(1) Prof. Alan Kemp, (2) Dr Vasili Savitski, Dr Giorgos Demetriou

Project Description:

Managing heat is the major hurdle in high performance laser design. High optical quality synthetic diamond is a novel optical material that potentially extends the flexibility available to solid-state laser designers by radically changing the way heat is managed. This has manifested itself commercially in the near ubiquitous use of diamond in commercial thin-disk lasers and semiconductor disk lasers, particularly at the high performance end of the market.

However, more sophisticated use of diamond promises to open up the way for much simpler high power lasers, with existing proposals including a laser for beaming solar energy back to earth (ref. 1 below). While this project will keep its feet firmly on the ground, it will use finite element analysis to examine the potential for using diamond in compact laser geometries. The objective will be to verify the thermal performance of novel laser designs such as picosecond-pulsed microchip lasers cooled with diamond and fibre-laser pump diamond Raman lasers. Although this project will be largely computational, if circumstances allow and the student is so inclined, there may be the potential for proving of the models against experimental lasers. A commercial finite element analysis package, Comsol Multiphysics, will be used to build the models for this package and so the project will develop skills widely used in industrial laser design.

This project will be embedded within an existing research team working in this area. It is also a project where the potential parameter space for exploration is large. Hence, it would best suit a student with good initiative and planning skills and a willingness to work constructively with the existing team.

Key References:

1. R. L. Fork, W. W. Walker, R. L. Laycock, J. J. A. Green, and S. T. Cole, "Integrated diamond sapphire laser," Optics Express, vol. 11, pp. 2532-2548, 2003.
2. A. J. Kemp, G. J. Valentine, J. M. Hopkins, J. E. Hastie, S. A. Smith, S. Calvez, et al., "Thermal management in vertical-external-cavity surface-emitting lasers: Finite-element analysis of a heatspreader approach," IEEE Journal of Quantum Electronics, vol. 41, pp. 148-155, Feb 2005.
3. S. Reilly, V. G. Savitski, H. Liu, E. Gu, M. D. Dawson, and A. J. Kemp, "Monolithic diamond Raman laser," Optics Letters, vol. 40, pp. 930-933, 2015/03/15 2015.

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: PH455 Topics In Photonics

Additional comments:

Safety Training Requirements: Laser safety training required

Photon velocity control on a silicon photonic chip

(1) Dr Michael Strain, (2) Dr Benoit Guilhabert

Project Description:

The vast majority of optical experiments and systems are realised using a few building block components such as beam-splitters, wavelength filters, mirrors and delay lines. Scaling modern experiments on an optical bench requires a huge number of components and critical, stable alignment of each beam path. A solution to the scaling issue has been proposed, using chip-scale optical devices. These mm^2 sized chips contain all of the functionality of standard optical benches at a fraction of the size and with mechanical stability guaranteed by their solid state. Beam splitting, waveguiding, filtering and even non-linear functions have been demonstrated on these chips, but a true optical delay line has not yet been achieved. Delay lines are usually created using a mirror on a movable stage, in essence, increasing the distance photons have to travel. This is not possible on a solid state chip, so other means must be found. Bragg grating devices can slow the velocity of photons travelling in a waveguide using resonant effects. Furthermore, by using electronically tunable Bragg grating devices the photon velocity, and hence on-chip delay time, can be set in an easily accessible manner.

State of the art silicon photonic Bragg grating devices have been fabricated and measured, in the Technology and Innovation Centre. In this project the student will use a custom built software analysis tool to simulate chipscale grating devices and analyse the existing measurement results. This work will show the link between electronic tuning signals and on-chip photon velocity\delay. There is a possibility for publication of this work in a peer-reviewed journal.

Key References:

1. M. J. Strain and M. Sorel, "Design and fabrication of integrated chirped Bragg gratings for on-chip dispersion control," Quantum Electron. IEEE J. **46**, 774–782 (2010).
2. M. J. Strain, M. Gnan, G. Bellanca, R. M. D. La Rue, and M. Sorel, "Retrieval of Bragg Grating Transmission Spectra by Post-process Removal of Spurious Fabry-Perot Oscillations," **17**, 2425–2427 (2009).

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites:

Additional comments: Some previous experience of Matlab would be desirable.

Safety Training Requirements:

Appendices

PH450 Project Request Form 2019/20

(To be returned to Students Office JA 8.31 by noon Monday 23/09/2019)

PH450 Students:

- **At least 5 choices** should be discussed with prospective supervisors and signed off by them. Optionally an **additional 5 choices (10 total)** can also be discussed and signed off. **Unsigned choices will not be allocated!**
- Fill in preferences after all project choices have been discussed and signatures obtained.
- Where there are several requests for the same project, it will be decided by 3rd year class rank
- Project allocation is subject to supervisor discretion and availability, announced by Friday 27th September 2019

Supervisors: By signing this form you agree to the following "*This project has been discussed by us, and we have agreed that it is appropriate for the student to undertake the work.*"

Student Name		**Student Number**	

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

Project Title			**Preference** (1, 2, 3, …)	
Supervisor		**Supervisor Signature**		

PH450 Project Literature Review & Summary

The first assigned task for students with new projects is the so-called literature review, due this year to be submitted by **noon on Monday, 21st October 2019** to MyPlace in **PDF** format.

It is important that students begin working on their projects without undue delay. Essentially we (The Supervisors) are carrying out a 'sanity check' to establish that you can describe, in your own words, the following:

1) The physics involved in the project
2) The current state-of-the-art of the topic area (the literature review)
3) How you intend to make progress (i.e. what will you actually do to achieve your aims?)
4) How success will be measured

A **cover page** should include:

- Title of Project
- Your name, student number, course
- Supervisor names (1st and 2nd)

The actual literature review (not counting cover page) should be between **500-800 words** plus **references** and diagrams and fit on at most 2 sides of A4.

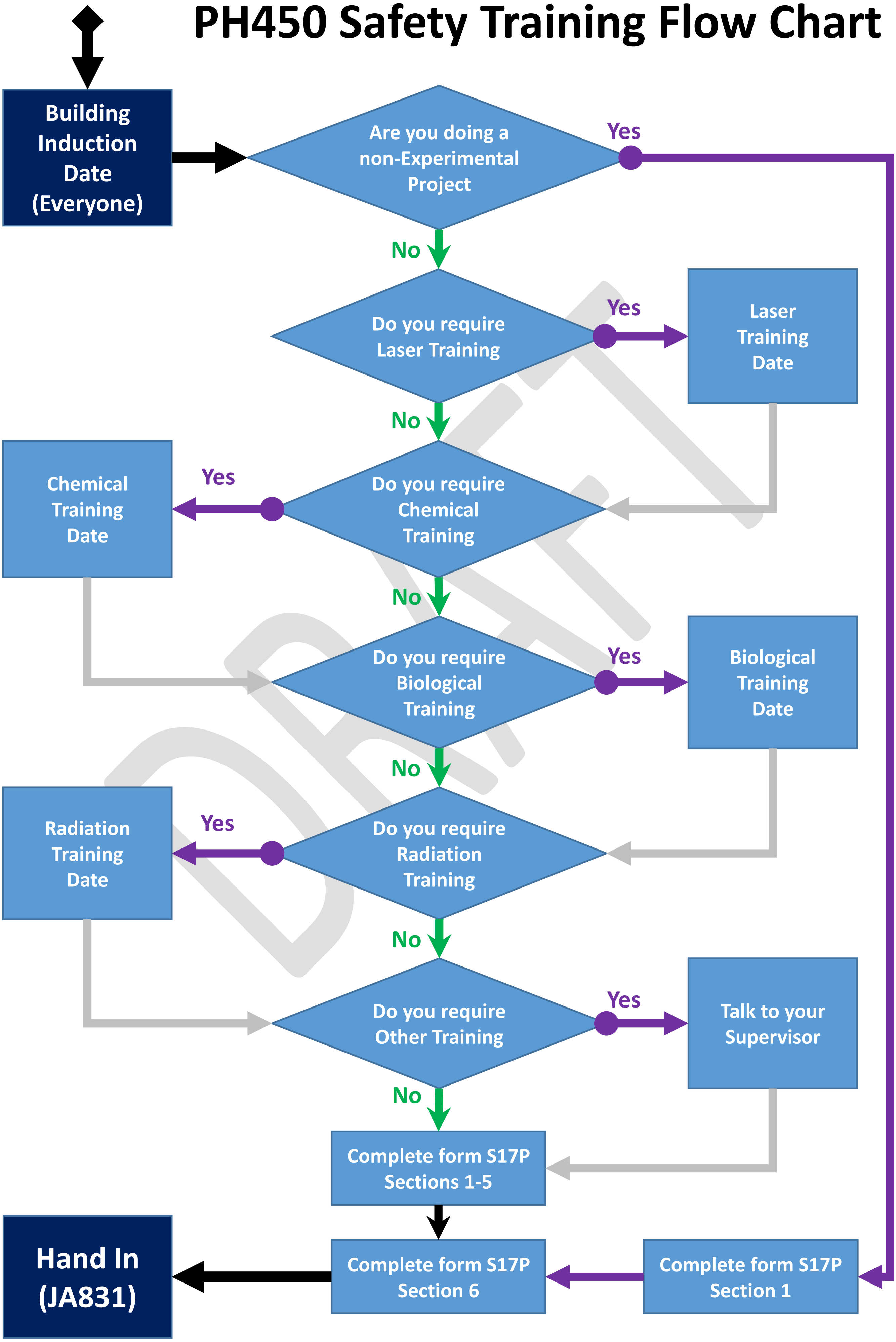
Submit the literature review **as a PDF** via TurnItIn on Myplace in the PH450 section.

Since these are early days, the literature survey is not expected to be complete by any means, the review is not assessed as such. However, it will usually form the basis of the first chapter of your Final Report, and is worth some thought and effort at this time. If you find anything unclear in these instructions, consult your supervisor.

Notes:

- The literature review should be aimed at the general physicist, hence **avoid excessive jargon** or specialist language
- **Be specific** where possible and not be vague, explain clearly the project, its aims, context, background, and in particular your expected contributions
- Use **proper referencing**/standard format, for example the same style as the key journals in the subject area
- Material in the Literature Review will be run through TurnItIn. However, it will not be compared with the final report. Hence there should not be any issues with including material from the Literature Review in the final Project Report (if it did not pose a problem in the first place).

PH450 Safety Training Flow Chart



DEPARTMENT OF PHYSICS

Induction training record for Undergraduate/M.Sc./Internships/Visitors

Project Work

(Must be completed before commencement of work)

1. I have attended the Departmental Building Safety Induction

   Building/s:………………………………Date/s:……..………..

2. I have attended the following lecture/training courses:

   ☐ Laser ☐ Chemical ☐ Biological ☐ Radiation

   Date: ………… ………… ………… …………

3. I have read and understood the specific area rules: ☐
   Areas:…………………………………………………………..

4. I have received an induction/Training in:
   - Physics Laser beam alignment procedures ☐
   - Local safety systems/controls for rooms ☐
     Rooms:...
   - Operating the following devices and/or instruments
     Devices:..
   - Relevant techniques:...

5. I have demonstrated specific competence to my Supervisor in
   - Local safety systems/controls:.. ☐
   - Devices/Instruments to be used:... ☐
   - Relevant techniques:... ☐

6. Signature …………………………………. Date……………………………..

   Print Name………………………………………………………………………………….

   Supervisor/Host…………………………….. Date……………………………..

   Print Name………………………………………………………………………………

<u>Return completed form to Deliveries and Inquiries office (Student Office) JA831</u>

PH450 Project Progress Report (1 Page)

*Due Noon Monday 13/1/2020: Submit an electronic copy on MyPlace in **PDF** format*

Student Name:		**Student Number:**	

Project title:	
Project aims: List the key aims of your project	
Progress: Summarise and list the key steps and milestones achieved in your project so far	

Student's signature:		**Date:**

PH450 Project Talk Notes

The project talk comprises 10% of the final project mark as well as provides valuable experience of public presentation. These notes give some guidance as to what is expected.

Talk Format

The timeslot per speaker is 15 mins (10+5 mins). The talk is only **10 mins long** and there will be an additional 5 mins for questions from the audience (including your supervisors, other staff, and your fellow students) as well as for allowing a changeover from one speaker to the next. As the schedule is very tight, the chairperson will keep time and make sure that you do not go over your allotted time.

Since 10 mins is not very long, we do not expect a very technical and in-depth presentation of comprehensive results. The talk is **not aimed at your supervisor**, but at a general physics audience of your peers (students) and other members of the department who may not work in the area of the project. Instead, aim to clearly explain (especially to your fellow students) your project and what you have been working on.

Guidance to Marking

The marking scheme gives a guide to what you should address in your talk:

Structure (30%)

- A good structure is important, guiding the audience through the series of steps helpful to understand your project. A talk outline slide should reflect this. Introduce the talk with your name, topic, and supervisor. Give **context** to understand why the project is important and how it relates to other research, then background/methods before going to describe your project work, any results, and your discussion and conclusion. The different parts of the talks should form a coherent whole. The background should provide what is needed to understand the body of the talk. A conclusion should summarise and discuss what you have just spoken about.
- Give a good impression. Make sure that you can be clearly heard. Not everyone in your audience will be a native English speaker, regional accents can be especially difficult for non-native-English speakers (science is very international) and it helps if you do not speak too quickly. **Connect** with the audience by looking at them occasionally. Spoken language is different from the written word. If you do choose to pre-write out your talk make sure it flows naturally when spoken. Else you may choose to use prompt cards with bullet points you can elaborate upon.
- Aim for a talk that is as close to 10 mins without going over it. At this stage of the project, the challenge should be choosing what to leave out, you may not be able to present everything you have done. Otherwise, take the time to **clearly explain** the project and your progress.

Scientific Content (40%)

- Choose your material carefully. The challenge is often to choose only a small subset of results with appropriate context and background. Remember that **most of your audience are not experts on your project subject** so be sure to cover the material they will need to appreciate your work.
- Be sure to explain, in a way comprehensible to your peers, the **relevant methods** you have used in your project. If there is a key detail necessary to understand how a certain result was obtained, then you should try to cover this.
- Hopefully you will have some results by now, but even if they are only preliminary you should be able to present and explain them clearly to your peers. Your audience should be able to come away from your talk with some idea as to what you have done and **what is means**.
- All of the above should be presented as **clearly** as possible.

Detail (20%)

- Make good use of your slides. A combination of spoken word, written text, and figures (e.g. pictures, diagrams, graphs) should work together to **convey** ideas, information, and data. Short pieces of text that concisely reinforce the points you want to make are better than long paragraphs that distract the audience from what you are saying.
- **Do not cram** slides with too much detail as this will serve to confuse, rather than help the audience. Break up your presentation into manageable and easily digestible chunks.
- Choose a professional and **easy to read font**. Use large fonts (make it easy for the visually impaired). Use a neutral colour scheme that does not distract from the content.
- Break up text-only slides with appropriate figures that illustrate the topic under discussion. Graphs and other data should be **properly presented** (correct axes labels, easily distinguished lines or data points, key parameters if relevant). Make sure that figures are large enough so that its details can be seen, e.g. numbers on axes, labels, lines.
- Avoid too many equations. Try to introduce the **minimum number** required to understand the project and your key results. Be sure to **explain the equations** you do introduce.

Performance at Discussion (10%)

- Answer clearly and directly any questions. If you do not know the answer, then it is perfectly acceptable to say that you do not know, but you should be able to **intelligently discuss** what the answer may be and any information relevant to the question. You can take a few seconds to consider before speaking to organize your thoughts and to figure out your answers. You may want to refer to your slides to illustrate your answer.

Scheduling of Talks

To streamline the process and minimise risk of technical difficulties, presentation files will need to be **uploaded to MyPlace the day before** the talks. Further details on preparing the talks will be available in a separate document.

Students are expected to be present throughout both presentation days, even at sessions in which they are not presenting, to **provide support and encouragement** for each other.

Further Guidance

Your supervisor should be able to give you guidance as to what is expected of the talk and the material that you should include. If they have the time, they may agree to listen to a practice talk and give advice.

A **practice** talk to your peers may help with identifying parts that are unclear. You may need to go through several versions of your talk, mainly to get it under 10 mins, **improve clarity**, and to make it sufficiently **focussed**.

Useful Youtube videos

Not all of the points given in the following are specifically applicable to your project talk but there are many useful tips, especially for presentation skills and slide design.

Giving a Scientific Presentation - Hints and Tips https://www.youtube.com/watch?v=gF3FWu56dc8

Designing effective scientific presentations https://www.youtube.com/watch?v=Hp7Id3Yb9XQ

10 Essential Components of Great Science Presentations https://www.youtube.com/watch?v=prmxTGlYhbQ

Creating effective slides https://www.youtube.com/watch?v=meBXuTIPJQk

Important

- Talk presentation files will need to be **uploaded to MyPlace the day prior** to the day you are scheduled on. These will be pre-loaded onto the presentation laptops to streamline the talks.
- **Only Powerpoint or PDF** formats (if prepared in a different program and exported) are available on the laptops used for the presentations. If you have multimedia content, e.g. animations, movies, audio clips, embed these in the presentation (if using Powerpoint). If they cannot be embedded, then inform the PH450 Co-ordinator as early as possible to arrange suitable playback software.
- Use the Strathclyde Science Faculty **official template**[2] or else a close facsimile if prepared in a different program and exported to PDF. The slides should have an aspect ratio of 4:3 (not 16:9), the main font is Arial.

Tips

- To get Powerpoint (as part of the Office suite of productivity software) "Office365 ProPlus is a service available to registered students with an Office365 email account enabling them to use the latest full version of Microsoft Office."[3] Otherwise use the University computer suites.
- Take your presentation and **run it on a different computer** to make sure everything works properly. The University computer suites have Office available so you can prepare and **test your presentations** using these.
- Be sure to embed all the necessary fonts in your presentation. Best to stick with standard fonts, ideally "official" university fonts. In particular, check that equations display correctly on other computers.
- You are advised to have a backup PDF version of your talk (if using Powerpoint) in case of technical difficulties, bring this on a USB memory stick to the talk.

[2] http://www.strath.ac.uk/media/publications/brand/ppt/science.pptx
[3] https://www.strath.ac.uk/professionalservices/is/software/microsoftoffice365proplus-windows/

PH450 Project Report Guidelines

The project report is an important and major component (50%) of the PH450 assessment. Besides contributing to your final mark, your project report can serve as a demonstration of your abilities to future employers.

Guidelines

Due to the volume of projects, markers appreciate reports that are clear, concise, easy to read and comprehend. Both content and structure are important. The narrative thread should flow easily from section to section and material introduced in a logical progression.

- The **purpose** of the project report is to summarize your work together with suitable background, motivation, and analysis. It should provide a coherent narrative of the topic area, previous work, project aims, methods, results, discussion, and conclusion.
- The **marking scheme** is available on MyPlace. This gives an indication of what the markers will be looking for in particular. Take the time to examine the criteria in detail and check that your report complies with them, for example "Is both the grammar and spelling correct?" or "Are the results presented clearly, discussed and analysed correctly?".
- The **provided template should be used**. This will be made available on MyPlace in LaTeX or Word formats.
- The **example reports** give an indication of the expected style. Two examples are given, one each for experimental and theoretical/computational projects. There is no prescribed template since every project is different but your report should be logically structured and comprehensive within reasonable limits. The marking scheme should give a good indication of what needs to be included.
- The report should be approximately **30 pages in length**, plus appendices and cover sheet. Some variation around this page number is expected but it is likely that a much shorter report will not be able to cover a typical project in sufficient depth. Conversely, a considerably longer report may not display sufficient conciseness or clarity. The uploaded PDF should be **less than 40MB** and should be in a form that is checkable by TurnItIn.
- **Appendices** should be used to include material ancillary to the main thread of the report, useful for an interested reader but not essential for following the report itself. Examples include program code, detailed calculations, raw data, and proofs (if not the actual subject of the report).
- **Program Code**, if included, should be properly attributed. Code in the main body of the report should be restricted to that essential to understanding the work, preferably code snippets or pseudocode. You may wish to include code that you have written in the appendices if it is not excessive (10s of pages). For large amounts of code, you may consider referencing a code repository.

Penalty for Late Submission of Reports

As agreed by the Teaching Committee, reports submitted past the submission deadline would normally be subject to a late penalty. The university policy on late submission of coursework can be found at:
https://www.strath.ac.uk/media/ps/cs/gmap/academicaffairs/policies/Policy_and_Procedure_for_the_Late_Submission_of_Coursework.pdf.pagespeed.ce.SumRNBN4PO.pdf

The students would be notified of this approach through the Student Handbook and at 1st Day Meetings.

Guidelines on Project Report Feedback for students

We recognise the importance of giving appropriate feedback to students preparing their project presentations and reports and of doing this with a level of consistency that is fair to all students. The feedback we give should supplement the training that is inherently associated with the supervision of the project and this includes giving students advice on how and what data are to be presented etc. The following guidelines hopefully will address this point:

1. The report should be the **student's own work** and we must avoid the report including large elements of the work of the supervisor(s). Students undertaking computational analysis and using pre-written programs to generate data should be considered in the same way as students who are undertaking experimental work using existing equipment. It is the analysis of the data that is of importance.
2. In order to provide a suitable level of guidance in project preparation each student should receive feedback, covering the correctness as well as presentation style, on approximately **10 pages** of material (submitted at least 1 week before the hand-in deadline). The **feedback** from the staff should be in the form of a discussion highlighting both good points and areas that need addressing rather than a re-writing of material.
3. In order to promote consistency across the department the supervisor(s) should **not be involved in an iterative process of correction** of, or input to, the report material. Guidance along the lines of “I think that you should include these data etc.” is appropriate.
4. We do however stress the importance of **general feedback throughout the project** and report writing. For example, wherever practicable supervisors should point out significant mistakes (for example, this figure plots the wrong quantity or this equation is incorrect). Care should be taken to avoid getting into a loop where the student is continually told that something is wrong but not directed on how to address the problem.
5. The Department will produce a list of the **common mistakes** made when producing a project report – e.g. labelling of figures, referencing
6. The Department will, subject to a receiving agreement from the relevant students, post **examples** of good reports on MyPlace. There will be an example of a theoretical report and an experimental report.
7. The Department will also ensure the project **marking schemes** are posted on Myplace.

N. Langford 10th October 2013, 4th December 2013.

Modified and Approved by Departmental Committee on 6th December 2013

University Policy on Plagiarism

You are reminded that as members of the academic community, you are responsible for ensuring that your work abides by the conventions and rules of that community and that this includes ensuring that the correct citation and referencing conventions are applied in their work.

You should be familiar with the University Policies, Procedures, & Guidelines on Plagiarism[4]. 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. Aside from plagiarism of the work of others, it is also not acceptable to duplicate or include material identical or substantially similar to coursework that you have already submitted for assessment (self-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. Attempting to circumvent plagiarism detection is also not acceptable. The Department will use the anti-plagiarism software Turnitin (https://turnitin.com/static/index.php) to check for plagiarism. Any student caught plagiarising may be reported to the University Disciplinary committee.

[4] https://www.strath.ac.uk/media/ps/cs/gmap/academicaffairs/policies/student-guide-to-academic-practice-and-plagiarism.pdf.pagespeed.ce.JAdO8rUCVq.pdf Accessed 5th August 2019

List of Common Mistakes

This is a list of the most common mistakes made when writing reports, it is not meant to be comprehensive.

Writing and Readability

- **Spelling and typographical mistakes**. Use a spell-checker. Ask someone to proofread your draft for grammar.
- **Overly long sentences and lack of clarity**. Break up sentences into easily digestible parts. Be specific and avoid generalities. Do not mistake obscurity with profundity. Try not to waffle.
- **Too technical**. Your reader will not necessarily be an expert in the subject so do not assume too much background knowledge. The *introduction* and *methods* sections should provide any specialist material required to comprehend your work.
- **Lack of Big Picture (Can't see the wood for the trees)**. Provide context and motivation for the work presented. Do not get lost in the minutiae. The introduction sets the scene for the whole project.
- **Incoherent Structure**. Structure the report in a logical and consistent manner. The example reports show some ways in which they can be structured well.
- **Lack of analysis and discussion of your results**. Do not simply present data. A level 4 research project is assessed on your critical evaluation and analysis of your results.
- **Poor presentation**. Use the provided template as the font sizes, margins and line spacing have been chosen for legibility and ease of marking.

References

- **Too few**. Demonstrate that you have made a comprehensive survey of the literature for relevant work.
- **Extraneous citations**. Do not include irrelevant references to artificially inflate the reference list.
- **Incorrect referencing**. Use a standard referencing convention, e.g. APA, Harvard, or *preferably Vancouver*. Consult the university library guidelines on proper forms of citations. Consult articles in leading journals in the area of the project for examples of proper citation. Make sure all the citations are correctly formatted and consistent.
- **Over reliance on Internet sources**. Avoid if possible online citations if academic sources exist and are more appropriate. Best to refer to primary (original) sources instead of secondary references. If you must use internet sources, consult the Library citation guidance as to how to do this properly (e.g. including date of access)[5][6].

Graphs and Figures

- **Too small**. Make sure text is legible and that lines and figures can be easily seen when printed.
- **Badly labelled axes**. Make sure axes are labelled properly, with appropriate units.
- **Unclear data**. Make sure presented data, e.g. lines and points on graphs, are clearly indicated. Use different line styles (e.g. solid, dotted, dashed etc.) or symbols (e.g. circles, triangles, squares etc.) to distinguish between different sets of data and include a legend if required.
- **Inadequate or missing captions**. Use captions effectively to clearly describe and explain graphs and figures. Give comprehensive details, e.g. experimental or simulation parameters, or assumptions. A reader should be able to gain a good understanding of the figure from the caption without having to refer to the main text.
- **Lack of reference to figures and tables in main text**. Connect your discussion with the visual and numerical material that you are including in the report.
- **Confusing layout**. Avoid confusing layout of text and figures. Place figures and tables near where they are first referenced (unless they are included in an appendix).

[5] http://guides.lib.strath.ac.uk/referencing_guide/home Accessed 5th August 2019
[6] http://www.citethisforme.com/guides/vancouver

PH450 Viva Notes

The project viva is an important aspect of the assessment (20% of final project mark) as well as providing valuable experience. These notes outline the procedure and what can be expected by the student.

The viva committee will usually consist of the Chair, Primary Supervisor, and an Independent Marker. Their task is to establish **your understanding** of the work presented in your report and any relevant background. The independent marker may have knowledge of the general area of the project but may not be an expert. The Chair will moderate the proceedings and may not be knowledgeable in the area of the project.

At the start of the viva, you will be given the opportunity to give a brief **5 minute summary** of your project, its aims and objectives, methodology, and results. You are not expected to present slides or give a formal talk. Instead, you should be able to explain with the aid of pen & paper or whiteboard. Your 5 minute outline should be at the level suitable for a non-expert (such as the Chair). Be sure to make clear what **your contributions** to the project have been and the "**take home message**" of your results.

The viva will then proceed with **questions from the viva committee** on any aspect of the project. This may include questions on background to the project and basic physics. They may ask you to clarify parts of the report or ask for more detail. You may be asked to **interpret your findings** and to discuss their **wider implications** or applications.

The question section of the viva will last for 30 minutes after which the committee will assess your performance in private and assign a mark. Refer to the PH450 Marking Scheme (in the appendices) for the list of assessment criteria that will be used.

FAQs

Q. When will the vivas take place?
A. In principle, the vivas can take place any time throughout the scheduled exam period. However, it is anticipated that most vivas will take place a few days after a student's last exam. This is all subject to the availability of the examination committee (Chair, Supervisor, Independent Marker) hence vivas may take place at other times during the exam period. If there are any particular scheduling issues, please consult your Supervisor. It may be possible to schedule a viva in a gap between exams if everyone is available.

Q. Can I bring in notes/thesis?
A. Yes, please bring along your thesis for reference. You may annotate it. Consult your supervisor if you would like to bring extra materials.

Q. Do I need to give a presentation?
A. You will be asked to give an **informal** description and overview of your project at the beginning. You may use a white board or pen and paper. This should last approximate 5 minutes.

General Marking Guidelines

The overall PH450 mark will comprise of the report mark (50%), supervisor's mark (20%), viva mark (20%), and talk mark (10%) Please consider the following guidelines when marking. These are based on the University's marking scheme given in the Guidance on Marking for Undergraduate Programmes:

http://www.strath.ac.uk/media/ps/cs/gmap/academicaffairs/policies/marking_guide_for_UG_programmes_-_Effective_Sep_14.pdf

Mark	Description
0	No work submitted for assessment
1-19	Minimal performance in learning outcomes - serious errors - extensive omissions and/or weaknesses of presentation and/or logic and/or evidence - deficient evidence of learning or deficient evidence of project work
20-29	Weak demonstration of learning outcomes: - a few key words, phrases or key ideas - extensive omissions and/or weaknesses of presentation and/or logic and/or evidence - serious errors - inadequate evidence of learning or inadequate project work
30-39	Inadequate demonstration of learning outcomes: - some relevant information and limited understanding (and where appropriate some project work completed under supervision) - omissions and/or weaknesses of presentation and/or logic and/or evidence - lack of familiarity with the subject of assessment and/or assessment vehicle
40-49	Limited demonstration of learning outcomes: - basic knowledge and understanding (and where appropriate basic project skills) - omissions and/or weaknesses of presentation and/or logic and/or evidence
50-59	Satisfactory demonstration of learning outcomes: - sound knowledge and understanding of essential material (and where appropriate essential project skills) - general accuracy with occasional mistakes and/or uncoordinated use of information
60-69	Comprehensive demonstration of learning outcomes: - wide appropriate knowledge and understanding (and where appropriate effective project work) with only occasional lapses in detail - evidence of reading and thought beyond programme/assignment materials - a high standard of writing and communication
70-79	Excellent demonstration of learning outcomes: - wide, appropriate knowledge and understanding (and where appropriate effective project work) including insight or originality - evidence of reading and thought beyond programme/assignment materials - appropriate use of references and exemplars - an excellent standard of writing and communication and/or presentation
80-100	Outstanding demonstration of learning outcomes: - wide, appropriate knowledge and understanding (and where appropriate effective project work) including insight and originality - evidence of reading and thought beyond programme/assignment materials - appropriate use of references and exemplars - an outstanding standard of writing and communication and/or presentation

PH450 Talk Marking Scheme

*Please provide a **mark out of 100 in each** of the four categories. They will be weighted in the proportion 3:4:2:1 respectively.*

Talk	**Student:**
Structure • Context • Coherence of subject matter • Use of available time	**Mark/100**
Scientific content • Choice of material to be presented • Appropriate details of methods included • Presentation and interpretation of results • Clarity of explanation	**Mark/100**
Detail • Use of text/graphics • Delivery	**Mark/100**
Performance at discussion • Did the student answer questions adequately?	**Mark/100**
Justification	

Date:

Marker's printed name and signature:..

PH450 Supervisor's Mark (2 Pages)

*Please provide a **mark out of 100 in each** of the categories. They will be weighted in the proportion 1:1:4:4 respectively.*

Student:		
Assessment Criteria	Prompts	
Effort		**Mark/100**
Interest shown	*Did student show some responsibility and ownership?*	
Time keeping and communication	*Did student's effort amount to the expected 400 hours on the project over the year (this should be a minimum of 1.5 days per week)?* *Did student keep in regular contact?* *Did student communicate effectively with peers, senior colleagues and specialists?*	
Justification		
Initiative		**Mark/100**
Independence	*Did student work effectively under guidance?*	
Justification		
Scientific approach		**Mark/100**
Quality of work	*Did student carry out thorough investigations identifying complex issues?* *Did student carry out appropriate interpretation of data/results?*	
Scientific judgement	*Did student identify relevant issues?*	
Original contribution	*Did student demonstrate originality and creativity?*	
Justification		

Continued Overleaf (Please Turn Over)

Scientific level attained	**Mark/100**
Comprehensiveness of literature survey	*Did student carry out literature survey in order to review and consolidate knowledge, skills and practices?*
Progress made	*Has student made appropriate progress towards attainable goals?*
Skills acquired	*Did student master the use of a range of advanced skills, techniques and practices at the forefront of the research area?*
Understanding acquired	*Did student acquire an extensive, detailed and critical understanding of current knowledge, skills and practices?*
Justification	

Identify student's main achievements throughout the year	
Identify any particular problems affecting student's performance	

Date:

Supervisor's printed name and signature:..

PH450 Project Report

*Please provide a **mark out of 100 in each** of the categories. They will be weighted in the proportion 3:7 respectively.*

Student:

Assessment criteria	Prompts
Structure and Detail	**Mark/100**
Scientific style/quality of writing	*Is the presentation clear and comprehensive?* *Is the scientific style appropriate?* *Are both the grammar and spelling correct?*
Presentation of work/results	*Do the figures and tables help with the understanding of explanations?* *Are labels and captions appropriate, correct and sufficient?*
Use and comprehensiveness of references/bibliography	*Are relevant and appropriate references listed and cited correctly?* *Are the scientific references based on primary sources?*
Justification	

Scientific content	**Mark/100**
Explanation, context and relationship to scientific background	*Awareness of the background for the research area and current state-of-the-art?* *Critical understanding of the project and its scientific background?* *Does the report relate the work presented to the scientific background?*
Explanation of scientific method	*Does the report demonstrate an understanding of the techniques used in project?*
Appropriateness of scientific level relative to attainable goals	*Is the subject treated in appropriate depth?* *Originality and creativity in dealing with scientific and technical issues?*
Discussion of results	*Does the report review and consolidate knowledge, skills and practices?* *Are the results presented clearly, discussed and analysed correctly?* *Are the results compared with existing work?* *Are appropriate software and graphics used in the interpretation of data/results?* *Are relevant issues that affected project identified and discussed appropriately?*
Conclusion	*Appropriate conclusion presented providing a summary of the key achievements?*
Justification	

Date:

Marker's printed name and signature: ....

Viva Marking Scheme

The viva will be used to test a student's understanding of the work undertaken in the project and this, in part, will be demonstrated by the student's ability to answer questions relating to the project and supporting physics.

Tick the box that best describes the student's performance and give an appropriate mark.

Student:		**Mark/100**
Mark Band	**Prompt**	**Tick**
90 – 100	Answered all questions correctly and fully without prompting, was able to support the answers with reference to current literature and put work into context	☐
80 – 89	Answered all questions correctly and fully without prompting and was able to support the answers with reference to current literature	☐
70 – 79	Answered most questions correctly without prompting and was able to support answers with reference to current literature	☐
60 – 69	Answered most questions correctly without prompting but did not support answers with reference to current literature	☐
50 – 59	Answered most questions adequately with prompting	☐
40 – 49	Answered some questions adequately with prompting	☐
30 – 39	Could describe project and could partially answer some questions with prompting	☐
20 – 29	Could describe project and could partially answer a few questions with prompting	☐
10 – 19	Could describe project but could not answer any questions even with prompting	☐
0 – 9	Could not describe project or answer any questions	☐

Date:

Markers' names and signatures:

Chair: ....

Primary: ....

Independent: ....

Index of Projects