DEPARTMENT OF PHYSICS

Fourth Year Research Projects

2015/16

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Health and Safety

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

16.4 Supervision of Students

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

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

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

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

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

With thanks,

Mr Ron Weston

Nanoscience Division

Predicting Solvation Thermodynamics of Bioactive Molecules

Project Supervisors: (1) Prof. Maxim V. Fedorov, (2) Dr. Neil Hunt & Dr. David Palmer

Project Description:

The project will study solvation thermodynamics of bioactive molecules by novel computer modelling methods.

One of the main causes of the unacceptable attrition rate in drug discovery is the failure of molecules to reach the market place because they have the wrong physico-chemical properties to allow them to be orally administered to patients. Indeed, as many as 40% of all drug failures on the market have been attributed to these problems.

Experimental high-throughput measurements of physico-chemical properties of bioactive molecules (solubility, pKa, logP, etc) are traditionally used to screen candidate drug molecules. However, such experiments are expensive, time-consuming and can only be applied to molecules that have already been synthesized. An alternative approach is to use computer simulations to calculate the properties of putative drug molecules.

Recently we developed a highly efficient method for predicting solvation thermodynamics parameters of bioactive molecules in a view of potential medical and environmental applications. The method is based on a molecular theory of solutions, Reference Interaction Sites Model (RISM). The student will have the opportunity to be involved into large-scale computational screening of thermodynamic properties of drug-like molecules and agrochemicals by this new method.

Reference: *Kerns, E. H. & Di, L. (2008), Drug-like properties: concepts, structure design and methods: from ADME to toxicity optimization, Academic Press;*

Additional references will be provided.

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

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Suitable for Masters-level students with good computer skills and an interest in chemical/molecular physics or biophysics. This is an excellent opportunity for students to get experience in novel state-of-the-art methods of molecular modelling.*

Safety Training Requirements: *none*

Molecular Mechanisms of Biological Adaptation to Extreme Ionic Environments

Project Supervisors: (1) Prof. Maxim V. Fedorov, (2) Dr. Neil Hunt & Dr. David S. Palmer

Project Description:

The project will study molecular mechanisms of protein resistance to extreme ionic environments by use of different methods of experimental and computational molecular biophysics.

Among different types of life there is one that exists under conditions considered for a long time as a dead zone. These living (micro) organisms are called “extremophiles”. They feel comfortable at such extreme conditions as high (>70° C) temperatures (*thermophile*), extreme pH (*alkaliphile, acidophile*), high salinity (*halophile*) etc.

This project will study molecular structures of enzymes from *halophilic bacteria* that inhabit hypersaline environments such as those found in the Dead Sea and saltern evaporation ponds. It was found that such aggressive media where ‘normal’ organisms cannot survive are the optimum living conditions for the halophilic species. During the billions years of evolution, the halophilic organisms developed *molecular mechanisms* of adaptation to highly concentrated salt environments. However, these mechanisms are still poorly understood. There are several hypotheses for the main mechanisms of halophilic proteins resistance to extreme ionic environments: (i) accumulation of negative charges on the protein surface; (ii) minimization of the solvent accessible surface area.

The main goal of the study will be to explore correlations between the surface charge and the surface area of different mutants of halophilic proteins compared to their homologous counterparts from ‘normal’ organisms. The project will involve experimental spectroscopic studies of polypeptides/proteins and homologous molecular modelling of proteins and structural analysis of the protein structures.

Key References: *Gross M. “Life on the Edge: Amazing Creatures Thriving in Extreme Environments”, New York (1998)*; *Lesk, A. M. “Introduction to protein architecture”, Oxford (2001); SWISS-MODEL Protein Modelling Environment (http://swissmodel.expasy.org); additional references will be provided.*

Ratio of effort: Exp/Theo/Comp	**Exp:**	**up to 50%**
	Theo:	**10%**
	Comp:	**40-70%**

Suitability: MPhys, BSc

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Suitable for students with good computer skills and an interest in molecular biophysics. The student will get experience in modern state-of-the-art tools of protein structural analysis and bioinformatics applications in molecular biophysics.*

Safety Training Requirements: *none*

Ionic Liquids at Charged Interfaces: Applications for Electrochemical Energy Storage

Project Supervisors: (1) Prof. Maxim V. Fedorov, (2) Dr. Yu Chen

Project Description:

The project is focused on the theoretical modelling of ionic liquids (IL) and electrified interfaces (ES). Ionic liquids are strongly believed to replace traditional electrolytes in high efficiency electrochemical devices for energy storage and transformation (e.g supercapacitors), due to their superior physicochemical properties, especially very low volatility and high electrochemical stability.

High-resolution modelling of the structure of ILs near the electrode surface is crucial for the understanding of electrochemical processes in RTILs. The results of the project would serve as a basis for understanding and rationalising the structure–potential and structure–property dependence of the electrified interface between ionic liquids and charged surface.

The main task of the project is to apply methods of Quantum Mechanics and Molecular Mechanics methods to investigate ILs at ES. The student will get experience with High Performance Computing (HPC) applications in chemical physics and theoretical/computational description of IL-based supercapacitors and batteries. The computational part of the project will be done with use of the ARCHIE-WeST HPC facilities (www.archie-west.ac.uk).

Key Reference (if applicable): M.*V. Fedorov and A.A. Kornyshev (2014). Ionic liquids at electrified interfaces. // Chemical Reviews,* ***114****(5), 2978.*

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

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

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Solid background in theoretical physics and statistical mechanics is strongly required. Some experience with computations and/or data analysis would be a plus.*

Safety Training Requirements: *None*

Development of Molecular-scale Computer Models for Enhanced Oil Recovery

Project Supervisors: (1) Prof. Maxim V. Fedorov, (2) Dr. Neil Hunt

Project Description:

The project is a part of ongoing collaboration with Schlumberger and it is focused on development of advanced molecular-scale models for enhanced oil recovery (EOR). Waterflooding is widely applied to boost declining oil reservoir pressure and sweep additional oil into production wells. Success in waterflooding is a key element to improved oil recovery.

In this project we intend to develop new computational model based on Molecular Dynamics for predicting and understanding characteristics of aqueous brines used for waterflooding in oil/gas reservoirs and complex mixtures of these brines with organic compounds. To facilitate this, a number of fundamental phenomena need to be understood by use of large-scale supercomputer simulations such as thermodynamics of ion solvation in brines; physico-chemical properties of brines at high temperature and pressure; the role of ions and counter-ions such as naturally occurring in sea water and ion effects on structural and thermodynamic properties of organic (bio)molecules.

The student will get experience with High Performance Computing (HPC) applications in chemical physics and use of HPC in development of advanced EORs. The computational part of the project will be done with use of the ARCHIE-WeST HPC facilities (www.archie-west.ac.uk).

Key Reference (if applicable): *(book) Israelachvili, J.N., 2011. Intermolecular and surface forces. Academic Press, Burlington, MA. (book) Frenkel, D., Smit, B., 2002. Understanding molecular simulation. Academic Press.*

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

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

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Solid background in theoretical physics and statistical mechanics is strongly required. Some experience with computations and/or data analysis would be a plus.*

Safety Training Requirements: *None*

Modelling of Wettability of Mineral Surface by Water and Oil

Project Supervisors: (1) Prof. Maxim V. Fedorov, (2) Dr. Yu Chen

Project Description:

The project is a part of ongoing collaboration with Schlumberger and it is focused on development of advanced molecular-scale models for understanding wettability of mineral (calcite) surface by water and hydrocarbons. Waterflooding is widely applied to boost declining reservoir pressure and sweep additional oil into producing wells. Success in waterflooding is a key element of Enhanced Oil Recovery (EOR) techniques. Specific interactions between crude oil/water/rock can lead to large variations in the displacement efficiency of water floods. The rock wettability by reservoir fluids affects not only the release of heavy ends of crude oil, but also the attachment of fine solids, e.g. clays, to the liberated mineral surface. Fundamental understanding of the wettability of mineral solids from oil reservoir could substantially enhance the efficiency of oil recovery.

In this project we intend to develop new computational model based on Molecular Dynamics for predicting and understanding interfacial properties of mineral-water-hydrocarbon systems. We aim to rationalize the wettability mechanism of the mineral surface by atomistic simulations of the rock/oil and rock/water interfaces.

The student will get experience with High Performance Computing (HPC) applications in chemical physics and theoretical/computational description of mineral/water and mineral/oil systems important for the oil & gas sector. The computational part of the project will be done with use of the ARCHIE-WeST HPC facilities (www.archie-west.ac.uk).

Key Reference (if applicable): *(book) Israelachvili, J.N., 2011. Intermolecular and surface forces. Academic Press, Burlington, MA. (book) Frenkel, D., Smit, B., 2002. Understanding molecular simulation. Academic Press.*

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

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

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Solid background in theoretical physics and statistical mechanics is strongly required. Some experience with computations and/or data analysis would be a plus.*

Safety Training Requirements: *None*

Effects of Salts on Surfactant Solutions

Project Supervisors: (1) Prof. Maxim Fedorov, (2) Dr. Neil Hunt

Project Description:

The project is focused on molecular-scale simulations of effects of ions on the stability of surfactant solutions. Aqueous surfactant solutions are widely used in many industries; however, we are particularly interested in surfactants used for enhanced oil recovery (EOR).

In this project we will use Molecular Dynamics simulations for understanding molecular-scale effects of dissolved inorganic salts on stability of aqueous surfactant solutions. We plan to use large-scale supercomputer simulations to investigate thermodynamics of ion and surfactant solvation in water; physico-chemical properties of surfactant/salt solutions at high temperature and pressure; the role of ions and counter-ions such as naturally occurring in sea water and ion effects on the phase diagram of surfactant solutions.

The student will get experience with High Performance Computing (HPC) applications in chemical physics and use of HPC in development of advanced EORs. The computational part of the project will be done with use of the ARCHIE-WeST HPC facilities (www.archie-west.ac.uk).

Key Reference (if applicable): *(book) Israelachvili, J.N., 2011. Intermolecular and surface forces. Academic Press, Burlington, MA.*

(book) Frenkel, D., Smit, B., 2002. Understanding molecular simulation. Academic Press.

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

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

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Solid background in theoretical physics and statistical mechanics is strongly required. Some experience with computations and/or data analysis would be a plus.*

Safety Training Requirements: *None*

Predicting molecular transport properties of pollutants in marine environments

Project Supervisors: (1) Prof. Maxim V. Fedorov), (2) Dr. David McKee

Project Description:

Accumulation of persistent organic pollutants (POPs) in natural marine environments is considered to be one of the main environmental threats in the 21st century. The POPs are volatile and frequently toxic compounds, which enter biosphere by dissolving in water. Despite of several decades of research, little is known about their environmental pathways in marine environments due to a large number of experimental challenges associated with monitoring vast areas of oceans, particularly in deep waters.

Recent progress in supercomputing technologies and development of accurate models for molecular transport properties of pollutants allows one to overcome these challenges with use of high-performance computing (HPC) modeling of environmental pathways of POPs.

Our group has recently developed a computational model that allows one to simulate molecular transport properties at different environmental conditions. This model allows studying environmental pathways of different chemicals and predicting effects of temperature, pressure and salts on their concentration in water.

The project will involve modelling of molecular transport properties of pollutants in a wide range of temperatures, pressures and salt concentrations. These parameters will be used for predicting their fate in the marine biosphere. During the project the student will get hands-on experience with a variety of modern methods of molecular and environmental modelling.

Key References: *(1) Barrat, J.-L. & Hansen, J.-P. Basic concepts for simple and complex liquids. (Cambridge University Press, New York, 2003); (2) 1.Atkins, P. & Paula, J. de. Atkins' Physical Chemistry. (OUP Oxford, 2009); (3) Peng J., Wan A., "Effect of ionic strength on Henry's constants of volatile organic compound", Chemosphere, Volume 36, Issue 13, June 1998, Pages 2731-2740.*

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

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

Recommended Classes/Pre-requisites: *Topics in Atomic, Molecular & Nuclear Physics (PH459)*

Additional comments: *Solid background in theoretical physics and statistical mechanics is strongly required. Some experience with computations and/or data analysis would be a plus.*

Safety Training Requirements: *None*

Uncovering the Early Stages of Protein Folding

Project Supervisors: (1) Dr. Neil Hunt, (2) Prof. Maxim Fedorov

Project Description:

The aim of this project is to use state of the art ultrafast laser based techniques to examine physical aspects of the topical subject of protein folding.

Proteins are of fundamental importance in biology as they play key roles in the life of every living organism. Proteins can be described as linear polymers of amino acids and their properties are determined by the structure of this polymer chain. Proteins tend to adopt only a limited number of spatial arrangements, the most common of which are the α-helix, a coil-like structure, the planar β-sheet motif and the random coil. Besides the obvious importance of folding in determining the properties of proteins, in recent years it has emerged that serious diseases, such as Alzheimer's, Diabetes and Creutzfeldt-Jakob disease, are associated with incorrect (mis-folded) protein conformations. The mechanism by which a protein undergoes changes in structure is therefore of great interest.

So far, the physics of protein folding are not fully understood. There is a general consensus that the final, fully folded, form of the protein is reached *via* a series of intermediate structures that exist for very short periods of time (10^{-12}-10^{-3}s) This project will examine these intermediate structures using a combination of Fourier transform infrared (FTIR) absorption spectroscopy and ultrafast 2D-IR spectroscopy. By examining short chain polypeptide models, we will build up a library of IR spectra under a range of conditions. The project will then progress to studies of isotopically-labelled peptides in order to gain site-specific information relating to the structure, dynamics and, ultimately, folding processes of these model proteins. If successful, there is scope to expand the project to larger protein systems.

Key Reference (if applicable): *N.T.Hunt, "2D-IR spectroscopy: ultrafast insights into biomolecule structure and function", Chem. Soc. Rev. 38, 1837-1848 (2009) doi: 10.1039/b819181f*

Ratio of effort: Exp/Theo/Comp	**Exp:**	**75 %**
	Theo:	**10 %**
	Comp:	**15 %**

Suitability: MPhys

Additional comments: *Suitable for Masters-level students with an interest in biophysics or chemical physics. The project will be multidisciplinary in nature and will require the student to be proactive in tackling associated new skills and subject matter.*

Safety Training Requirements: *Chemical and Laser Safety*

A Physical Investigation of Protein-drug Binding

Project Supervisors: (1) Dr. Neil Hunt, (2) Dr. Daniel Shaw

Project Description:

This project will use physical methods such as infrared and ultraviolet absorption spectroscopy to investigate the interactions between a drug molecule and the protein that it targets. The drug in question is currently used clinically to treat patients but a long course of treatment is required, which can lead to resistance. The aim of this project is to understand the physics of the binding between drug and protein by examining the structural interactions and hydrogen bonding that underpin drug activity and ultimately to discover ways of improving the effectiveness of future drug candidates.

If the project is successful later stages may progress to using ultrafast laser spectroscopy techniques to examine drug binding in real time.

The project lies at the boundary between physics and the life sciences and is an excellent opportunity to experience multidisciplinary research in the lab and to learn the skills that are required for this increasingly common type of study. The project will suit a motivated and ambitious student interested in taking part in a challenging project.

Key Reference (if applicable):

Ratio of Experiment/Theory/Computation:	**Exp:**	**75 %**
	Theo:	**15 %**
	Comp:	**10 %**

Suitability: MPhys

Additional comments: *A background in biology (or chemistry) is not required but would be an advantage*.

Safety Training Requirements: *Laser and Chemical Safety*

Noble Metal Quantum Dots

Project Supervisors: (1) Dr. Yu Chen, (2) Dr. Olaf Rolinski

Project Description:

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

Key Reference (if applicable):

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

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

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

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

Suitability: MPhys, BSc

Safety Training Requirements: *laser safety*

Optical Modes and Multiple Scattering

Project supervisors: (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

Twisted Nanostructures

Project Supervisors: (1) Dr. Ben Hourahine (2) Prof. Maxim Fedorov

Project Description:

In addition to the familiar repeating arrays of atoms in crystals, there are several other types of large ordered arrangements of atoms which occur in nature which are not periodic. For example there are many structures that are fundamentally helical in nature, these include carbon nanotubes, screw-dislocated nanowires, the tails and capsids of many viruses, amyloid fibrils, and perhaps most famously, DNA. Traditionally these are investigated by either using large clusters of atoms to describe segments of the helical structure, or as a crystal with a large number of atoms in its unit cell to include a complete twist of the helix. Both of these approaches require the simulation of very large numbers of atoms (in principle up to an infinite number in some cases), even though the fundamental repeat unit of the structure is often much smaller.

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

Key References:

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

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

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

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

Recommended Classes/Pre-requisites:

Additional comments:

Targeting chosen eigenvectors and singular vectors

Project Supervisors: (1) Dr. Ben Hourahine (2) Dr. Francesco Papoff

Project Description:

This project investigates the decomposition of matrices into their eigenvalues and eigenvectors. But instead of finding all of the components of the decomposition, this project will look at methods to produce the eigenvalues and vectors that correspond to particular features of the physical system that gives rise to the matrices. These could for example be the electronic levels in a crystal associated with band edge states or defects, or the specific optical modes excited by light scattering from a nano-structure. The methods derived by Tackett et al. apply to symmetric square matrices, but more general rectangular matrices can also be decomposed into their *singular* values and vectors. Depending on success in decomposing the square matrix cases, the project will then move to these more powerful decomposition cases.

Key References:

Targeting specific eigenvectors and eigenvalues of a given Hamiltonian using arbitrary selection criteria. Alan R. Tackett and Massimiliano Di Ventra Phys. Rev. B 66, 245104 (2002)

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

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: *This is a relatively mathematical project, and would suit someone with a good grasp of linear algebra.*

Safety Training Requirements:

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

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

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

Key References:

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

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

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

Suitability: MPhys, BSc, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *None*

Additional comments: *N/A*

Safety Training Requirements: *General laboratory safety*

Optical spectroscopy of distant sources

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

Project Description:

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

Key References:

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

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

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

Suitability: MPhys, BSc, BSc Physics with Teaching

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

Additional comments: *None*

Safety Training Requirements: *General lab safety*

Spectroscopic Studies of Melanin Fibrils; Spectra, Kinetics, Modulators

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

Project Description:

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

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

Key Reference:

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

Ratio of effort: Exp/Theo/Comp	**Exp:**	**65 %**
	Theo:	**25 %**
	Comp:	**10 %**

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

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

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

Efficiency of green LEDs: How serious is the “green gap”?

Project Supervisors: (1) Prof. Robert Martin, (2) Dr. Jochen Bruckbauer

Project Description:

The invention of blue light emitting diodes (LEDs) is revolutionising the lighting and display industries and led to the award of the 2014 Nobel Prize in Physics (see further reading). One of the dramatic aspects of these devices is their extremely high efficiency for converting electrical energy into light, exceeding that of conventional energy saving bulbs based on compact fluorescent tubes. Very similar technology, employing the semiconductor Indium Gallium Nitride, can be used to make green LEDs but their efficiency is so far notable worse than the blue (and red) counterparts – the so called “green gap” in efficiency. This project will explore the current status of green emitters, measuring commercial green LEDs to accurately quantify and compare the efficiencies and then to go on to consider the factors limiting these numbers. An important aspect will be to verify the claims of increasing efficiency made by some manufacturers and to carefully establish a robust approach to quantifying efficiencies. Photometric measurements will be performed in an integrating sphere as a function of drive current, looking to push the LEDs into the regime of “efficiency droop”. The project will also have to consider the effects of heating of the diodes at high currents.

Key Reference:

2014 Nobel Prize lectures :

http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/nakamura-lecture.html

http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/amano-lecture.html

Ratio of effort: Exp/Theo/Comp	**Exp:**	**75%**
	Theo:	**25%**
	Comp:	**0%**

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

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*

Phosphorescence of glowstones™.

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

Project Description:

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

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

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

Key papers:

[*1] http://www.jncht.net/photoluminescent_stone.HTM*

[2] See Wikipedia.

[3] Luminescence decay in disordered low dimensional semiconductors, X. Chen, B. Henderson and K.P. O'Donnell. Applied Physics Letters 1992, Vol.60, No.21, pp.2672-2674.

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

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

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

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

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

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

Project Description:

Rare earth ions in semiconductors have been studied for several decades [1] with the aim of extending the range of emission wavelengths of optoelectronic devices [2]. Optical spectra of tri-positive rare earth (RE^{3+}) ions in crystalline solids feature sharp lines at characteristic wavelengths that depend rather weakly on the host material. At the same time, the *spectral patterns* of such transitions are sensitive to the *symmetry* of the RE local environment in a way that can be described by simple crystal-field theory. Double-doping of epitaxial GaN samples with Mg and Eu introduces both metastable and quasistable defects associated with an extrinsic hysteretic photochromism, which may form the basis of a novel solid-state *qubit*.

In this project, we will utilize RE spectroscopy as a probe to monitor Eu^{3+} photochromism and photo-induced migration of Mg acceptors in GaN.

Key papers):

[1] P.N. Favennec, H. L'Haridon, M. Salvi, D. Moutonnet and Y. Le Gillou, Electronics Letts. ***25****, 718 (1989); see also K.P.O'Donnell, P hys. Status Solidi C, 1–3 (2015) / DOI 10.1002/pssc.201400133*

[2] K.P. O'Donnell and V. Dierolf (eds.), Topics in Applied Physics ***124*** *(Springer, Dordrecht, 2010)*

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

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

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

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

RE-doped III-nitrides for solid state lighting applications

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

Project Description:

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

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

Key papers:

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

Ratio of effort: Exp/Theo/Comp

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

Suitability: BSc, M.Phys

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

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

Gravity Gradiometry with Satellite Constellations

Project Supervisors: (1) Dr. Nicholas Lockerbie, (2) Dr. Daniel Oi

Project Description:

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

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

Key References:

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

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

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

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

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Revisiting Fluorescence Quantum Yield: New Light on an Old Approach

Project Supervisors: (1) Dr. Olaf Rolinski, (2) Prof. David Birch

Project Description:

The accurate measurement of fluorescence quantum yield (Φ) of a dye molecule remains one of the outstanding problems in spectroscopy. Φ is defined as the rate of fluorescence photon emission divided by the rate of photon absorption. Since the photons don't pile-up in molecules (i.e. what energy goes in must come out!) this can be conveniently expressed as $\Phi = k_r / (k_r + k_{nr})$ where k_r is the radiative rate, k_{nr} the non-radiative rate and $k_r + k_{nr} = 1/\tau$, with τ the fluorescence lifetime.

Ideally measuring Φ would involve recording rates of absorption and emission, but has proved to be very difficult. Traditionally this has led to the recourse of measuring the emission spectrum of a dye, correcting this for instrumental wavelength response, integrating and comparing the result with a "known" quantum yield standard. However, this method, although popular, results in a precision of $\pm$ 5% at best.

This project involves measuring τ, and then measuring the absorption spectrum, which leads to τ_r the pure radiative lifetime given by $1/k_r$. The approach is taken directly from the Einstein A and B coefficients for emission and absorption. The approach is not new, but seems to have been forgotten as, when it was first considered, measuring τ and the absorption spectrum were then difficult. Fortunately today both these measurements are accurate and routine.

During the project comparisons will be made with quantum yield values reported in the literature and the limitations of the approach assessed.

Key References:

Birks JB. Photophysics of Aromatic Molecules. London: Wiley-Interscience;1970.

Würth C, Grabolle M, Pauli J, Spieles M, Resch-Genger U. Relative and absolute determination of fluorescence quantum yields of transparent samples. Nat. Prot. 2013;8:1535-1550.

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

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

Recommended Classes/Pre-requisites: *Good Matlab skills are recommended.*

Additional comments: *The project uses optical spectroscopy to bridge between basic atomic physics and the behaviour of larger assemblies of atoms in molecules. As such it provides some preparation in one of the research areas that underpin "real-world" problems in the life sciences and medicine.*

Safety Training Requirements: *The Lecture 'Introduction to laboratory safety' provided by the Photophysics Group is compulsory before the experimental part can be undertaken.*

Transient Fluorescence Spectra of Proteins

Project Supervisors: (1) Dr. Olaf Rolinski, (2) Prof. David Birch

Project Description:

Intrinsic fluorescence of proteins provides rich information on their structure, interactions and activities, which finds numerous applications in many disciplines, eg medicine, where fluorescence measurements allow monitoring molecular-level mechanisms of diseases.

Fluorescence signal $I(\lambda,t)$, following a short pulse excitation of the sample, is in principle a function of the detection wavelength λ and the time t after excitation and usually decays within nanoseconds. There are two main molecular mechanisms determining the experimental fluorescence intensity decays: the depopulation of the excited states through radiative and non-radiative processes and dielectric relaxation causing shift of the emission spectrum towards red.

In the traditional fluorescence time-resolved experiment the quantity measured is the fluorescence intensity decay $I_\lambda(t)$ at the fixed detection wavelength λ.

In this project we will focus on the other quantity: the evolution of the fluorescence spectrum of the sample after excitation. For this purpose we will analyse a series of fluorescence decays of the same sample detected at the different wavelengths and determine the transient fluorescence spectra $I_t(\lambda)$. We hope to make step towards developing a new experimental approach to separate the effects of the excited states depopulation and the dielectric relaxation.

Key References:

Toptygin, D., Ch.9 in: Y.Engelborghs and A.J.W.Visser (eds.), Fluorescence Spectroscopy and Microscopy: Methods and Proticols, Methods in Molecular Biology, vol.1076, Springer (2014).

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

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

Recommended Classes/Pre-requisites: *Good Matlab skills are 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 is compulsory before the experimental part can be undertaken.*

Metal foils for electron energy filtering

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

Project Description:

Electron channelling contrast imaging (ECCI) is a scanning electron microscopy technique used to map small variations in local crystal orientation with nanometre spatial resolution [1]. The contrast of such images is degraded by the contribution of low energy electrons to the detected signal. In this project, we will investigate the possibility of using thin metal foils to filter out low energy electrons before they reach the electron detector. The performance of a silicon *p-i-n* diode detector will be simulated using existing Monte Carlo electron trajectory simulations [2], and the effect on the energy response of adding thin layers of metal to the front of the detector will be modelled. Comparisons with experimental data will be made.

Key References:

[1*] G. Naresh-Kumar, B. Hourahine, P. R. Edwards, A. P. Day, A. Winkelmann, A. J. Wilkinson, P. J. Parbrook, G. England and C. Trager-Cowan (2012) "Rapid nondestructive analysis of threading dislocations in wurtzite materials using the scanning electron microscope", Physical Review Letters* ***108*** *135503.*

[2] D. Drouin, A. R. Couture, D. Joly, X. Tastet, V. Aimez and R. Gauvin (2007) "CASINO V2.42—A fast and easy-to-use modeling tool for scanning electron microscopy and microanalysis users", Scanning ***29*** *92–101.*

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

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

Recommended Classes/Pre-requisites: *PH453: Topics in Solid State Physics*

Additional comments:

Safety Training Requirements: *None*

Noise and System Response of CCD Spectrographs for Luminescence Spectroscopy

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

Project Description:

Charge-coupled device (CCD) detectors have transformed many areas of scientific research, allowing optical spectra to be collected rapidly and with high signal-to-noise ratios. This project will examine limiting factors in the signal-to-noise ratio of luminescence spectroscopy measurements carried out using CCD spectrographs. The response of such systems is a strong function of both wavelength and polarization, and the project will investigate these aspects both theoretically and through experimental measurements. CCD noise will be quantified with the aim of determining which factors dominate under typical measurement conditions (e.g. during the acquisition of a cathodoluminescence hyperspectral image). The relative influence of shot noise (Poissonian) and read-out noise (Gaussian) will be compared for different sensors: not only conventional CCDs but also electron-multiplying (EMCCD) and image-intensified (ICCD) variants. The project may also be broadened to include the implications of the noise distribution for the pre-treatment of data prior to the application of multivariate statistical analysis methods.

Key Reference:

M. Lesser, "Charge coupled device (CCD) image sensors", in High Performance Silicon Imaging, edited by Daniel Durini, Woodhead Publishing, 2014, Pages 78-97, [10.1533/9780857097521.1.78](10.1533/9780857097521.1.78)

P. R. Edwards, L. Krishnan Jagadamma, J. Bruckbauer, C. Liu, P. Shields, D. Allsopp, T. Wang, R. W. Martin (2012) Microscopy and Microanalysis ***18*** *1212–1219 [10.1017/S1431927612013475](10.1017/S1431927612013475)*

Ratio of effort: Exp/Theo/Comp

Exp:	**50%**
Theo:	**25%**
Comp:	**25%**

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

Additional comments:

Safety Training Requirements:

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

Project Supervisors: (1) Dr. T.P. J. Han (2)

Project Description:

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

Key papers (two; possibly one review, at least one research paper):

i. C. *Jiang, F. Wang, N. Wu, X. Liu, Adv. Mater., 20, (2008) 4826.*

ii. L. Yang, H. Han, Y. Zhang, J. Zhong, J. Phys. Chem. C, 113, (2009) 18995.

iii. V. Mahalingam, R. Naccache, F. Vetrone, J.A. Capobianco, Chem. Eur. J., 15, (2009) 9660.

iv. M. Wang, G. Abbineni, A. Clevenger, C. Mao, S. Xu, Nanomedicine: Nanotechnology, Biology and Medicine, 7, (2011) 710;

v. F. Wang, X. Liu, Chem. Soc. Rev. 38, (2009) 976.

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

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

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

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

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

Safety Training Requirements: *Laser safety.*

An optical study of lanthanide ion doped BaY_2F_8 single crystals.

Project Supervisors: (1) Dr. T.P. J. Han (2)

Project Description:

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

Key papers (two; possibly one review, at least one research paper):

i. A.*C.S. de Mello, A.B. Andrade, G.H.G. Nakamura, S.L. Baldochi, M.E.G. Valerio, J. Luminescence, 138, (2013) 19.*

ii. *F. Cornacchia, D. Parisi, C. Bernardini, A. Toncelli, M. Tonelli, Optics Express, 12(9), (2004) 1982.*

iii. *H.J. Eichler, J. Findeisen, B. Lui, A.A. Kaminskii, A.V. Butachin, P. Peuser, IEEE Journal of selected topics in quantum electronics, 3(1), (1997) 90.*

iv. *V. Toccafondo, A. CerqueiraS., S. Faralli, E. Sani, A. Toncelli et al., J. Appl. Phys., 101, (2007) 023104.*

v. *S.A. Pollack, D.B. Chang, R.A. McFarlane, H. Jenssen, J. Appl. Phys., 67, (1990) 648.*

Ratio of effort: Exp/Theo/Comp	**Exp:**	**85%**
	Theo:	**10%**
	Comp:	**5%**

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

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

Additional comments: *(e.g. course suggested)*

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

Safety Training Requirements: *Laser safety.*

Optics Division

Beam Quality of Broad-area Diode Lasers

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

Project Description:

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

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

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

Key Reference: *[1] R. Herrero et al., Beam shaping in spatially modulated broad-areasemiconductor amplifiers, Opt Lett. 37, 5253 (2012); [2] Crump et al., Experimental and theoretical analysis of the dominant lateral waveguiding mechanism in 975 nm high power broad area diode lasers. Semicond. Sci. Technol.* ***27*** *(2012) 045001*

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

Suitability: MPhys, BSc

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

Safety Training Requirements: *laser*

Characterization of Optically pumped Quantum Well and Quantum Dot Vertical-cavity Structures

Project Supervisors: (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 (if applicable):

Bhattacharya et al., Quantum dot polarized light sources, Semicond. Sci. Technol. 26 (2011) 014002

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.*

Safety Training Requirements: *Laser safety*

Interaction of light with Rubidum vapour

Project Supervisors: (1) Prof. Thorsten Ackemann, (2) Dr. Aidan Arnold

Project Description:

Refractive index and absorption coefficient are macroscopic manifestations of light-matter interaction in semiclassical approximation, i.e. treating the atoms quantum mechanically and the light classically. Although these calculations can be done from first principles, they can become quite involved if the atoms have a complex atomic structure. The aim of the project is to measure the change in beam properties (absorption, Faraday rotation, lensing) after transmission through a Rb vapour cell and compare it with calculations from a software package. We are also interested in the transient properties including the time it needs to establish the linear refractive index and absorption. The investigations might be transferred to cold atoms towards the end of the project or in year 2.

Key References: P. *Siddons et al., J. Phys. B 41, 155004 (2008); S.M. Rochester: Modelling Nonlinear Magneto-optical Effects in Atomic Vapors, PhD thesis, University of California, Berkeley (2010). The software is at this link: http://rochesterscientific.com/ADM/*

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

Suitability: MPhys, BSc, BSc Maths and Physics (with interest in experiments)

Recommended Classes/Pre-requisites: *Good knowledge in atomic physics, possibly PH459, PH4xx Topics in Quantum Optics*

Additional comments:

Safety Training Requirements: *laser*

Observing Beam Propagation by Fluorescence

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

Project Description:

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

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

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

Suitability: MPhys

Additional comments: *Lab JA3.04A*

Safety Training Requirements: *Laser safety training required.*

Bose-Einstein condensate experiments

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

Project Description:

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

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

Key References:

*[1] M.E. Zawadzki, P.F. Griffin, E. Riis, and A.S. Arnold, Spatial interference from well-separated split condensates, Phys. Rev. A **81**, 043608 (2010).*

*[2] A.S. Arnold, C.S. Garvie, and E. Riis, Large magnetic storage ring for Bose-Einstein condensates, Phys. Rev. A **73**, 041606(R), (2006).*

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys only

Additional comments:

Safety Training Requirements:

Cold Atom-Light Interactions

Project Supervisors: (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

Project Supervisors: (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

Project Supervisors: (1) Dr. Gordon Robb, (2) Dr. Nigel Langford

Project Description:

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

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

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

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

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

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

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

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

Additional comments:

Safety Training Requirements: *N/A*

Four-wave Mixing in Atomic Gases

Project Supervisors: (1) Dr. Gordon Robb, (2) Dr. Aidan Arnold

Project Description:

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

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

Key References:

[1]"Nonlinear Optics" by R. Boyd

[2] A. Vernier, S. Franke-Arnold, E. Riis, and A. S. Arnold , Optics Express 18, 17020 (2010)

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

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

Recommended Classes/Pre-requisites: *none*

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

Safety Training Requirements: *None*

Quantum Measurement in the Jaynes-Cummings Model

Project Supervisors: (1) Dr. Daniel Oi, (2) Dr. John Jeffers

Project Description:

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

Key Reference:

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

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

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

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

Additional comments:

Safety Training Requirements:

Modelling CubeSat to Ground Quantum Communication

Project Supervisors: (1) Dr. Daniel Oi, (2) Dr. Paul Griffin

Project Description:

CubeSats are a promising platform for quantum key distribution systems in low Earth orbit. However, their small size, mass, and power restricts the equipment it is able to carry so innovative solutions are required. A key issue is the diffraction limited spot size of single photon transmission between satellite and the ground. The project would model the optical channel from a CubeSat to a receiving station in order to characterize losses and the effect of beam shape, pointing jitter, and atmospheric turbulence.

Key Reference:
Quantum optics for space platforms, W. Morong, A. Ling, D. Oi, Optics and Photonics News ***23*** *p.42 (2012)*
http://quantumlah.org/media/story/2012_OPN_Alexfeature.pdf

Ratio of effort: Exp/Theo/Comp

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

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

Additional comments:

Safety Training Requirements:

Ancilla-driven Quantum Dynamics

Project Supervisors: (1) Dr. Daniel Oi, (2) Dr. Marco Piani

Project Description:

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

Key Reference:

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

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

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

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

Additional comments:

Safety Training Requirements:

Floquet theory for trapped atoms in optical lattices.

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

Project Description

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

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

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

Key References:

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

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

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

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

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

Safety Training Requirements: No special safety training requirements.

Matrix product state representation of quantum states

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

Project Description

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

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

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

Key References:

[1] I. Affleck, T. Kennedy, E. H. Lieb, H. Tasaki, Comm. Mat. Phys. 115 477 (1998)

[2] D. Perez-Garcia, F. Verstraete, M.M. Wolf, J.I. Cirac, Quantum Inf. Comput. 7, 401 (2007)

[3] White S. PRL 69, 2863 (1992)

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

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

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

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

Safety Training Requirements: No special safety training requirements.

Transport Dynamics of Quantum Gases in Optical Potentials

Project Supervisors: (1) Prof. Andrew Daley, (2) Dr. Alexandre Tacla

Project Description:

Quantum gases are engineered quantum systems, typically consisting of millions of atoms, which can be precisely manipulated by optical potentials to study quantum effects in a large many-body scale. These are highly controllable systems that can be trapped in arbitrary geometries and have their interactions tuned to study exotic quantum states of matter, such as the quantum phase transition between an insulator and a superfluid, and to possibly develop groundbreaking technologies, such as quantum computers. Such remarkable achievements have demonstrated our strong theoretical understanding of atomic systems on a microscopic level and our ability to numerically simulate the quantum many-body dynamics with high accuracy.

This project investigates non-equilibrium transport dynamics of quantum gases in one-dimensional optical lattice potentials. The goal is to investigate the flow of atoms through the lattice and passing through barriers, including impurity atoms. The student will learn techniques to treat the many-body dynamics in different levels of approximation, ranging from a simplified mean-field description in terms of the discrete nonlinear Schrödinger equation, to powerful numerical techniques, such as time-dependent Density Matrix Renormalization Group, which allow for virtually exact calculations of the many-body dynamics in many interesting regimes. This project is directly related to existing experiments, including some in the photonics group in this department.

Key References:

*[1] I. Bloch, Ultracold quantum gases in optical lattices. Nature Physics **1**, 23 (2005).*

*[2] A. J. Daley, P. Zoller, and B. Trauzettel, Andreev-like reflections with cold atoms. Physical Review Letters **100**, 110404 (2008).*

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

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

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

Safety Training Requirements: *No special safety training requirements.*

Dynamics of Impurity Atom Coupled to a Quantum Gas

Project Supervisors: (1) Prof. Andrew Daley, (2) Dr. S. McEndoo

Project Description:

Cold atomic systems provide an exciting and varied landscape of tools and materials for investigating and manipulating quantum systems in precise ways. From macroscopic quantum objects such as Bose-Einstein condensates to the manipulation of single atoms, we now have a large range of experimental and theoretical systems at our disposal. By investigating such systems, we can study fundamental physics at close quarters, while providing new ideas and methods for manipulating information at a quantum level.

Because we can consider both the wave and particle natures of atoms, we can use a quantum gas to take the role of the electric field and recreate optical phenomena using atoms alone. For example, when an atom in an excited state is coupled to quantum gas, the atom is able to undergo spontaneous emission, but instead of emitting a photon as it drops to the ground state, the atom creates an excitation in the quantum gas.

In addition to being able to recreate spontaneous emission as it is in the photonic case, by using quantum gases we can move into new regimes, taking advantage of the different properties of the quantum gas, and the gas-atom coupling.

In this project we look at how the properties of the atoms and the quantum gas can affect the dynamics of the system and can be used to engineer particular states of the atom. A large component of this project will involve numerical simulation of these systems including, if appropriate, methods such as time-dependent DMRG. We will also take a theoretical approach parallel to the numerical approach, particularly for interesting cases where there is an analytical solution. This project is directly related to existing experiments, including some in the photonics group in this department.

Key References:

*I. Bloch, Nature Physics **1**, 23 - 30 (2005)*

*A. J. Daley, P. O. Fedichev, and P. Zoller, Phys. Rev. A **69**, 022306 (2004).*

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

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

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

Safety Training Requirements: *No special safety training requirements*

Resonances in Clouds of Cold Atoms

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

Project Description:

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

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

Suitability: MPhys, BSc

Modelling scanning near-field microscopy

Project Supervisors: (1) Dr. F. Papoff, (2) Dr. B. Hourahine

Project Description:

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

Key References:

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

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

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

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

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

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Parametric difference resonance in lasers

Project Supervisors: (1) Dr. F. Papoff, (2) Dr. Gordon Robb

Project Description:

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

Key References:

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

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

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

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Computational Modelling of X-ray Free Electron Lasers

Project Supervisors: (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 (if applicable):

[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

Project Supervisor: (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 (if applicable):

[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)
***For MPhys students the project should be designed to last for two years**
Additional comments:
Safety Training Requirements: *Normal office/computer user induction.*

The scientific applications of X-ray Free Electron Lasers

Project Supervisor: (1) Dr. Brian McNeil (2) Dr. Gordon Robb

Project Description:

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

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

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

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

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

Key Reference (if applicable):

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx

*[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, **4**, 814, 2010*

[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

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

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

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

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

Modelling a Hybrid Atom-Superconductor Quantum System

Project Supervisors: (1) Dr. Jonathan Pritchard, (2) Dr. Daniel Oi

Project Description:

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

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

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

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

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

Suitability: MPhys, BSc, BSc Maths and Physics

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

Additional comments:

Safety Training Requirements:

Characterising micro-mirror devices

Project Supervisors: (1) Dr. Paul Griffin, (2) Dr. Alison McDonald

Project Description:

Microfabricated optical elements are key components for the development and integration of optics into a range of research and commercial areas. To date, the majority of the work in microphotonics has been in refractive elements, i.e. microlenses. However, typically these suffer from large aberrations. As such efforts are now focused on the design of suitable reflective elements such as parabolic and Fresnel micro-mirror arrays. This project will involve using an adapted confocal microscope to collect detailed 3D data sets about the focal plane of these devices. The experimental results will be compared with angular spectrum simulations. This data would then be used to determine the suitability of these devices for atomic physics and tweezing experiments.

Key References:

[1] Alison McDonald, Gail McConnell, David C. Cox, Erling Riis, and Paul F. Griffin, "3D mapping of intensity field about the focus of a micrometer–scale parabolic mirror," Opt. Express 23, 2375-2382 (2015)

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

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

Recommended Classes/Pre-requisites:

Additional comments: *The project requires a student with good experimental and analysis skills.*

Safety Training Requirements: *Laser safety training required.*

Programming a Gaussian-beam calculator with MATLAB

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

Project Description:

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

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

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

Suitability: MPhys, BSc, BSc Maths and Physics,

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

Safety Training Requirements: *None.*

3D-Printing of optics equipment in a laser laboratory

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

Project Description:

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

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

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

Suitability: MPhys, BSc, BSc Maths and Physics,

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

Safety Training Requirements: *None.*

Quantum enhanced imaging

Project Supervisors: (1) Dr. John Jeffers, (2) Dr. Wojciech Roga

Project Description:

The goal of the project is to apply quantum coincidence (ghost) imaging to modern digital imaging techniques and analyse their features.

In this project you will work on:

- Modern digital imaging techniques, including image perfecting and image enhancement.
- Application of quantum entanglement and other forms of correlations in photonic system to imaging (features of coincidence imaging).
- Applications of the imaging techniques e.g. data compression, biological imaging.

You will learn to use the following techniques:

- Fourier optics.
- Matrix analysis.
- Numerical simulations (Matlab).

Key References:

1. *Leonid P Yaroslavsky, Advanced Digital Imaging Laboratory Using MATLAB, IOP Publishing, Bristol 2014.*
2. *Joseph W. Goodman, Introduction to Fourier Optics, Roberts & Company Publ. Englewood, Colorado 2005.*
3. *Jeffrey H. Shapiro · Robert W. Boyd , The physics of ghost imaging , Quantum Inf Process (2012) 11:949–993*

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:

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

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

Additional comments: *The project is mainly theoretical with possible collaboration with experimental groups.*

Safety Training Requirements: *None*

Quantum State Comparison Amplification Protocol

Project Supervisors: (1) Dr. John Jeffers, (2) Dr. Luca Mazzarella

Project Description:

The perfect and deterministic amplification of an unknown quantum state is a task forbidden by the fundamental principles of quantum theory. On the other hand, in the past decade many methods of imperfect amplification of various optical quantum states (e.g. Fock states or coherent states) have been devised that rely on different experimental resources. The use of these systems will represent a leap forward in the field of Quantum Communication and Quantum Technologies in general.

The state comparison amplification protocol (SCAMP) is a non-deterministic method aimed to amplify coherent states, from a known set, which operates at high gain, high success probability and high fidelity and it is implemented with relatively simple resources (linear optical components and APD detectors).

The goal of this project will be to investigate how the key feature of the SCAMP, such as gain, fidelity and scalability, are affected by the noise and disturbances induced by the transmission in the atmosphere and by imperfections in the experimental implementation.

Key References:

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

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

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

Suitability: MPhys, BSc, BSc Maths and Physics

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

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

Safety Training Requirements: *N/A*

Distinguishability of quantum states

Project Supervisors: (1) Dr. Marco Piani, (2) Dr. John Jeffers

Project Description:

The state of a quantum system is encoded in a density matrix, which allows one to compute the expectations of any possible observation made on the system, and is the correspondent of a classical probability distribution for a classical random variable. A basic task, important both from a physical and an information-theoretical point of view, is that of distinguishing two (or more) states of the same system. This is done by performing a measurement on the system. A key parameter is the optimal success probability in distinguishing such states, which is dictated by a mathematical distance between the corresponding density matrices, and depends on the `prior' expectation, since it might be more likely that one state is prepared than the other one. The project regards the study of the dependence of the success probability on such a prior. The student will become familiar with basic notions of quantum information (states, measurements) and matrix analysis. The student will also learn about semidefinite programming optimization techniques, and employ them numerically when studying relevant examples.

Key References:

- *M. A. Nielsen and I. L. Chuang, Quantum computation and quantum information. Cambridge University Press, 2010.*
- *J. Watrous, Lecture notes on Theory of Quantum Information, available at https://cs.uwaterloo.ca/~watrous/LectureNotes.html*
- *G. M. D'Ariano, M. F. Sacchi, and J. Kahn, Minimax quantum state discrimination, Phys. Rev. A 72, 032310 (2005), arXiv:quant-ph/0504048*

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: *The student should be familiar with basic concepts of quantum physics, with linear algebra and some basic matrix analysis, with the use of Matlab*

Additional comments: *None*

Safety Training Requirements: *None*

Quantifying the entanglement of global quantum evolutions and measurements

Project Supervisors: (1) Dr. Marco Piani, (2) Dr. Daniel Oi

Project Description:

Entanglement is a very non-classical property of quantum systems composed by many parts. When such parts are entangled, joint properties may dominate over individual properties, and may lead to the appearance of stronger-than-classical correlations. With the advent of quantum information processing, entanglement has acquired the status of resource, to be exploited to perform tasks that are impossible in its absence. Global quantum evolutions of many subsystems may generate entanglement, and may require to use up pre-existing entanglement stored in ancillary systems to simulate a target evolution with restricted operations that do not allow the generation of entanglement, like local operations aided by classical communication. This project regards the quantification of the entanglement needed to implement global quantum operations, like global quantum measurements or global transformations. The student will learn concepts of quantum information theory, and about entanglement. The student will also learn about semidefinite programming optimization techniques, and employ them numerically when studying relevant examples.

Key References:

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

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

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

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

Additional comments: *None*

Safety Training Requirements: *None*

Plasmas Division

Simulation and measurement of two-dimensional periodic surface lattice

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

Project Description:

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

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

Key Reference (if applicable):

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

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

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

Suitability: PH550 M.Phys.

Additional comments:

Safety Training Requirements:

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

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

Project Description:

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

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

Key Reference (if applicable):

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

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

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

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 BSc

Additional comments:

Safety Training Requirements:

Femtosecond chemistry with laser-plasma-accelerators

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

Project Description:

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

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

Ratio of effort: Exp/Theo/Comp	**Exp:**	**10 %**
	Theo:	**70 %**
	Comp:	**30 %**

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

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

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Coherent and incoherent combination of laser pulses

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

Project Description:

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

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

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

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

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

The future is fibre accelerators, Nature Photonics 2013

Ratio of effort: Exp/Theo/Comp	**Exp:**	**10 %**
	Theo:	**70 %**
	Comp:	**30 %**

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

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

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Mid-Infrared Laser Wakefield Acceleration

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

Project Description:

Laser Wakefield Acceleration (LWFA) is a trending topic worldwide, and Strathclyde has a leadership role based on its decade-long track record. State-of-the-art laser wakefield acceleration ultilises Ti:Sapphire laser pulses with a central wavelenth of 800 nm. This is mainly because in order to excite a strong plasma wave one needs laser pulses with gigantic powers of the order of tens of TW or more, and Ti:Sapphire is a strightforward medium to achieve that. However, there is a novel class of laser systems on the horizon which operates instead at mid-IR wavelengths up to CO2-laser wavelength of 10 µm. This is a very different regime but has certain benefits, such as regards the production of ultralow emittance beams – which may have disruptive impact on photon science as well as high energy physics.

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

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

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

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

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

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Space Radiation Reproduction and Testing

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

Project Description:

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

Key References: www.scapa.ac.uk http://silis.phys.strath.ac.uk/wp/ www.hybrids.desy.de
Design Considerations for the use of laser-plasma-accelerators for advanced space radiation studies, T. Königstein, O. Karger, G. Pretzler, J.B. Rosenzweig, and B. Hidding, J. Plasma Physics, 2012
Laser-plasma-accelerators -- A novel, versatile tool for space radiation studies, B. Hidding, T. Königstein, O. Willi, J.B. Rosenzweig, K. Nakajima, and G. Pretzler. Nucl. Instr. Meth. A, Vol. 636, 1, 2011.

Ratio of effort: Exp/Theo/Comp

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

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

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

Additional comments:

Safety Training Requirements: *laser and radiation safety*

Beam-driven Plasma Wakefield Acceleration (PWFA)

Project Supervisors: (1) Prof. Bernhard Hidding, (2) Prof. Dino Jaroszynski

Project Description:

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

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

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

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

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

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

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

Medical Radioisotope Production using a Laser-Plasma Wakefield Accelerator

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

Project Description:

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

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

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

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

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

Modelling of plasma instabilities relevant to laser-driven ion acceleration

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

Project Description:

Plasma instabilities are a fundamental process in various fields of physics such as astrophysics, fusion and laser-driven accelerators. The interaction of an ultra-intense laser pulse with solid matter can be used to generate high energy particle beams. The dynamics of these particles in the presence of the laser pulse can make the system susceptible to the growth of a variety of plasma instabilities. These can be detrimental, such as the Rayleigh Taylor instability which may induce bubble-like break-up of the resultant ion beam, or beneficial, such as the relativistic Buneman instability that can facilitate energy exchange between the electrons and ions.

This project will investigate the growth of various instabilities in the context of laser-ion acceleration. This will involve numerical modelling through the use of particle-in-cell simulations and comparisons with theoretical analysis of the expected properties of these instabilities based on the simulation parameters.

Key References:

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

Suitability: BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Ion Acceleration in Relativistically Intense Laser- Solid Interactions

Project Supervisors: (1) Prof. Paul McKenna, (2) Dr. Ross Gray

Project Description:

By focusing petawatt-scale pulses of laser light to intensities exceeding 10^{20} Wcm^{-2}, solid density matter is heated to temperatures of $>10^9$ K on timescales of 10's of femtoseconds. Under these conditions the solid target at the focus of the laser quickly evolves into an exotic state of matter called a *relativistic plasma,* as electrons in the material are accelerated to velocities approaching the speed of light. In this regime we are able to observe in the laboratory and in simulations Einstein's special theory of relativity at work. In plasmas with these extreme temperatures where electrons are approaching the speed of light, they gain additional mass due to the increasing Lorentz factor, g. These more massive electrons induce a reduction of the fundamental electron plasma frequency which defines the minimum frequency of electromagnetic radiation that can propagate in the plasma. This change in plasma frequency means that as g increases the plasma will become suddenly transparent to certain laser frequencies. Our understanding of so-called "relativistic induced transparency" is rapidly evolving and may have important implications for fundamental physics and for so called laser-driven ion acceleration. To date the acceleration of ions by lasers has been mostly studied in plasmas which are opaque to the laser. Now we are beginning to explore through simulations and experiment if the process of ion acceleration is enhanced when the plasma becomes relativistically transparent making it no longer opaque to the laser.

The objective of this project is to investigate the onset of relativistic induced transparency in dense plasmas irradiated by ultra-intense laser pulses and the subsequent effect on ion acceleration. This involves simulating the response of the plasma electrons and ions to the fields created at the focus of the laser pulse, using a particle-in-cell code running on a high performance computer. As well as performing analysis on the simulation data using tools such as MATLAB.

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

Suitability: BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Laser pulse compression in underdense plasma

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

Project Description:

Plasma as the fourth state of matter is pervasive in space, laboratory, and also in our life. It is formed when bounded electrons are released from atoms (such as by the high electric fields of a laser pulse) to become free electrons so that the system is made of free electrons and ions. The plasma as a medium exhibits distinct electric and magnetic properties, different from those in normal gas and solid targets. Recently with the development of chirped pulse amplification (CPA) technology, one can produce ultrashort and high intensity laser pulses. Such laser pulses can find wide applications including charged particle acceleration, high power X-ray radiation, advanced laser fusion, and the creation of high energy density matter etc.

Currently, typical high power laser pulse duration is about 40-50fs. For some applications, one needs to the laser pulse duration can be further reduced to less than 30fs. It is found that the plasma as a nonlinear medium can be used to compress the high intensity laser pulse. The main task of this project is to find suitable plasma parameters to compress the laser pulse duration. This includes the effect of plasma density inhomogeneity. The student will use a one-dimensional particle-in-cell (PIC) code to study this problem.

Key References:

1. H. Y. Wang et al., Phys. Rev. Lett. 107, 265002 (2011).

2. O. Shorokhov et al., Phys. Rev. Lett. 91, 265002 (2003).

3. Z. M. Sheng et al., Phys. Rev. E 62, 7258 (2000).

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

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

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

Additional comments: *No*

Safety Training Requirements: *No*

Compact X-ray sources from nonlinear Thomson scattering based upon all-optical schemes

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

Project Description:

The civilisation of humankind is always accompanied with the development and applications of light sources. The importance of light for our modern society is still increasing, which is partially reflected by the dedicated "International Year of Light 2015" adopted by the United Nations.

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

Key References:

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

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

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

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

Additional comments: *No.*

Safety Training Requirements: *No.*

Numerical simulation of laser interaction with magnetised overdense plasma

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

Project Description:

Recently with the development of chirped pulse amplification (CPA) technology, one can produce ultrashort and high intensity laser pulses. Such laser pulses can find wide applications including charged particle acceleration, high power X-ray radiation, advanced laser fusion, and the creation of high energy density matter etc.

In intense laser solid interaction, it is found that free electrons at the solid surface can be driven into oscillation with relativistic high speeds by the incident laser pulse. As a result, high harmonics of the laser pulse will be produced. In the meanwhile, some quasi-static magnetic fields up to 100MG will be produced around the solid surface. Such magnetic field cannot be measured directly. But this magnetic field may change the high harmonics generation, which may provide an indirect measurement of the magnetic field. The aim of this project is to investigate how the magnetic field at the solid surface can change the spectrum and efficiency of high harmonics generation. A one-dimensional particle-in-cell (PIC) code developed by the supervisors will be used to study this problem.

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. U. Wagner et al., Phys. Rev. E 70, 026401 (2004).
4. M. Tatarakis et al., Nature (London) 398, 489 (2002).

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

Suitability: MPhys, BSc, BSc Maths and Physics

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

Additional comments: No.

Safety Training Requirements: No.

Excitation of Heavy Atomic Species for ITER

Project Supervisors: (1) Prof. Nigel Badnell, (2) Prof. Bob Bingham (tbc)

Project Description:

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

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

Key Reference (if applicable): *http://www.iter.org/*

Ratio of Experiment/Theory/Computation:

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

Suitable for: MPhys

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

Safety Training Requirements:

Atomic Processes for Astrophysical Plasmas

Project Supervisors: (1) Prof. Nigel Badnell, (2) TBC

Project Description:

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

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

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

http://www.apapnetwork.org/

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

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

Suitability: MPhys, BSc, BSc (Maths Physics)

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

Safety Training Requirements: *N/A*

Stochastic Particle Heating of Charged Particles by Plasma Waves

Project Supervisors: (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:

Simulation of Electromagnetic Waves in Magnetized Plasmas

Project Supervisors: (1) Dr. Bengt Eliasson, (2) Dr. Kevin Ronald, Dr. David Speirs

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 plasma changes the propagation characteristics of electromagnetic waves, and the magnetic field breaks the symmetry and makes the plasma anisotropic. Electromagnetic waves such as radio waves can be reflected from and interact with the plasma in the ionosphere, and microwaves are used to study artificially created plasma in the laboratory. The plasma and the magnetic field also introduces a number of new wave modes in addition to the usual electromagnetic waves in vacuum. Hence, the propagation of electromagnetic waves into a plasma is a non-trivial problem.

The project aims at building a numerical model of the propagation of electromagnetic waves into a magnetised plasma, to study the propagation and nonlinear interactions between the electromagnetic wave and the plasma. Through similarity principles, the physics of a plasma can be scaled so that ionospheric physics with length-scales of the order 10 km or more can be studied in the laboratory with length-scales of the order 1 m, and vice versa. Hence, the project has relevance to the study of microwaves propagating into magnetically confined plasma (an experiment currently under construction at Strathclyde), as well as to existing experiments involving radio waves injected into ionospheric plasmas from ground-based transmitters or from satellites surrounding the Earth and other planets in the Solar system.

Experience with programming in Matlab or other simulation languages is beneficial.

Key Reference (if applicable): *Bengt Eliasson: Full-scale simulations of ionospheric Langmuir turbulence. Modern Physics Letters B 27(8), 1330005 (27 pages), doi:10.1142/S0217984913300056 (2013).*

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

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

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

Project Supervisors: (1) Dr. Wenlong He, (2) Dr. Liang Zhang

Project Description:

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

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

Key References:

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

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

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

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments:

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

Design and Measurement of a Mode Converter for a Microwave Amplifier

Project Supervisors: (1) Dr. Wenlong He, (2) Dr. Craig Donaldson

Project Description:

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

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

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

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

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

Suitability: MPhys

Additional comments:

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

Monte Carlo Simulation and Cooling Performance of the MICE Step V Laboratory Experiment.

Project Supervisors: (1) Dr. Kevin Ronald, (2) Dr. Alan Young

Project Description:

A Neutrino Factory based on a muon storage ring represents the ultimate tool for the study of neutrino oscillations, including the potential discovery of leptonic CP violation. It is also the first step towards the construction of a μ+μ– collider. Ionisation cooling of muons can make a significant contribution to both the performance (up to a factor of 10 in neutrino intensity) and cost (as much as 20%) of a Neutrino Factory. This potential benefit has motivated the undertaking and construction of the Muon Ionisation Cooling Experiment (MICE), a significant undertaking that has various key stages in its physical implementation. There are various potential lattice configurations currently under consideration for MICE Step V – the final operating configuration for the experiment. Simulating and evaluating these potential configurations is currently a critical activity in order to implement a successful MICE Step V experiment. The aim of this project is therefore to conduct a variety of simulations using the MICE Analysis User Software (MAUS), a Monte Carlo Simulation Tool which predicts the trajectories of the muons through a complex system of magnetic fields, solid beamline objects and accelerating cavities, to determine and evaluate the most suitable Step V lattice configurations and operating conditions, and to define the performance requirements of key detectors to ensure a successful MICE experiment and first practical demonstration of ionisation cooling.

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:	**30%**
	Comp:	**70%**

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

Additional comments:

Safety Training Requirements:

High-Power Microwave Sources

Project Supervisors: (1) Dr. Phil MacInnes, (2) Dr. Kevin Ronald

Project Description:

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

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

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

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

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

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

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

Safety Training Requirements:

Institute of Photonics

Neurophotonic Systems for Interfacing with the Retina

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

Project Description

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

Key Reference (if applicable):

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

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

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

Suitability: MPhys, BSc

Additional comments:

Safety Training Requirements: *Laser Safety Training*

Photonic Neurons: Spiking information processing with lasers

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

Project Description:

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

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

Key References:

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

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

Ratio of effort: Exp/Theo/Comp	**Exp:**	**70%**
	Theo:	**15%**
	Comp:	**15%**

Suitability: MPhys BSc

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

Safety Training Requirements: *Laser safety*

Modelling Non-linear Processes in Micro-waveguides

Project Supervisor (1) Dr. Michael Strain, (2) Dr. Nicolas Laurand

Project Description:

Waveguides with sub-micron cross-sectional dimensions have proven extremely successful in non-linear optical applications. By using materials with high refractive index, such as silicon, light can be confined into ultra-small volumes, producing extremely high local field intensities. If these materials also exhibit an optical non-linearity, i.e. their susceptibility\refractive index is a function of the strength of the optical field, then a wide array of devices can be designed. For example, ultra-fast photonic switches can be created that are triggered using optical pulses (i.e. without the need for electronics) with potential applications in optical signal processing. Non-linear processes can also create new wavelengths of light in a device, for example allowing a signal input at λ_1 to be broadcast on a wide range of new wavelengths, simply by propagating through a non-linear device. Finally, these devices can take a single laser wavelength input and, through self-phase modulation, generate a supercontinuum of light.

The effects of dispersion in non-linear waveguides are critical in the design of these devices. The refractive index as a function wavelength of nanowire waveguides exhibits a strong dependence on the waveguide geometry. The dispersion induced by the waveguide in turn induces variation in the non-linear optical processes in the waveguide. In order to achieve efficient operation, a balance must be achieved between increasing the field intensity by reducing the waveguide cross sectional area and finding the optimal waveguide dispersion regime.

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

Key Reference (if applicable):

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

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

Suitability: MPhys, BSc

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

Safety Training Requirements: *N/A*

Receiving Information from Smart Illumination

Project Supervisor (1) Dr. Johannes Herrnsdorf, (2) Dr. Michael Strain

Project Description:

Illumination is classically done with a simple lamp that shines light more or less uniformly onto the illuminated area. For a range of applications, particularly in imaging and smart lighting, it is beneficial if instead of uniform illumination, the scene is lit by a temporal sequence of cleverly chosen patterns. A detector that monitors the intensity corresponding to each pattern can then extract information (e.g. position) that would be difficult to obtain under uniform illumination. Here, we use computer-controlled light-emitting diode (LED) arrays to provide the patterned illumination. These can in principle be operated at MHz rates and serve multiple functions, e.g. positioning of devices in the illuminated area through patterned illumination and wireless data transfer to these devices.

Different pattern sequences can be chosen according to desired key properties such as fast recognition, error detection or an option of coarse/fine detection. To take full advantage of a specific pattern sequence, a dedicated decoding algorithm needs to be implemented. This requires understanding of the underlying physical properties of the illumination-receiver system as well as the mathematical properties of the pattern sequence.

In this project the student will implement decoding algorithms for pattern sequences displayed by a 16×16 LED array. This work will underpin the development of smart LED-based systems with widespread applications. The student will write the software code for decoding and then apply it in an experimental setup.

Key Reference (if applicable):

1. *Zhang et al., 1.5 Gbit/s Multi-Channel Visible Light Communications Using CMOS-Controlled GaN-Based LEDs, J. Lightwave Technol.* ***31****, 1211 (2013)*
2. *A detailed documentation of the pattern sequences in question will be provided by the start of the project*

Ratio of effort: Exp/Theo/Comp

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

Suitability: MPhys, BSc

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

Safety Training Requirements: *Laser Safety Training*

Allocated Projects (Fifth Year students)

Project Name	*Supervisors*	*Student Name*
A Physical Investigation of Protein-drug Binding	Neil Hunt, Maxim Fedorov	ELAINE ADAIR
Spiral Bandwidth Control in Optical Parametric Oscillators	Alison Yao, Francesco Papoff	SAMUEL ANDERSON
Modelling laser-driven plasma expansion and ion acceleration dynamics	Paul McKenna, Ross Gray	ALAN BROWN
Computational modelling of X-ray Free electron Lasers	Brian McNeil, Kevin Ronald	MATTHEW BROWN
Photonic materials and devices for Visible Light Communication (VLC)	Benoit Guilhabert, Nicolas Laurand	MARK CARMICHAEL
Ghost imaging and the Klyshko approach	John Jeffers, Marco Piani	LEON CHAN
Single-shot, 3D reconstruction of the spatial profile of a laser beam	Paul Griffin, Nigel Langford	MATTEO DEMELAS
Computational Modelling of Gaussian Beam Propagation in a Non Resonant Optical Cavity	Nigel Langford, Alison Yao	JAMES DENHOLM
Interaction of Spatial Optical Solitons	Gian-Luca Oppo, Thorsten Ackemann	PHILIP DOYLE
Uncovering the early stages of protein folding	Neil Hunt, Maxim Fedorov	ANDREW FARRELL
Dynamics of Coupled Laser Systems	Gian-Luca Oppo, Gordon Robb	CRAIG GORDON
Effect of Varying Structure on Efficiency of InGaN LEDs	Rob Martin, Jochen Bruckbauer	ANTHONY HOWLEY
Resonant Electron Beam-light Interactions	Brian McNeil, Gordon Robb	MARTYN HUNTER
Design study on plasma optics	Paul McKenna, Ross Gray	JONATHAN JARRETT
Statistical analysis of defect distributions in semiconductor thin films	Carol Trager-Cowan, Rob Martin	ROSS JOHNSTON
Medical Radio-isotope Production using a Laser-Plasma Wakefield Accelerator	Mark Wiggins, Bernhard Hidding	GEMMA KING
BEC simulations	Gordon Robb, Aidan Arnold	STEVEN LENNOX
Chirp management of LEDs (experimental and computational)	Nigel Langford, Alison Yao	GREGOR MCDOWALL
Laser Selective Excitation Studies of Nd3+ doped mixed garnets	Tom Han, Ben Hourahine	STACEY MITCHELL
Coherence measurements of X-rays from a plasma accelerator and tomographic imaging	Enrico Brunetti, Dino Jaroszynski	CRAIG MURDOCH
Spectroscopic Studies of Rare-earth ions doped in LiNbO3	Tom Han, Ben Hourahine	DAVID NEWTON
Laser Wakefield Acceleration and Betatron Gamma Ray Radiation	Ranaul Islam, Zheng-Ming Sheng	ADAM ROSS
Quantifying quantum steering via semidefinite programming	Marco Piani, Daniel Oi	BENJAMIN ROSS
Noble Metal Quantum Dots	Yu Chen, Olaf Rolinski	CALLUM RUNCIMAN
Parametric difference resonance in lasers	Francesco Papoff	STEVEN RUSSELL
Computational modelling of X-ray Free electron Lasers	Brian McNeil, Kevin Ronald	SCOTT THOMAS
Dynamics of impurity atom coupled to a quantum gas	Andrew Daley, Suzanne McEndoo	KAREN WALLACE
Self-structuring and Optomechanics of Cold Atoms	Gian-Luca Oppo, Gordon Robb	MATHIAS WEISEN

Appendices

Safety induction training record for Undergraduate students undertaking project work

This form **MUST** be completed by student and supervisor and returned **before** student enters a laboratory and by 27th November 2015 at the **latest.**

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

N/A ❑

Others: ……………………………………………………………………

……………………………………………………………………………

2) I have attended the following safety training lectures:

Physics Laser Safety ❑ **N/A** ❑

Others: …………………………………………………………………..

……………………………………………………………………………

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

……………………………………………………………………………

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

…………………………………………………………………………..

…………………………………………………………………………..

5) I received an induction in the following techniques:

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

Others: …………………………………………………………………

…………………………………………………………………

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

Name (print): ....

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

Name (print) ....

Please return this completed form to Students Office, JA 8.31

Project allocation request form 2015/16

(To be returned by the student to Students Office JA 8.31 by 4pm 29/09/15)

Student Name: **Student Number:**

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

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

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

Note: where several allocation request forms are submitted for the same project, I will choose the successful student by lot.

Projects allocated will be announced on Thursday 1st October 2015 – *Daniel Oi*

Project Timetables

PH450

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

14th September 2015 Project booklet available to students

Students will receive project handbook with project request page.

15th September – 29th September 2015 Students choose projects

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

4pm 29th September 2015 Deadline for submission of Project choice form to JA8.31

1st October 2015 Official start of Projects

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

16th October 2015 Literature review complete

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

27th November 2015 Completed safety form to be returned to JA 8.31 by this date

18th January 2016 Progress report with aims of project to be returned by students to JA 8.31 by this date

23rd March & 30th March 2016 Project Talks 1-5 pm in parallel Sessions

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

25th April 2016 Project reports submitted

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

Week beginning 23rd May 2016 Viva week

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

Project Information for Continuing 5th Year Students

PH 550

Taken in 5th year by MPhys Physics students. The expectation is that students will continue with the project started in 4th year.

Week beginning 21st September 2015 Meeting with supervisor during Week 1

23rd October 2015 Progress report to be returned by students to JA 8.31 by this date

2nd December 2015 Project Talks 1-5 pm in parallel sessions

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

14th December 2015 Deadline for draft project paper to supervisor for feedback before 21st December 2015

8th January 2016 Project papers submitted

Project papers to be submitted as PDF format through MyPlace and then passed through Turnitin for plagiarism detection.

The final report for PH550 is a paper in the format of Physical Review Letters (see MyPlace for examples):

- 1 page title sheet, 4 pages for the paper and references
- Prof O'Donnell wrote in answer to one student struggling to keep the paper within the 4 page limit, *"part of the challenge of paper-writing is to develop your (self-) critical facility. The task of preparing work for publication is not so much one of condensation as of selection. You don't have to include everything that you did in the project, in fact, you will probably need to leave something out."*
- Instead reference as much as you can. By all means have a longer version of the report for yourselves, for example, with full derivations, for the viva, but this is not what the supervisor and examiners will mark.

Paper writing will form part of the PH551 Research Skills class

Week beginning 18th January 2016 Vivas

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

Plagiarism

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

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

Index of Project Titles