DEPARTMENT OF PHYSICS

Undergraduate Research Projects

2012/13

Table of Contents

Health and Safety

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

16.4 Supervision of Students

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

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

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

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

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

With thanks,

Mr Ron Weston

NOTE: Laser safety training will be delivered on 10^{th} October 2012 (time and venue to be confirmed)

NANOSCIENCE DIVISION

Predicting Solvation Thermodynamics of Bioactive Molecules

Project Supervisors: (1) Prof. Maxim V. Fedorov, (2) Dr Neil Hunt & Dr David S. 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: **PH450 MPhys**
12 521 MSci Bio

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.

In the current project we 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 envirnments: (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: Plenum (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:	**PH450 MPhys BSc**
	12 521 MSci Bio

Additional comments: *Suitable for students at all levels 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*

Effects of Salts (Inorganic, Organic and Ionic Liquids) on Stabilization and Bundle Formation of Carbon Nanotubes in Liquid Dispersions

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

Project Description:

The main focus of the proposed project is the effects of different additives (room-temperature ionic liquids (RTILs), inorganic salt) on the mechanisms of carbon nanotube (CNT) bundle formation in their liquid dispersions in different organic solvents (N-methyl-2-pyrrolidone, 1-octyl-2-pyrrolidone, 1-vinyl-2-pyrrolidinone).

Despite rapid progress in the area of solvent engineering for carbon nanotubes and other carbon nanomaterial (e.g. graphene) dispersions, the main physical-chemical mechanisms of solvent effects on CNTs have not been sufficiently explored. Even less studied have been the effects of other solution/dispersion components, such as salts and co-solvents.

We will add different amounts of salt additives to prepared carbon nanotube dispersions to investigate their effects on the stability of the dispersions and on the mechanisms of bundle formation of CNTs. We will monitor the changes in the CNT dispersions by optical absorption spectroscopy as well as by visual inspection of the samples. That will allow us to make quantitative analysis of the changes in the dispersions upon additions of different salts.

This research will generate a fundamental knowledge for development of next generation nanocarbon-based electronics and sensors tools. The project should be also important for environmental sciences, because to estimate the potential environmental risks of modern nanotechnologies we need to understand the basic mechanisms of interactions between nanoobjects and liquid environments. In addition, the results of the project can be used for several energy applications, such as nanoporous electrochemical supercapacitors. The project is a part of an ongoing collaboration with the Brookhaven National Laboratory (BNL) in the USA and there are opportunities for the project students to participate in the research visit exchange program between BNL and our University.

Key References:
Carbon Nanotubes and Related Structures: New Materials for the Twenty-first Century by Peter J. F. Harris; Carbon Nanotube and Graphene Device Physics by H.-S. Philip Wong and Deji Akinwande; Molecular mechanisms of salt effects on carbon nanotube dispersions in an organic solvent (N-methyl-2-pyrrolidone) by Frolov, A. I., Arif, R. N., Kolar, M., Romanova, A. O., Fedorov, M. V. & Rozhin, A. G. 2012 In : Chemical Science. 3, 2, p. 541-548. 8 p.

Ratio of effort: Exp/Theo/Comp	**Exp:**	**up to 100%**
	Theo:	**up to 20%**
	Comp:	**0-20%**

Suitability: **PH450 MPhys BSc**
12 521 MSci Bio

Additional comments: *Suitable for students at all levels with good experimental skills and an interest in nanotechnology. The student will get experience in modern state-of-the-art tools of nanofabrication and experimental spectroscopy applications in nanotechnology.*
Safety Training Requirements: *Spectroscopy Lab Safety Training*

Effects of Alcohols on Stabilization and Bundle Formation of Carbon Nanotubes in Aqueous Dispersions Stabilized by Surfactants

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

Project Description:

The main focus of the proposed project is the effects of different alcohols on the stability on the mechanisms of carbon nanotube (CNT) bundle formation in their aqueos dispersions in water stabilised by different conventional surfactans (SDS, SDBS, Triton-X and and polyvinylpyrrolidon

Carbon nanotubes (CNTs) as well as other carbon nanomaterials (e.g. graphene) are attractive in biological and medical applications for imaging purposes and in photonics and optoelectronics due to their linear and non-linear optical properties. However, their incorporation into the liquid or 'soft matter' biological environments is a challenging task because as a rule, nanoparticles are difficult to solubilise in the most commonly used solvents (e.g. water).

Different surfactants are actively used for non-covalent functionalisation of nanoparticles to make them soluble in water. However, despite the fact that most biological processes take place in complex aqueous solutions, the role of solvent conditions (in particular, addition of alcohols) on the formation of nanoassemblies is far from being understood.

We will add different amounts of various alcohols (from ethanol to octanol) to prepared carbon nanotube dispersions to investigate their effects on the stability of the dispersions and on the mechanisms of bundle formation of CNTs. We will monitor the changes in the CNT dispersions by optical absorption spectroscopy as well as by visual inspection of the samples. That will allow us to make quantitative analysis of the changes in the dispersions upon additions of alcohol co-solvent.

This research will generate a fundamental knowledge for the development of next generation bio-sensing and medical diagnostic tools. The project should also be important for environmental sciences, because to estimate the potential environmental risks of modern nanotechnologies we need to understand the basic mechanisms of interactions between nano-objects and biological aqueous environments. The project is a part of an ongoing collaboration with the Brookhaven National Laboratory (BNL) in the USA and there are opportunities for the project students to participate in the research exchange visit program between BNL and our University.

Key References:

Carbon Nanotubes and Related Structures: New Materials for the Twenty-first Century by Peter J. F. Harris;
Carbon Nanotube and Graphene Device Physics by H.-S. Philip Wong and Deji Akinwande;

Ratio of effort: Exp/Theo/Comp		**Exp:**	**up to 100%**
		Theo:	**up to 20%**
		Comp:	**0-20%**
Suitability:	**PH450 MPhys BSc**		
	12 521 MSci Bio		

Additional comments: *Suitable for students at all levels with good experimental skills and an interest in bionanotechnology. The student will get experience in modern state-of-the-art tools of nanofabrication and experimental spectroscopy applications in nanotechnology.*

Safety Training Requirements: *Spectroscopy Lab Safety Training*

Biodegradable Choline-based Surfactants for Improving Stability of Carbon Nanoparticle Dispersions in Water

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

Project Description:

The main focus of the proposed project is the development of new environmentally-friendly methods for stabilising aqueous dispersions of carbon nanoparticles in water.

Carbon nanotubes (CNTs) as well as other carbon nanomaterials (e.g. graphene) are attractive in biological and medical applications for imaging purposes and in photonics and optoelectronics due to their linear and non-linear optical properties. However, their incorporation into the liquid or 'soft matter' *biological* environments is a challenging task because as a rule, (i) nanoparticles are difficult to solubilise in water; (ii) most of conventional stabilising agents (surfactants like SDS, SDBS, Triton-X) are not very environmentally and biologically friendly (toxicity, allergic reactions etc).

In this project we well study effects of new biodegradable and biocompatible choline-based surfactants (actually choline is one of the B-vitamins!). We will add different amounts of various choline-based surfactants to prepared carbon nanotube dispersions to investigate their effects on the stability of the dispersions and on the mechanisms of bundle formation of CNTs. We will monitor the changes in the CNT dispersions by optical absorption spectroscopy as well as by visual inspection of the samples. That will allow us to make quantitative analysis of the changes in the dispersions upon additions of alcohol co-solvent.

This research should lead to development of new generation of biocompatible and biodegradable dispersing agents for making nanoparticle applications in biomedicine areas. The project should also be important for environments, because the new biodegradable dispersing agents should dramatically reduce potential environmental risks of nanocarbon-based technologies. The project is a part of an ongoing collaboration with the Brookhaven National Laboratory (BNL) in the USA and there are opportunities for the project students to participate in the research exchange visit program between BNL and our University.

Key References:

Carbon Nanotubes and Related Structures: New Materials for the Twenty-first Century by Peter J. F. Harris; Carbon Nanotube and Graphene Device Physics by H.-S. Philip Wong and Deji Akinwande; Dispersion of Carbon Nanotubes: Mixing, Sonication,Stabilization, and Composite Properties by Yan Yan Huang and Eugene M. Terentjev In: Polymers 2012, 4, 275-295; doi:10.3390/polym4010275.

Ratio of effort: Exp/Theo/Comp	**Exp:**	**up to 100%**
	Theo:	**up to 20%**
	Comp:	**0-20%**

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments: *Suitable for students at all levels with good experimental skills and an interest in bionanotechnology. The student will get experience in modern state-of-the-art tools of nanofabrication and experimental spectroscopy applications in nanotechnology.*

Safety Training Requirements: *Spectroscopy Lab Safety Training*

Modifying Melanin's Structure

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

Project Description:

Melanin is a ubiquitous pigment that occurs in the eye, the brain, hair and skin. Melanin has an interesting combination of properties (1). It is probably best known for its broad spectral absorption that gives skin its optical protective properties, but it also is conductive, photo-conductive and binds metal ions readily. Despite widespread investigation over decades, somewhat surprisingly, the structure of melanin is still under debate. However, recent work in the Photophysics Group (see the Herald 13th August 2012) has found new evidence that melanin has a sheet structure like graphite and is formed from a pre-fabricated protomolecule (2). The structure of melanin has direct bearing on melanoma, the most virulent form of skin cancer as until the structure is known the causes and therapeutics for melanoma are difficult to study. Although the structure is unknown the project will seek to determine what influences melanin's optical properties in terms of changes in absorption and fluorescence spectra and how these are linked to structural changes. The structural effect of metal ions, salts, pH, temperature etc will be studied as melanin is synthesized. By understanding how melanin self-assembles new forms and exotic structures such as fibrils might also be produced (3) and lead to new materials for applications in such as photonics and sun-screens.

An interest in biology, its relationship to healthcare and optical techniques are required.

Key Reference (if applicable): (1) *The physical and chemical properties of eumelanin*, P

Meredith and T Sarna, *Pigm. Cell Res.*, 19, 572-594, 2006.

(2) *Eumelanin Kinetics and Sheet Structure*, J Sutter, T Bidláková, J Karolin and D J S Birch. App. Phys. Letts., 100, 113701 (4 pages), 2012.
(3) *Eumelanin fibrils.* R McQueenie, J Sutter, J Karolin and D J S Birch. J. Biomed. Optics. 17, 075001 (7 pages), 2012.

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys
12 521 MSci Bio

Safety Training Requirements: Chemical handling.

Energy Transfer as a Nanoscale Ruler

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

Project Description:

Forster resonance energy transfer (FRET) has served as a molecular ruler, commonly used for biological research to measure molecular distance and report conformational changes, based on the 6th order dependence of energy transfer rate on the separation of a donor and an acceptor. However, FRET technique is restricted to the upper limit of separation of only 8nm, as the energy transfer becomes too weak beyond this distance. Recent study on the energy transfer between dye molecules and metallic nanoparticles shows the possibility of extending the upper limit. This project intends to investigate the energy transfer mechanism and to understand the energy transfer from dye to metallic nanoparticle in order to exploit this process as a ruler for quantitative measurement of nanodistance.

Key Reference (if applicable): *T. Sen et al, Appl. Phys. Lett, 91, 043104 (2007)*

Ratio of Experiment/Theory/Computation:

Exp:	80 %
Theo:	10 %
Comp:	10 %

Suitable for : PH450 *MPhys and BSc*

Safety Training Requirements: Contact the project Supervisor for further advice

Optical Properties of Nanoparticles

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

Project Description:

Noble metal nanoparticles have great potentials for applications in biochemical sensing, medical diagnostics and therapeutics, as well as biological imaging due to their unique optical properties originating from the excitation of local surface plasmon resonance. In particular, gold nanoparticles, have attracted intensive interests because they are low toxic, photostable, and can be attached, readily, to molecules of biological interest.

The aim of this project is to investigate the optical properties of gold nanoparticles of different geometries and the environmental influence on their optical properties. Student will have an opportunity to become familiar with some aspects of nanotechnology and gain hands-on experience in using optical absorption spectroscopy as well as the state-of-the-art scanning near field optical microscope.

Reference: Relevant papers will be provided

Ratio of Experiment/Theory/Computation:	Exp:	80 %
	Theo:	10 %
	Comp:	10 %

Suitable for: PH450 *MPhys and BSc*

Safety Training Requirements: Contact the project Supervisor for further advice

Fabricating Amyloid Functional Materials for Artificial Photosynthesis

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

Project Description:

Propensity of certain peptides and proteins to self-assemble into oligomers and fibrils (amyloids) that are rich in β-sheet secondary structure first received attention through its association with diseases related to protein misfolding, including neurodegenerative disorders, like Alzheimer's and Parkinson's diseases. However, amyloid materials have also been used for functional purposes over millions of years of evolution by organisms ranging from bacteria to mammals. Moreover, a range of peptides and protein have been observed to self-assemble in certain conditions *in vitro*, paving the way to manufacturing the artificial functional nanomaterials.

The proposed project includes monitoring and control of self-assembling of amyloids to fabricate the light-harvesting functional materials for artificial photosynthesis.

The role of such a material is to transform the broad energetic spectrum of the sunlight into a possibly narrow band that can be efficiently converted into electricity by a solar cell. The molecular mechanism to execute such transformation will be fluorescence resonance energy transfer (FRET) between two organic molecules, donor (D) and acceptor (A). The photon of higher energy, that cannot be exploited by the solar cell directly, will be absorbed by D, its excitation energy transferred via FRET to A, and A will emit the photon of fluorescence of the lowered energy, suitable for the solar cell response. Fabricating the amyloid light-harvesting materials will be based on triggering self-assembly of the dye-labelled beta-amyloids in controlled conditions.

Key Reference (if applicable): Relevant research papers will be provided

Ratio of Experiment/Theory/Computation:	Exp:	80 %
	Theo:	10 %
	Comp:	10 %

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments: Project is a part of the current research of the Photophysics Group

Safety Training Requirements: Laser safety training

Intrinsic Fluorophores in Sensing Applications

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

Project Description:

Fluorescent aminoacids, tryptophan (Trp), tyrosine (Tyr) and phenylalanine (Phe) occur in most proteins and are involved in a large number of bioactivities. Their fluorescence responses, usually altered by this activity or an analyte, provide valuable information on the events occurring in nanometre scale. For example, binding ligands to proteins is usually reflected by shifts in the absorption and fluorescence spectra, changes in quantum yield and alterations in fluorescence decay kinetics.

The aim of the project is to investigate the spectroscopic properties of the number of dyes, including fluorescent aminoacids, and determine their excited-state kinetics. Student will have an opportunity to become familiar with some aspects of photophysics, sensing, fluorescence, time-resolved spectroscopy and state-of-the-art SNOM instrumentation.

Reference: http://www.photobiology.info/Visser-Rolinski.html
Relevant research papers will be provided

Ratio of Experiment/Theory/Computation:
Exp: 80 %
Theo: 10 %
Comp: 10 %

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional Comments: Project is a part of the current research of the Photophysics Group

Safety Training Requirements: Laser Safety Training

Ocean Colour Radiometry – Data Processing and Image Interpretation

Project Supervisors: (1) Prof. Alex Cunningham, (2) Dr David McKee

Project Description:

Remote sensing using data from polar-orbiting satellites offers the only practical means of obtaining synoptic information on patterns of spatial and temporal variability in the marine environment.

This project involves the acquisition of ocean colour data via the NASA Goddard Data archive, the processing of this data to produce atmospherically corrected imagery using the SeaDAS data processing software, and the interpretation of these images to give insights into physical and biological interactions in shelf seas.

Key Reference (if applicable): http://oceancolor.gsfc.nasa.gov/

Ratio of Experiment/Theory/Computation:

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

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments: The student needs to assimilate a lot of background material in oceanography, marine optics and satellite image processing.

Safety Training Requirements: None

Quantitative Hyperspectral Beam Attenuation Meter.

Project Supervisors: (1) Dr David McKee, (2) Prof. Alex Cunningham

Project Description:

Light beams propagating through coloured particle suspensions experience absorption, *a*, and scattering, *b*. In the ocean scattering is generally heavily weighted towards forward angles. Transmissometers are commonly used to measure beam attenuation, *c=a+b*. However these measurements are adversely affected by forward scattering owing to the difficulty of separating light scattered at very narrow angles from the undeflected beam . We want to design and construct a new hyperspectral transmissometer with minimised scattering collection angle that will be used to validate a recently published scattering correction method for commercially available instruments. The instrument will employ a new supercontinuum laser system and a state of the art CCD spectrometer to give precise measurements across the entire visible spectrum. The project will involve optical design, experiment fabrication and statistical data analysis.

Key Reference (if applicable): McKee et al. Scattering error corrections for in situ absorption and attenuation measurements. Optics Express 2008 Vol. 16, No. 24 19480-19492

Ratio of effort: Exp/Theo/Comp:		
	Exp:	60%
	Theo:	20%
	Comp:	20%

Suitability: **PH450 MPhys BSc**
12 521 MSci Bio

Additional comments: Basic programming skills would help, but could be developed during the project.

Safety Training Requirements: Laser Safety Training essential

Design, Modelling and Interfacing of a 3rd-yr Undergraduate Experiment: Coupled Harmonic Oscillators

Project Supervisors: (1) Dr T.P.J. Han, (2): Prof. K.P. O'Donnell

Project Description:

The aim of this project is to examine a coupled oscillator system and develop it for a 3rd-yr. undergraduate teaching experiment. The motion of a single, 2-coupled and 3-coupled identical pendulums will be studied. The student will interface the experiment to a computer and also use computational method to model the oscillators and compare with the experimental observation.

Key Reference (if applicable):

Ratio of effort: Exp/Theo/Comp:	Exp:	80%
	Theo:	7%
	Comp:	13%

Suitability: **PH450 BSc**

Additional comments:

This project requires experimental skills in both electronics and computational techniques and student choosing this project should have a good understanding of his/her 1st and 2nd yr. Physics and comfortable with Matlab or equivalent.

Safety Training Requirements: General laboratory safety.

Optical Properties of ZnO Powder Doped with Lanthanide and Transition-metal Ions

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

Project Description:

Due to its wide bandgap and large exciton-binding energy, ZnO has attractive properties for optoelectronics applications. This project proposed to look at the optical properties of ZnO prepared by solid state reaction route, incorporation of lanthanide and transition-metal ions, effect of charge compensation, surface and internal effects and also intrinsic defect studies. Experimental techniques such as optical absorption, laser spectroscopy and fluorescence decaytime measurements will be used to characterised the materials. If time permits, energy transfer will also be investigated.

Key Reference (if applicable):

W.M. Jadwisienczak, H.J. Lozykowski, A. Xu, B. Patel, Journal of Electronic Materials, 31, #7, (2002) 776.

Ratio of effort: Exp/Theo/Comp

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

Suitability: **PH450 MPhys BSc**

Additional comments:

This is a relatively speculative project where positive results may be difficult to obtain but other researchers have shown promising results. The student should be interested in experimental work and will be working with lasers and chemicals.

Safety Training Requirements: General laboratory and Laser safety.

Photo-thermal Measurements of Optical Absorption

Project Supervisors: (1) Dr T. Han, (2) Dr N. Lockerbie

Project Description:

Photo-thermal measurements can potentially provide a higher sensitivity than traditional transmission measurements because rather than observing small changes in a large quantity, absorption-induced heating is detected directly. This project involves the development, construction and characterization of a sensitive thermistor-based thermal detector and then applying it to the photon-thermal measurements of the optical absorption of single crystals doped with various lanthanide or transition-metal ions. If time permits, one could also investigate the partition of non-radiative and radiative processes by combining these results with photo-excitation measurements.

Key Reference:

Ratio of Experiment/Theory/Computation:

Exp:	90 %
Theo:	7 %
Comp:	3 %

Suitability: PH450 MPhys BSc

Additional comments: This project requires experimental skills in both electronics and spectroscopic techniques and student(s) choosing this project should have a good understanding of his/her 3rd yr Solid State Physics.

Safety Training Requirements: General Laboratory and Laser safety.

A Pedagogy Study of the Effectiveness of Hands-on, Simulated and Remote Access of Laboratory Learning

Project Supervisors: (1) Dr T.P.J. Han, (2) Dr I.S. Ruddock

Project Description:

Laboratory-based courses play a critical role in scientific education. The use of computers and multimedia, as well as the world-wide-web and new communication technologies, allows new forms of teaching and instructional processes especially in areas such as distance learning, blended learning, use of virtual libraries and simulations. The development of remote laboratories making use of the widespread availability of local area networks (LAN) and web access to provide students with web-based access to real laboratory experiments gives students hands-on experience with direct control over instruments and devices. It is the intention of this project i) to analyse and implement a remote laboratory using only non-proprietary software. Lack of any standards (for example, computer interface, website-control software interface etc.) leads to many individual solutions, and therefore to unnecessary hurdles for hosts and users. The focus here is more on the technical problems (for example, client–server communication, server architecture and programming, data transmission) and to access the required skill, efforts and financial resources needed to implement and in particular to maintain a remote laboratory; and ii) to compare and contrast the three methods against a common set of aims and outcome. The effectiveness of each method can then be evaluated by considering the students' learning experiences and outcomes from a pedagogical perspective.

Key Reference (if applicable):

Ratio of effort: Exp/Theo/Comp	**Exp:**	**45%**
	Theo:	**5%**
	Comp:	**50%**

Suitability: **PH450 MPhys BSc**
12 521 MSci Bio

Additional comments:
This project requires experimental skills in both electronics and computing. Student(s) choosing this project should enjoy computing and interfacing/control computer to the 'real' world.

Safety Training Requirements: None

A Physical Investigation of Protein-drug Binding

Project Supervisors: (1) Dr N. Hunt, (2) Dr P. Hoskisson (SIPBS)

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: PH450 MPhys
12 521 MSci Bio

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

Safety Training Requirements: Laser and Chemical Safety

The Physics of DNA

Project Supervisors: (1) Dr N. Hunt, (2) Drs K. Adamczyk (Physics), G. Burley (Pure and Applied Chemistry)

Project Description:

This project will use physical methods such as infrared spectroscopy and 2D-IR spectroscopy to investigate the binding interactions of DNA molecules in solution. The DNA molecule is central to biology but the physical details of the hydrogen bonding interactions that are fundamental to processes such as Watson-Crick base pairing or DNA binding to proteins are not well understood. In this project we will use infrared spectroscopy to determine useful infrared probe signatures for DNA and apply this to studies of processes such as thermal melting of DNA duplexes and investigations of DNA binding to species such as polyamides that find applications in DNA-based nanomaterials. If time allows we will apply new ultrafast 2D-IR spectroscopic methods to investigate the dynamics of these processes in real time.

The project lies at the boundary between physics, chemistry 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): 'DNA-templated photonic arrays and assemblies: Design principles and future opportunities' Su, W., Bonnard, V., Burley, G.A. Chem Eur J 2011, 17, 7982
'2D-IR spectroscopy: ultrafast insights into biomolecule structure and function' Hunt, N. T. *Chem Soc Rev* 2009, 38, 1837-1848,

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

Suitability: PH450 MPhys
12 521 MSci Bio

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

Safety Training Requirements: Laser and Chemical Safety

Renormalization of Alloys

Project Supervisors: (1) Dr Ben Hourahine, (2) Prof. Gian-Luca Oppo

Project Description:

One of the major breakthroughs in statistical physics during the 20th century was the development of renormalization group methods (based on concepts first used in particle physics). The main idea of this approach is that interactions between particles on a given scale (say subatomic particles) lead to effective interactions on a larger scales (nuclear physics) which in turn give rise to effective interaction on still longer scales (atomic structure) and in turn even longer scales (solids), etc... In each case the effective interactions on a given scale doesn't require detailed knowledge of the scale below (or the effective levels above). This family of methods is the best way to understand many processes such as phase transitions, where there are simultaneous effects on many length scales, but also can produce coarse-grain models on large scales. However, these techniques are often applied to model systems (see the reference for a discussion about the Ising model). In this project we will investigate the feasibility of applying the Kadanoff method to study an alloy material, looking for evidence of phase transitions.

Key Reference: Chapter 5 (section 5.5) of "Principles of condensed matter physics" by Chaikin and Lubensky in the library (D 530.41 CHA)

Ratio of Experiment/Theory/Computation: Exp: 0 %
Theo: 40 %
Comp: 60 %

Suitability: PH4550 MPhys BSc

Additional comments: Interest or previous experience in programming would be an advantage

Safety Training Requirements: None

Understanding the Optics of Marine Diatoms

Project Supervisors: (1) Dr Ben Hourahine (2) Dr Francesco Papoff & Prof. Alex Cunningham

Project Description:

Diatoms are a group of common singled cell marine plants. Their cells are covered by a layer of amorphous silica, often of a complicated shape. It has been suggested that one reason for this layer is to act as an optical concentrator for light to increase the efficiency of photosynthesis. However this idea remains unproven, and several alternative possible functions for this layer have also been suggested.

In this project a recently developed method to simulate the optical properties of small particles will be applied to models of some of the simpler shapes of diatom. Initially, the structure will be modelled as an elliptical silica particle, calculating the light intensity and distribution inside of the particle for a range incident fields to simulate the surrounding optical conditions in the ocean. In the later stage of the project, a more realistic model containing an additional optically absorbing chloroplast will be considered.

Reference: K. Holms, B. Hourahine, F. Papoff, `Calculation of internal and scattered fields of axisymmetric nanoparticles at any point in space", Journ. Opt A, 11, 054009 (2009)

Ratio of Experiment/Theory/Computation:	Exp:	5 %
	Theo:	35 %
	Comp:	60 %

Suitable for: PH450 MPhys and BSc

Safety Training Requirements: None

Characterisation of Bulk and Thin film Semiconductor Layers for Solar Cells

Project Supervisors: (1): Prof. Robert Martin, (2) Dr Michael Yakushev

Project Description:

To be efficient thin-film solar cells require an absorber layer with a high optical absorption coefficient and a band-gap near 1.5 eV to match the solar spectrum. The semiconductor compound Copper Indium Gallium Diselenide (CIGS), alloying $CuInSe_2$ and $CuGaSe_2$, satisfies these criteria very well. CIGS-based thin film solar cells hold the record conversion efficiency, of over 20%, amongst thin film single junction photovoltaic devices. This project is an optical spectroscopy study of the least understood component of CIGS, namely $CuGaSe_2$, with possible extension to the related material $CuInTe_2$. Recent work in our group has determined important fundamental parameters of the electronic structure of $CuGaSe_2$ by study of single crystals of this material (see key reference) and this project will extend the work by investigating thin films of $CuGaSe_2$ and $CuInTe_2$ crystals. The layers will be investigated by photoluminescence (PL) and reflectivity. Dependencies of the PL spectra on the power of the exciting laser and on the sample temperature will help to understand the nature of the observed PL. Scanning electron microscopy, combined with microprobe analysis will be used to image the surfaces and map the elemental composition using X-ray fluorescence induced by the electron beam. The aim of the project is to better understand the optical and electronic properties of $CuGaSe_2$ and $CuInTe_2$, exploring similarities and differences of the single crystals and thin films.

Key Reference (if applicable): "Diamagnetic shift of the A free exciton in CuGaSe2 single crystals" by F. Luckert et al. in Applied Physics Letters vol 97, 162101 (2010)

T. Mise, T. Nakada, Low Temperature Growth of Cu-Deficient CuInTe2 Thin Films for Narrow Bandgap Solar Cells, Proceedings of 24th European Photovoltaic Solar Energy Conference, 21-25 September 2009, Hamburg, Germany, p. 3062 - 3065

Ratio of effort: Exp/Theo/Comp

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

Suitability: **PH450 MPhys BSc**

Safety Training Requirements: Laser safety training required

Modelling the Interaction of Electron Beams with Semiconductor Devices

Project Supervisors: (1) Prof. R. W. Martin, (2) Dr P. R. Edwards

Project Description:

When a semiconductor is irradiated with a beam of high energy electrons, electrons/hole pairs are generated in the material. This injection of excess carriers forms the basis of several scanning electron microscope (SEM) based characterisation techniques, such as cathodoluminescence and electron beam-induced current measurements. While this carrier generation can be readily simulated using existing Monte Carlo code, modelling the steady-state carrier concentrations requires the subsequent movement of carriers to be considered. This project will build on partly-developed code which uses finite difference methods to solve the carrier transport and Poisson's equations. The results will be used to determine the threshold for high-injection conditions in semiconductor samples, and to predict the spatial resolution of the SEM techniques in different materials. Comparison will be made with experimental SEM measurements, and the modelling will be extended beyond bulk semiconductors to simulate more complex device structures such as the *p-n* junctions and quantum wells found in LEDs.

Key Reference (if applicable): "Introduction to Semiconductor Device Modelling",

C. M. Snowdon (World Scientific Publishing, 1987)

Ratio of effort: Exp/Theo/Comp:

Exp:	20	%
Theo:		%
Comp:	80	%

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments: The student should be an enthusiastic programmer, with knowledge of MATLAB.

Safety Training Requirements:

Inter and Intra-band Spectroscopy of GaN Quantum Dots

Project Supervisors: (1) Prof. Kevin O'Donnell, (2) Prof. Rob Martin

Project Description:

GaN (gallium nitride) is a material that forms the basis for a new generation of solid-state lighting and UV-visible laser technologies. By isolating a "quantum dot" (QD) of GaN within a matrix of larger-bandgap semiconductor (for example (AlN) it is possible to modify the band structure in interesting ways, through (1) the reduction of dimensionality from 3D to 0D, and (2) the operation of the quantum size effect, which generally increases electronic energies in confined surroundings. This project will undertake a detailed spectroscopic study of silicon-doped GaN QD with particular attention to comparing inter-band electronic transitions (from conduction band to valence band) with intra-band transitions (between quantum-confined levels in the conduction band). In particular we will attempt the first demonstration of optical double resonance in the AlN/GaN materials system.

Key Reference (if applicable): A general introduction to QD can be found in the library: Semiconductor and metal nanocrystals Nanocrystal quantum dots, Victor I Klimov, 2nd ed. Boca Raton : Taylor & Francis 2010

Ratio of Experiment/Theory/Computation: Exp: 60 %
Theo: 20 %
Comp: 20 %

Suitability: PH450 MPhys BSc
12 521 MSci

Additional comments: Potential students should be familiar with Band Theory and be registered for 12.423 Semiconductor Physics and Devices.

Safety Training Requirements: Laser safety training required.

Luminescence Hysteresis

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

Project Description:

The Semiconductor Spectroscopy group recently discovered luminescence hysteresis in the optical spectra of europium-doped GaN. We are currently investigating this new phenomenon with a view to elaborating a tentative explanation of it, in the area of solid state defect physics, as described in the Key (and only!) Reference below.

Hysteresis is generally a consequence of *path dependence* in physical processes. In the present case, the luminescence spectrum of Eu-doped p-type GaN at a given temperature depends upon the sample's thermal history. The measured spectrum will be different, for example, if the sample is cooled from room temperature to the measuring point or warmed from low temperature to that point.

The project will examine the dynamics of the process leading to hysteresis in this case, using a fast CCD camera to acquire luminescence spectra as a function of sample history. For this we will need to collect and analyse quite a lot of data, providing an excellent opportunity for a student who are is attracted by laboratory work and is good with computers, used in particular for data handling and reduction

Key Reference (if applicable): "Temperature-Dependent Hysteresis of the Emission Spectrum of Eu-implanted, Mg-doped HVPE GaN" by K.P. O'Donnell et al.

Proceedings of the 31st International Conference on the Physics of Semiconductors. (Zurich, 2012)

Ratio of effort (Exp/Theo/Comp):

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

Suitability: PH450 MPhys BSc

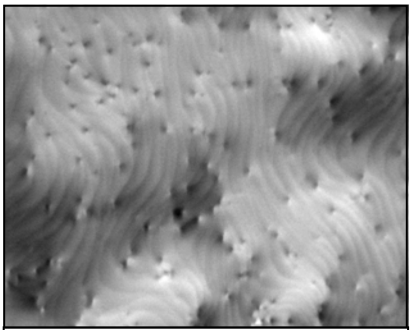
Additional comments:

Safety Training Requirements: some laser spectroscopy may be required.

Nanoscale Characterisation of Nitride Semiconductors using Electron Channelling Contrast Imaging

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

Project Description:



ECC image from GaN

Today's scanning electron microscopes allow the properties of materials and devices to be interrogated on the nanoscale. The technique of electron channelling contrast imaging (ECCI), in the scanning electron microscope, can reveal defects such as dislocations in nitride semiconductor thin films (i.e., the "black spots" in the image opposite). Nitride-based optoelectronic devices are commercially available, e.g., UV/blue laser diodes, UV/visible LEDs and white LEDs; however, the presence of dislocations can limit the performance of these devices. Here at Strathclyde, using an FEI Sirion scanning electron microscope; experiments, computer simulations of electron channelling contrast and image processing software are under development to understand the distribution of defects in nitride semiconductors. This project will involve the use of the scanning electron microscope to acquire electron channelling images and image analysis to analyse and extract information from the acquired images. There may also be the opportunity to combine ECCI with other imaging techniques such as hyperspectral cathodoluminescence imaging which is used to interrogate the optical properties of the material under study.

Reference: http://ssd.phys.strath.ac.uk/index.php/Electron_channeling_contrast_imaging
C. Trager-Cowan, F. Sweeney, P. W. Trimby, A. P. Day, A. Gholinia,, N. -H. Schmidt, P. J. Parbrook, A. J. Wilkinson and I. M. Watson, "Electron backscatter diffraction and electron channelling contrast imaging of tilt and dislocations in nitride thin films", Phys. Rev. B 75, 085301 (2007).

Ratio of Experiment/Theory/Computation:

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

Suitable for: PH450 MPhys and BSc. **NB Available to two students**

Safety Training Requirements: None

OPTICS DIVISION

Coherent Population Trapping in Atomic Vapours

Project Supervisors: (1) Prof. Erling Riis, (2) Dr Paul Griffin

Project Description:

Atomic clocks are the most accurate measurement tools we have. They are based on driving atomic transitions between closely spaced levels using a laser operating on two frequencies. When the frequency difference exactly matches the energy difference between the atomic levels there is a quantum mechanical interference, that means that the atoms are not excited and the transmission increases. We are going to study this and its application in atomic clocks and magnetometers.

Key Reference (if applicable):

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

Suitability: PH450 MPhys BSc

Additional comments: Challenging project suited for a student potentially interested in going on to do a PhD

Safety Training Requirements: Lasers, general

Historical Physics Equipment

Project Supervisors: (1) Prof. Erling Riis, (2) Prof. K.P. O'Donnell

Project Description:

There is a lot of old equipment around the department. It would be good to find out what the physics and history behind it are, how it works, who used it and for what, does it still work and can we make a nice display out of it.

An outcome of the project would be to prepare written material for displaying the equipment in renovated display cabinets in the Department.

Key Reference (if applicable):

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

Suitability: PH450 BSc

Additional comments:

This is a project suited for a student, who primarily is interested in history of science and science communication. **The project will only be available at level 4.**

Safety Training Requirements: General

Self-organized Patterns in Rb Vapour

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

Project Description:

Atoms are a well controlled nonlinear optical medium. We will be looking at the spontaneous emergence of spatial patterns (hexagons, squares) from homogeneous excitation of Rb vapour with two counterprogating pump beams. The project will set up an external-cavity laser system at the D1 and D2-lines and locking electronics for the nonlinear optical spectroscopy of Rb vapour. The laser will be used to investigate spatial self-organization effects due to the interplay of diffraction and nonlinearities in a hot Rb cell and explore effects of magnetic field, polarization and perturbation of the circular beam symmetry on patterns.

Key Reference (if applicable): Petrossian et al., Europ. Phys. Lett. 18,689 (1992); Arnold et al., Rev. Sci. Instr. 69, 1236 (1998); Ackemann and Lange, Appl. Phys. B 72, 21 (2001)

Ratio of effort Exp/Theo/Comp:

Exp:	75	%
Theo:	10	%
Comp:	15	%

Suitability: PH450 MPhys BSc

Additional comments: Student should also attend PH455, Topics in Photonics. The project demands the commitment to experimental work, in particular tedious and time demanding optical alignments, and to engage with Gaussian beam optics and basic electronics.

Safety Training Requirements: lasers

Polarization and Feedback Dynamics of VCSELs

Project Supervisors: (1) Dr Thorsten Ackemann, (2) Prof. Erling Riis

Project Description:

Vertical-cavity surface-emitting lasers (VCSELs) are a type of semiconductor laser with a very short cavity and a circular beam profile. Due to their nominal rotational symmetry, the polarization axis is only weakly pinned and polarization switching is common [1]. Due to the high nonlinearities of semiconductors, they can also show bistable emission with frequency-selective feedback [2], which might be interesting for all-optical information processing. These features were mainly investigated for quantum-well VCSELs at 850 nm [1.2]. VCSEL at telecommunication wavelengths are increasingly emerging. First investigations for quantum dot VCSELs indicate a quite different polarization switching behaviour [3]. The project will characterize the polarization properties and feedback dynamics of telecommunication VCSELs. Depending on the final availability of devices, focus will be on 1300 nm quantum dot VCSELs or 1550 nm quantum well VCSELs.

Key Reference: [1] Sondermann et al., IEEE J. Quantum Electron. 40, 97 (2004)
[2] Naumenko et al., Opt. Comm. 259, 823 (2006)
[3] Olejniczak et al. Opt. Exp. 19, 2476 (2011)

Ratio of effort: Exp/Theo/Comp

Exp:	75	%
Theo:	10	%
Comp:	15	%

Suitability: PH450 MPhys BSc

Additional comments: Student should also attend PH455, Topics in Photonics. The project demands the commitment to experimental work, in particular tedious and time demanding optical alignments, and to engage with Gaussian beam optics and basic electronics.

Safety Training Requirements: Laser

Bose-Einstein Condensate Experiments

Project Supervisors: (1) Dr Aidan Arnold, (2) Prof. Erling Riis

Project Description:

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 Reference (if applicable): [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 Experiment/Theory/Computation:	Exp:	70 %
	Theo:	20 %
	Comp:	10 %

Suitability: PH450 MPhys only

Safety Training Requirements: Laser Safety Training

Quantum Cascade Laser Sensing of Gaseous Isotopes

Project Supervisors: (1) Dr N. Langford, (2) Prof. G. Duxbury

Project Description:

This project will involve the use of a laser based optical spectrometer to detect and compare isotopologues of atmospheric trace gases such as nitrous oxide, N_2O.

The concentration of the isotopologues varies according to the locations in which nitrous oxide, methane or carbon dioxide are released. For example, very different concentrations could be measured in the Flow country, a very large boggy area in the north east of Scotland, than in areas where intensive farming is taking place, such as the NERC test farm near Edinburgh.

The project will involve training in the use of a laser based optical spectrometer. This will include training in spectrum acquisition, spectral analysis, and the intercomparison of the variation of the isotopologue concentrations in different molecules.

Key Reference (if applicable): RSC Tutorial (Chem Soc Review. 34, 921-934, 2005)

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

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments:

Safety Training Requirements: Laser safety training, gas handling training

Resonant and Non-resonant Optical Cavities

Project Supervisors: (1) Dr Nigel Langford, (2) Prof. Geoffrey Duxbury

Project Description:

Optical absorption is an effective way of detecting pollutants. Many key pollutants exhibit low absorption coefficients per unit length and an effective way to produce detectable signals is to have a long interaction length between the pollutant and the light. The simplest way is to allow the light to travel a long way through the sample but in many cases this is impractical. An alternative approach is to use an optical cavity. The aim of this project is to investigate the design of optical cavities that can produce effective long path lengths and look at the effect of controlling the light that enters the cavity. You will design and develop a computer program that will simulate and give a visual output of the optical path a beam of light will take around a cavity.

Reference: *Astigmatic mirror multipass absorption cells for long-path-length spectroscopy; J. B. McManus, P. L. Kebabian, and M. S. Zahniser APPLIED OPTICS, Vol. 34, p 3336, 1995*

Ratio of Experiment/Theory/Computation:

Exp:	10 %
Theo:	10 %
Comp:	80 %

Suitable for: PH4550 *BSc*

Additional Comments: *An interest in programming.*

Safety Training Requirements*:*

Helical Waves in Optical Cavities

Project Supervisors: (1) Prof. Gian-Luca Oppo, (2) Dr Alison M. Yao

Project Description:

Spatial patterns are ubiquitous features in broad-area optical and, more generally, complex systems outside of thermodynamic equilibrium [1]. A system that displays many of these features is the optical parametric oscillator where a crystal in an optical cavity generates twin photons under the action of an external pump [2]. When the frequency of the twin photons is the same, helical waves of peculiar shape can be generated [2]. Helical waves correspond to light beams with a phase surface in the shape of a corkscrew (or fusilli pasta) and intensity distributions with a hole in their centre. Recently, progress has been made in the superposition of helical wave states without a cavity (also known as orbital angular momentum states) [3]. This project investigates the formation of even more exotic and counter-intuitive light beams in optical cavities leading for example to fractional helical waves and complex ensembles of angular momenta states.

Numerical codes have already been developed in our research group [2,3] so that the project directly focuses on the theory and simulation of a variety of new helical waves with possible comparison with experimental results.

Key Reference (if applicable):

[1] 'Formation and control of Turing patterns and phase fronts in photonics and chemistry', G.-.L. Oppo, J. Math. Chem. **45**, 95 (2009)

[2] 'Spatial structures in parametric oscillators', G.-L. Oppo, A.J. Scroggie and W.J. Firth, Phys. Rev. E **63**, 066209 (2001)

[3] 'Angular momentum decomposition of entangled photons with an arbitrary pump', A.M. Yao, New J. Phys. **13,** 053048 (2011)

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys BSc

Additional comments: Excellent project. The "experimental" part is related to the understanding of experimental results and their comparison with numerical simulations.

Safety Training Requirements: None.

Interaction of Spatial Optical Solitons

Project Supervisors: (1) Prof. Gian-Luca Oppo, (2) Prof. William Firth

Project Description:

Spatial optical solitons are beams of light in which nonlinearity counter-balances diffraction, leading to a robust single-hump structure which propagates without change of form. In the case of light propagating through a medium, the simplest spatial soliton is due to self-focusing and Kerr nonlinearity, that is, a refractive index which changes in proportion to the intensity of the light. More general schemes can however support stable soliton-like solutions with lots of intriguing and new properties, if dissipation and driving and/or feedback are introduced. Among these, localized bright spots in driven-optical cavities have received a great deal of attention because of their experimental realisability in semiconductor lasers and potential applications in information processing. These are usually referred to as laser cavity solitons (LCS). In this project we study the interaction of two LCS belonging to separate families, one tall and narrow and the other one short and fat. This is a very peculiar situation that can arise in semiconductor lasers with saturable absorption and optical feedback. The numerical codes are already in operation and produce 2D and 3D movies of static and dynamic interactions.

Key Reference (if applicable): T. Ackemann, W.J. Firth and G-L Oppo, "Fundamentals and Applications of Spatial Dissipative Solitons", Adv. At. Mol. Opt. Phys. 57, 323 (2009)

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys BSc

Additional comments: The "experimental" part is related to the understanding of experimental results and their comparison with numerical simulations.

Safety Training Requirements: None.

Simulations of Spin-Polarized Vertical-Cavity Surface-Emitting Lasers

Project Supervisors: (1) Prof. Gian-Luca Oppo, (2) Dr Thorsten Ackemann

Project Description:

Spin-polarized vertical-cavity surface-emitting lasers (known as VCSELs) offer the exciting prospect of output polarization control through the injection of spin-polarized electrons. Such capabilities could lead to many new applications in the field of spectroscopy, communications and information processing. In this project we simulate the rate equations that describe the right- and left-circularly polarized complex fields and the carrier densities, as originally introduced in [1], to detect and describe the instabilities leading to self-sustained oscillations [2]. The numerical integration is made via MATLAB while the output is characterized by power and optical spectra. We look at the description of Vertical External Cavity devices, bifurcation diagrams, high frequency oscillations and possible transitions to chaotic motion for spin-polarized lasers. The effects of an injected signal and modulations of losses or cavity parameters are also investigated.

Key Reference (if applicable):

[1] G. P. Puccioni, M. V. Tratnik, J. E. Sipe and G.-L. Oppo, “Low instability threshold in a laser operating in both states of polarization” Optics Letters **12**, 242 (1987)
[2] R. Al-Seyab, D. Alexandropoulos, I. D. Henning, and M. J. Adams, “Instabilities in Spin-Polarized Vertical-Cavity Surface-Emitting Lasers” IEEE Photonics Journal **3**, 799 (2011)

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys BSc

Additional comments: Good performance in the course PH254 Computational Physics is recommended. The “experimental” part is related to the understanding of experimental results and their comparison with numerical simulations.

Safety Training Requirements: None.

Simulations of Coupled Laser Networks

Project Supervisors: (1):Prof. Gian-Luca Oppo, (2) Dr Thorsten Ackemann

Project Description:

It is well known that lasers can synchronise by locking their phases when the coupling strength is large enough. Typical examples are lasers injecting each other that behave like locked coupled oscillators. This project looks at the simulations of large arrays of coupled lasers generated in a degenerate cavity [1]. By introducing optical feedback, sections of the arrays can find preferential coupling with distant areas of the same array (long range coupling) leading to unusual synchronisation features. The models are then extended to simulate laser networks in semiconductor-based devices such as vertical-cavity surface-emitting lasers (known as VCSELs). Here the synchronisation behaviour of the array can be compared to that generated by coupled spatial solitons when the optical feedback is frequency selective [2]. Laser arrays and laser networks find natural applications in optical communications and in information processing.

Key Reference (if applicable):

[1] M. Nixon, E. Ronen, A. A. Friesem, and N. Davidson, "Geometric Frustration in Large Arrays of Coupled Lasers**"** Paper CA9_4 at the CLEO/Europe conference in Munich (May 2011)
[2] P. V. Paulau, C. McIntyre, Y. Noblet, N. Radwell, W. J. Firth, P. Colet, T. Ackemann, and G.-L. Oppo, "Adler synchronization of spatial laser solitons pinned by defects", Phys. Rev. Lett. **108**, 213904 (2012)

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

Suitability: PH450 MPhys BSc

Additional comments: The "experimental" part is related to the understanding of experimental results and their comparison with numerical simulations. **Safety Training Requirements:** None.

Quantum Optical Computational Toolbox

Project Supervisors: (1) Dr John Jeffers, (2) Prof. Gian-Luca Oppo

Project Description:

The aim of this project is to develop a computer program to mimic the propagation of light through optical elements, and to take account of quantum processing such as unitary evolution (e.g. beam splitters, polarisers and interferometers) and nonunitary evolution (e.g. measurement, loss). It is expected that the student will use Matlab, but other mathematical programming packages could be used.

Ratio of Experiment/Theory/Computation:	Exp:	0 %
	Theo:	30 %
	Comp:	70 %

Suitable for: BSc MPhys

Additional Comments: This project will suit a mathematically and computationally minded student. Not suitable for those who simply do not like experiments. Students must have taken, and passed well, 12.321 Quantum Physics. Taking 12.483 Quantum and Nonlinear Optics would be an advantage, although not essential.

Safety Training Requirements: None

Electromagnetic Resonances in Nanoparticles

Project Supervisors: (1) Dr Francesco Papoff, (2) Drs Ben Hourahine & Yu Chen

Project Description:

Metallic nano-particles can massively enhance the local electromagnetic field close to the particle (the near field). This effect is used to visualize biological samples near to nanoparticles, even at the level of single molecule detection, and to transfer and process information and energy at scales smaller than the wavelength of the incident light. The basis all these applications is that particle-light interactions, which depend on the composition and shape of the particle and on the properties the incident light, can become very strong around resonances. Recently we have devised a new theoretical method able to find the resonances of nano- and micro-particles based on finding the surface fields that are characteristic of the particle. In this project, we aim to expand this theory to particles of arbitrary shape and determine how the structure of the particle affects its resonances.

Key Reference (if applicable): K. Holms, B. Hourahine, F. Papoff, ``Calculation of internal and scattered fields of axisymmetric nanoparticles at any point in space", Journ. Opt A, 11, 054009 (2009)

Ratio of Experiment/Theory/Computation:

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

Suitability: PH450 MPhys BSc

Safety Training Requirements: None

Surface Fields in Nano and Micro Particles

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

Project Description:

Nano- and micro-particles have remarkable optical properties: they can massively enhance the local electromagnetic field close to the particle (the near field) while also acting as optical cavities with exceptionally high Q factors. Recently we have devised a theoretical method which is able to calculate the response of nano and micro particles to external electromagnetic fields and predict their emitted light at any point in space. In this project, we aim to apply this theory to calculate the responses of this type of particle when illuminated by light sources that are close to the particle surface. This mimics the conditions used by an experimental group we collaborate with in Japan, where they precisely measure the surface fields of particles by exciting them with a light source close to the particle via a small optical probe, and measuring the resulting emitted light.

Key Reference (if applicable): K. Holms, B. Hourahine, F. Papoff, "Calculation of internal and scattered fields of axisymmetric nanoparticles at any point in space", Journ. Opt A, 11, 054009 (2009)

Ratio of Experiment/Theory/Computation: Exp: 0 %
Theo: 40 %
Comp: 60 %

Suitability: PH450 MPhys BSc

Safety Training Requirements: None

Fluctuations and Noise in Cold Atoms

Project supervisors: (1) Dr F Papoff (2) Dr Gordon Robb

Project Description:

Noise plays a crucial role in all physical systems and in many cases it is not an hindrance, but an essential ingredient for the observation of processes as important as laser emission, for instance. In this project we will investigate theoretically and numerically the nature of small noisy fluctuations present in cold atoms interacting with coherent light, a very important system where it is possible to observe collective phenomena, linear and non-linear behaviour and many types of instabilities. In particular, we will find how noisy perturbations affect the the collective behaviour of cold atoms and explore regimes where they are be amplified.

Key Reference (if applicable): http://sbfel3.ucsb.edu/www/vl_fel.html

F. Papoff, G. D'Alessandro, G.-L. Oppo, Phys. Rev. Lett. 100, 123905, 1-4, (2008)

F. Papoff, G.R.M Robb, Phys. Rev. Lett. 108, 113902 (2012)

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

Suitability: PH450 MPhys BSc

Additional Comments:

Safety Training Requirements:

Modelling 4th Generation Light Sources

Project Supervisors: (1) Dr Brian McNeil, (2) Dr Gordon Robb

Project Description:

Free Electron Lasers (FELs) are the next (4th) generation light sources. These can generate very intense, short pulses of electromagnetic radiation in the UV and in the future beyond into the x-ray. Such output would allow resolution of both the spatial and temporal resolution of atomic processes. This will allow 'movies' to be made of atomic bonds being made and broken and therefore potentially allow the process to be directly influenced and controlled.

The active medium of the FEL is a beam of relativistic electrons. When these electrons interact with an undulating magnetic field they radiate at a well-defined wavelength. Subsequent interaction modulates the electron beam density at this wavelength so generating coherent light. You will develop the mathematical model of this process and then solve the resulting equations numerically. A good student can expect to use their model to research new physical processes that may occur and possibly make a new and useful contribution to the field.

Reference: Free-Electron Lasers: The Next Generation by Davide Castelvecchi New Scientist, January 21, 2006. See also: www.4gls.ac.uk, www-ssrl.slac.stanford.edu/lcls/, xfel.desy.de/, http://www.newlightsource.org/

Ratio of Experiment/Theory/Computation:

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

Suitable for: PH450 MPhys BSc

Additional Comments: Students will require or will be expected to develop a working knowledge of a computer language (such as Fortran or MATLAB.) and have a good proficiency at mathematics.

Safety Training Requirements: Contact the project Supervisor for further advice

Resonant Electron Beam-light Interactions

Project Supervisors: (1) Dr Brian McNeil, (2) Dr Gordon Robb

Project Description:

Electron motion can be driven by the electromagnetic field of light. But accelerated electrons can also be the source of electromagnetic radiation. These mutual interactions can be applied to create coherent sources of high power radiation from mm wavelengths into the hard x-ray. Such light sources use different methods to achieve this, such as the Cyclotron Resonance Maser and the Free Electron Laser. The light-electron interactions may also be used to accelerate electrons possibly to very high (relativistic) energies.

You will develop a mathematical model of both the radiation source and acceleration processes and then solve the resulting equations numerically. A good student can expect to use their model to research new physical processes that may occur and possibly make a new and useful contribution to the field.

Key Reference (if applicable):

Free-Electron Lasers: The Next Generation by Davide Castelvecchi New Scientist, January 21, 2006

See also: www.4gls.sc.uk, www-ssrl.slac.stanford.edu/lcls/, xfel.desy.de/

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

Suitability: PH450 MPhys BSc

Additional comments: Students will require or will be expected to develop a working knowledge of a computer

language (such as Fortran or MATLAB.) and have a good proficiency at mathematics.

Safety Training Requirements: None

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

Nonlinear 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].

This project will involve modelling nonlinear wave-mixing in atomic systems and will involve numerically solving coupled equations describing the evolution of the atomic and optical field dynamics [2].

Key Reference (if applicable):
[1]"Nonlinear Optics" by R. Boyd
[2]"Nonlinear Optics" by Newell & Moloney

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys BSc

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.

Colour Digital Photography

Project Supervisors: (1) Dr Daniel Oi, (2) Dr Ben Hourahine

Project Description:

Conventional digital imaging devices register the absorption of light in a silicon photodiode. A bare photodiode has a broadband response in the visual spectrum leading to monochrome, or “black & white” images. To create colour photographs, a Bayer colour matrix filter array is commonly used, whereby an alternating pattern of red, green, and blue colour filters is placed over the photodiodes modifying their spectral response functions. The resultant captured data is “de-mosaiced” to reconstruct an approximation of the colour and detail at the image plane. Bayer matrix capture and reconstruction can suffer from artefacts such as moiré and staircasing. Eliminating these can compromise other aspects of the image such as sharpness, colour fidelity, and noise performance. New patterns and reconstruction algorithms operating in the combined spatial-spectral domain have been proposed to ameliorate artefacts yet remaining computationally simple. This project will examine the information sampling theory behind Bayer reconstruction and relate these new image sampling and reconstruction approaches to compressive sensing.

Reference : Bayer Patent http://www.pat2pdf.org/pat2pdf/foo.pl?number=3971065
R. Ramanath, W. Snyder, G.L. Bilbro, W.A. Sander, "Demosaicking Methods in Bayer Color Arrays", Journal of Electronic Imaging, 11(3): 306-315, July 2002
http://www.accidentalmark.com/research/papers/Hirakawa08CFA_TIP.pdf
http://www.greyc.ensicaen.fr/~lcondat/publis/condat_icip09_newCFA.pdf
http://dsp.rice.edu/cs Compressive Sensing Resource

Ratio of Experiment/Theory/Computation: Exp: 0 %
Theo: 70 %
Comp: 30 %

Suitable for : PH450 MPhys BSc

Additional Comments: This project would be suitable for the more mathematically able student and also involves computational simulation. Background in linear algebra and familiarity in Mathematica or Matlab would be useful.

Safety Training Requirements: None

Super resolution Free-space Single-photon Distribution

Project Supervisors: (1) Dr Daniel Oi, (2) Dr Shashank Virmani

Project Description:

Quantum cryptography offers the possibility of secure communication guaranteed by the laws of physics. Current commercial systems operate over optical fibres but are restricted to distances ~100km or less due to absorption. Free-space entanglement distribution using satellites could extend the range of quantum cryptography to intercontinental distances. However, diffractive losses could pose a severe limitation on the effective key rate. This project would look at the possibility of using superresolution techniques to boost transmission probabilities.

Key Reference (if applicable): Ground to satellite secure key exchange using quantum cryptography, J G Rarity, P R Tapster, P M Gorman and P Knight, 2002 New J. Phys. 4 82

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments:

Safety Training Requirements: None

Adaptive Bayesian Quantum System Identification

Project Supervisors: (1) Dr Daniel Oi, (2) Dr Shashank Virmani

Project Description:

In order to build a quantum computer, we must be able to characterise the operational behaviour of each of its components in order to control them with extreme precision. An essential task is that of quantum system identification, determining the parameters describing the coherent and incoherent dynamics of a quantum device with only limited initial resources including state preparation and measurement capabilities. To make most efficient use of the time and number of measurements required to determine a system to some accuracy, adaptive sampling and Bayesian inference has been applied. However it is still an open question as to the ultimate efficiency of such methods compared to offline (non-adaptive) techniques. This project will compare different system identification strategies.

Key Reference (if applicable): Quantum system characterization with limited resources, Daniel Oi, Sophie Schirmer, http://arxiv.org/abs/1202.5779

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 MPhys BSc
12 521 MSci Bio

Additional comments:

Safety Training Requirements: None

Simulating Entangled Quantum States with Communication

Project Supervisors: (1) Dr Shashank Virmani, (2) Dr Daniel Oi

Project Description:

One of the most remarkable features of quantum theory is the phenomenon of non-locality. When two quantum particles are prepared in a special type of state (an entangled state) and separated over long distances, then measurements of the particles can exhibit so-called non-local correlations. These correlations cannot be generated by classical physical systems unless you allow them to communicate instantly. In recent papers the amount of instant communication required has been quantified: we know that for particular families of measurement on a singlet state, one bit of communication is sufficient. The project will require the student to understand the papers that have led to this result, and to understand whether the results can be extended to cover other types of measurement.

Reference: B. Toner and D. Bacon, "Communication Cost of Simulating Bell Correlations", Physical Review Letters, Vol 91, No. 18, 189704 (2003)

Ratio of Experiment/Theory/Computation:

Exp:	0%,
Theo:	at least 65%
Comp:	at most 35%

Suitable for: PH450 MPhys BSc

Additional Comments: Don't attempt this project just because you don't like experiments. You need to be comfortable with the mathematics of quantum theory, in particular Dirac notation and how to compute probabilities of measurement outcomes.

You must have taken and passed well 12.321 Quantum Physics. Course 12.483 Quantum and Nonlinear Optics would be useful background, but is not strictly necessary.

Safety Training Requirements: Contact the project Supervisor for further advice

Does D-Wave really have a Quantum Computer?

Project Supervisors: (1) Dr Shashank Virmani, (2) Dr Daniel Oi

Project Description:

In the race to build a quantum computer, the Canadian company D-Wave has generated some controversy. They claim to have a machine composed of 128 superconducting quantum bits (qubits) that can solve difficult problems in a truly quantum mechanical way. They have even sold devices to illustrious companies such as Lockheed-Martin and Google. However, there remains a great deal of scepticism in the scientific community. The goal of this project is to understand in detail the physics of the D-Wave devices, and perform an analysis to determine whether they really have a machine operating with such large scale quantum coherence. The project could take many different directions depending upon the interests of the student – from trying to decide whether the core technological claims are too good to be true, to designing classical methods for simulating their devices as efficiently as possible.

Key Reference (if applicable):
http://www.nature.com/nature/journal/v473/n7346/full/nature10012.html
http://www.scottaaronson.com/blog/?p=954
http://www.dwavesys.com/en/dw_homepage.html
http://www.dwavesys.com/en/publications.html

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

Suitability: PH450 BSc

Additional comments: This theoretical project about quantum physics, so students should be confident with the material of PH352 Quantum Physics and Electromagnetism, as well as with matrix manipulation and Dirac notation.

Safety Training Requirements: None

Sampling Negative Probability Distributions

Project Supervisors: (1) Dr Shashank Virmani, (2) Dr Daniel Oi

Project Description:

It is often argued that quantum theory's most enigmatic features are a consequence of the negative transition probabilities [1,2] that arise when we try to write it as a conventional classical probabilistic process. If we want to simulate such processes on a computer, we need to have an efficient way of sampling from the resulting probability distributions. This appears to be difficult, but no one knows why. The first goal of this project will be to take a type of quantum system (so called stabilizer quantum systems [3]) that can be efficiently simulated classically, and rewrite it as a probabilistic process with negative transition probabilities that are as large as possible. The second goal will be to understand why these negativities can still be efficiently simulated classically.

Key Reference (if applicable):

[1] Feynman, R. P. (1987): "Negative Probability," First published in the book *Quantum Implications : Essays in Honour of David Bohm*, by F. David Peat (Editor), Basil Hiley (Editor) Routledge & Kegan Paul Ltd, London & New York, pp. 235–248

[2] http://en.wikipedia.org/wiki/Negative_probability#cite_note-1

[3] http://en.wikipedia.org/wiki/Gottesman%E2%80%93Knill_theorem

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

Suitability: PH450 BSc

Additional comments: This is a mathematical project. Students should be very comfortable with probability theory, matrices and eigenvalues.

Safety Training Requirements: None

PLASMAS DIVISION

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: PH450 MPhys

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

Safety Training Requirements: Contact the project Supervisor for further advice

Design and Simulation of Millimetre Wave Cavities

Project Supervisors: (1) Dr Adrian Cross, (2) Dr Helen Yin

Project Description:

A project is proposed to design, simulate and numerically model a millimetre wave cavity. The project will involve the design of a millimetre wave cavity for a beam wave interaction region using analytical theory. The cavity will be computationally modelled using Microwave Studio with the transmission and reflection properties of the cavity as well as their Q-factors calculated. The beam/wave interaction will be modelled using the numerical simulation code MAGIC.

The prerequisite skills required for this project are successful completion of the undergraduate **quantum electromagnetism course.**

Ratio of Experiment/Theory/Computation: Exp: 0%
Theory: 40%
Computational: microwave studio-30% and MAGIC-30%

Suitability: PH450 BSc

Safety Training Requirements: Contact the project Supervisor for further advice

Sweep Frequency Microwave Pulse Compression using a Helically Corrugated Waveguide

Supervisors: (1) Dr Kevin Ronald, (2) Dr Wenlong He

Project Description:

A project is proposed to investigate a new type of pulse compressor based on compression of frequency-modulated pulses using a helically corrugated waveguide as a dispersive medium. If the wave group velocity in the dispersive medium is an increasing function of frequency then the tail of the pulse will overtake its leading edge, resulting in pulse shortening and a corresponding growth in the amplitude if the loses are sufficiently low. A helically corrugated waveguide operating far from cut off can be used to couple a rotating TE31 wave and a counter rotating TE22 wave, and in the region of their coupling the group velocity of the eigenwave can be a rapidly varying function of frequency, which is attractive for pulse compression. An experimental and theoretical study of swept-frequency based pulse compression will be carried out. A conventional X-band TWT with an output power of 5kW driven by a solid-state frequency tuneable oscillator will be used to generate an input pulse for the compressor. A pulsed generator will be used to produce a sweep voltage which will be applied to a special pin of the solid state source to control its oscillation frequency. The frequency modulation of the input pulse will be measured using a heterodyne technique and a fast digitising oscilloscope. The maximum optimum power compression ratio, time compression factor and efficiency will be measured. In addition the dispersive properties of a circular waveguide with a helical corrugation on its inner surface will be measured using a vector network analysers with the results compared to the predictions obtained using numerical simulation codes such as Magic. The prerequisite skills required for this project is successful completion of the third year undergraduate course on electromagnetic theory.

Reference'Compression of frequency-modulated pulses using helically corrugated waveguides and its potential for generating multigigawatt RF radiation', 2004, S.V. SamsonovA.D.R. Phelps et al, Physical Review Letters, 92,

Ratio of Experiment/Theory/Computation:	Exp:	50 %
	Theo:	25 %
	Comp:	25 %

Suitable for: PH450 MPhys BSc

Safety Training Requirements: Contact the project Supervisor for further advice

Laser Wakefield Acceleration and Betatron Gamma Ray Radiation

Project Supervisors: (1) Prof. Dino Jaroszynski, (2) Dr M Ranaul Islam

Project Description:

The student will carry out analytical and numerical work on laser plasma wakefield acceleration. This is a method of accelerating electrons using plasma waves. The attraction of this method, being investigated experimentally and theoretically at Strathclyde University, lies in the propagation of intense laser pulses in under-dense Plasma, which can accelerate energetic electron beams up to 1 GeV by utilizing the huge longitudinal electrostatic fields produced by displaced electrons. These forces create a bubble-like ion structure, and the transverse restoring force in such ionic-background leads to acceleration and the emission of intense femtosecond duration gamma-ray betatron radiation. The emphasis of this project will be on controlled acceleration, investigating ways to obtain high energy X-rays, and studying the efficiency, which can be comparable with conventional accelerators. These new types of radiation sources could be used to probe the structure of matter on unprecedented length and time scales. The student will use particle-in-cell (PIC) codes such as VORPAL and OSIRIS. The project forms part of the ALPHA-X project at Strathclyde University.

Reference : (1)PhD thesis http://alexandria.tue.nl/extra2/200212656.pdf (2) http://phys.strath.ac.uk/alpha-x (3) Mangles, S. P. D. et al. Electron acceleration from the breaking of relativistic plasma waves. Nature 431, 535538 (2004).

Ratio of Experiment/Theory/Computation: Exp: 0 %
Theo: 30 %
Comp: 70 %

Suitable for: PH450 MPhys

Additional Comments: This is challenging project requiring good mathematical and numerical skills. Anyone interested in this project should contact the supervisors in advance.

Safety Training Requirements: Contact the project Supervisor for further advice

Radiation Reaction

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

Project Description:

This project is an opportunity to investigate the interaction of a charged particle with its own radiation field. As well as being vital for the development of new technologies at the cutting edge of scientific discovery, this is a problem of fundamental importance in classical and quantum electrodynamics. Indeed, it is one of the classic unsolved problems in physics.

The Lorentz-Dirac equation, which describes radiation reaction, exhibits unexpected behaviour, such as unbounded accelerations and particles responding to a force before it acts. You will explore the origins of these pathologies and some of the attempts to eliminate them, as well as applying the equation to some of the latest accelerator designs and interactions of electrons with the electromagnetic fields that will be available from a new generation of powerful laser sources, such as that being constructed at the EU Extreme Light Infrastructure.

Reference:
J.D. Jackson, Classical Electrodynamics, 3rd ed. New York : Wiley, 1999. Main Library: D537.6 JAC;
E. Poisson, An introduction to the Lorentz-Dirac equation, arXiv: gr-qc/9912045.

Ratio of Experiment/Theory/Computation: Exp: 0 %
Theo: 70 %
Comp: 30 %

Suitable for: PH450 MPhys BSc

Additional Comments: This challenging project will be of interest to someone with strong mathematical skills, who enjoys exploring technical and conceptual questions. Anyone interested in pursuing this project should contact the supervisors beforehand

Safety Training Requirements: Contact the project Supervisor for further advice

Non-linear Optics in Plasma: Raman Amplification and Frequency Mixing

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

Project Description:

This project offers the opportunity to investigate, both theoretically and numerically, non-linear interactions between (transverse) electromagnetic waves through a (longitudinal) plasma wave. It has been suggested to use such a process, stimulated Raman scattering, to amplify a seed pulse by extracting energy from an intense pump pulse to provide a new type of light amplifier to reach petawatts, exawatts and beyond. Plasma as a non-linear optical medium for intense laser pulses has additional interest when optical pulses are sufficiently intense to drive electrons (and holes or positrons) to relativistic energies, and thus to generate astrophysical conditions in the laboratory.

The investigation may build on an existing code for the hydrodynamic simulation of plasma taking into account a variable number of carrier species, such as electron-positron plasmas, and electrons and ions, or holes in the case of a semiconductor plasma.

Reference: William L. Kruer: The physics of laser plasma interactions, Addison-Wesley, Redwood City, Calif. c1988. Main Library: D 530.44 KRU (or other textbooks on laser-plasma interaction)

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

Suitable for: PH450 MPhys BSc Maths/Phys

Additional Comments: Knowledge in the following areas would be advantageous: wave propagation, Fourier theory; computer programming (C or similar). Anyone interested in taking up this project should contact the supervisors beforehand.

Safety Training Requirements: Contact the project Supervisor for further advice

Electron Beam Transport and Diagnostics

Project Supervisors: (1) Prof. Dino Jaroszynski, (2) Dr Enrico Brunetti

Project Description:

Laser-driven particle accelerators are compact sources of high quality electron beams with potential applications to fields such as medicine, biology and material science. Since many applications require the transport and focusing of a beam over long distances, a good quality transport system is essential. This project consists of the theoretical study of the transport of an electron beam through magnetic devices, with particular emphasis on properties such as transverse emittance and bunch length.

Reference: Wiedemann, Particle Accelerator Physics, Springer, 2007 Jackson, Classical Electrodynamics, Wiley, 1999 Esarey, Schroeder and Leemans, Physics of laser-driven plasma-based electron accelerators, Rev. Mod. Phys. 81, 1229–1285 (2009)

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

Suitable for: PH450 MPhys BSc Maths/Phys

Additional Comments: Knowledge in the following areas would be advantageous: wave propagation, Fourier theory; computer programming (C or similar). Anyone interested in taking up this project should contact the supervisors beforehand.

Safety Training Requirements: Contact the project Supervisor for further advice

Capillary Discharge Waveguides for Laser-Plasma Interactions

Project Supervisors (Joint): (1) Prof. Dino Jaroszynski, (2) Dr Mark Wiggins/ Dr Gregor Welsh

Project Description:

The project is part of the ALPHA-X project to harness plasma using high power lasers as compact radiation and particle sources. An intense 30 femtosecond duration laser pulse, with a peak power of more than 30 TW, is used to excite density waves in plasma. These perturbations in the plasma density can act as a non-linear optical medium to parametrically amplify laser pulses, or as a compact accelerator, where the extremely high electrostatic forces of charge separation can accelerate particles with unprecedented accelerating gradients, more than 1000 times larger than in a conventional accelerator. The plasma medium is a central component of these amplifiers and accelerators. In the project we will investigate the formation of stable plasma waveguides in a capillary formed by an electrical discharge. The capillary acts as a waveguide for the intense laser pulse, which allows the laser intensity to maintained over several centimetres thus allowing the length of the accelerator or amplifier to be extended beyond the diffraction (Rayleigh) length .

The project involves evaluating and characterising uniform, tapered and structured plasma waveguides. Both experimental and theoretical methods will be used, which will include valuable hands-on experience with high-voltage pulsed power supplies and plasma diagnostics systems in the TOPS laser laboratory. There will also be an opportunity to test the capillaries in the current Raman amplification and laser-driven wakefield accelerator experiments at Strathclyde. This is an opportunity to be involved in a ground breaking project.

References: Relevant papers will be provided

Ratio of Experiment/Theory/Computation:

Exp: 80 %
Theo: 10 %
Comp: 10 %

Suitable for: PH450 MPhys BSc

Safety Training Requirements: Contact the project Supervisor for further advice

Radiotherapy using Beams from Laser-plasma Accelerators

Project Supervisors: (1) Prof. Dino Jaroszynski, (2) Silvia Cipiccia

Project Description:

Gamma rays are the most common form of radiation used in radio-therapy to treat cancer. However, another option exist: particle beams are also very effective forms of treatment. Heavy particles such as protons and carbon ions have the advantage that they deposit their dose in a very localised region in the body and thus can be used to destroy tumours while sparing healthy tissue. Unfortunately, accelerating these heavier particles is very expensive, with costs exceeding £300m for a facility. 20 MeV electrons from radiotherapy accelerators are often used for treating superficial tumours located within a few centimetres of the skin. However, by increasing the energy of the electrons to more than 100 MeV, beams can penetrate the whole body and become an effective form of radiotherapy. In this project we will utilise electron beams from a laser-plasma wakefield accelerator at Strathclyde (part of the ALPHA-X project) to study their therapeutic effect. A model system, using real cells, will be investigated using electron beams with energies between 100 MeV and 200 MeV to establish the effectiveness of the modality. The project will also involve investigating the dose distribution in a so called "phantom" that mimics biological matter making up the body. The project will involve both experimental methods and the use of simulation tools such as GEANT4 to study the interaction of energetic particles with matter. The student will have the opportunity to collaborate extensively with both radiobiologists and physicists, thus making the project very cross-disciplinary. This is an opportunity to be involved in a ground-breaking project.

References: L. Papiez, et al., “Very high energy electrons (50-250 MeV) and radiation therapy”. *Technology in cancer research treatment*, *1*(2), 105-110 (2002). C Yeboah, et al., "Optimization of intensity-modulated very high energy (50-250 MeV) electron therapy." *Physics in Medicine and Biology*, *47*(8), 1285-1301. (2002). http://www.ncbi.nlm.nih.gov/pubmed/12030556 T. Fuchs et al.,“Treatment planning for laser-accelerated very-high energy electrons”, Phys. Med. Biol. 54 (2009) 3315-3328 Y Glinec et al., “Radiotherapy with laser-plasma accelerators: Monte Carlo simulation of dose deposited by an experimental quasimonoenergetic electron beam”. *Med Phys.* **33** 155 (2006) O Rigaud, et al., (2010) “Exploring ultrashort high-energy electron-induced damage in human carcinoma cells”, *Cell Death and Disease* **1**, e73

Ratio of Experiment/Theory/Computation: Exp: 80 %
Theo: 10 %
Comp: 10 %

Suitable for: PH450 MPhys BSc

Safety Training Requirements: Contact the project Supervisor for further advice

High Energy Ion Acceleration in Intense Laser-plasma Interactions

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

Project Description:

The interaction of intense laser pulses with matter is opening up new frontiers in physics via the production of extreme pressures, temperatures and intense electric and magnetic fields. This is leading to the use of high power laser radiation for exploring the properties of hot dense matter, the production of high energy particles and radiation, and the development of schemes to generate energy by inertial confinement fusion. The possibility of using high power lasers to generate high-quality beams of energetic ions is attracting global interest. In particular, laser-based ion acceleration schemes may lead to compact and relatively low-cost sources which can be used in science, medicine and industry.

The project involves an investigation of multi-MeV ion acceleration driven by ultraintense laser-plasma interactions and has two components. The first involves an analysis of existing experimental data obtained using the Astra-Gemini high power laser at the UK's Central Laser Facility. The second part of the project involves a full characterisation of two new ion spectrometers, including mapping of the field distributions and simulating the resulting ion trajectories using charged particle optics software.

The project will provide the student with a background in the physics of high power laser-based sources of ions, diagnostic techniques and in the simulation and modelling of experimental results.

Key Reference (if applicable):

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 BSc

High Energy Radiation from Intense Laser-solid Interactions

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

Project Description:

When an ultraintense laser pulse interacts with dense matter it produces very short bursts of highly energetic and directed electrons. As these electrons propagate through matter they lose energy through scattering and radiative interactions. At ultrahigh laser intensities the electrons can also lose energy to radiation due to their damping motion in the strong electric field of the laser pulse. The resulting X-rays have energies from tens of keV to tens of MeV. The X-ray burst typically lasts only femtoseconds to picoseconds, is extremely bright and has many potential imaging and probing applications.

The project involves characterisation of a new scintillator-based diagnostic designed to measure the angular and spectral distributions of X-rays produced in intense laser-solid interactions. The first part involves calibration of the diagnostic and analysis of data obtained using it on a recent experiment at the Astra-Gemini laser facility at the Rutherford Appleton Laboratory. A second part involves development of the diagnostic for subsequent follow-on experiments. The project will provide the student with a background in the physics of high power laser-based radiation sources, diagnostic techniques and in the simulation and modelling of experimental results.

Key Reference (if applicable):

Ratio of effort: Exp/Theo/Comp

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

Suitability: PH450 BSc

Allocated Projects (Fifth Year students)

Project Name	*Supervisors*	*Student Name*
The Physics of DNA	Neil Hunt, Katrin Adamczyk, Glenn Burley	Gordon Hithell
Bose-Einstein Condensate Experiments	Aidan Arnold, Erling Riis	Billy Robertson
A Laser System for Laser Cooling of Rubidium Atoms	Erling Riis, Aidan Arnold	Callum Muirhead
Radiotherapy using Beams from Laser-plasma Accelerators	Dino Jaroszynski, Silvia Cippicia	Hersimerjit Padda
BEC Simulations	Gordon Robb, Aidan Arnold	Stefan Celosia
Modelling the Interaction of Electron Beams with Semiconductor Devices	Rob Martin	Martin McGregor
Semiconductor Doped Glasses	Thomas Han	Penny Mitchell
Energy Transfer as a Nanoscale ruler	Yu Chen, Olaf Rolinski	Ben Russell
Capillary Discharge Waveguides for Laser-Plasma Interactions	Dino Jaroszynski, Mark Wiggins	Robbie Wilson
Optical Properties of Nanoparticles	Yu Chen, Olaf Rolinski	Zetao Xu

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 30th November 2012 at the **latest.**

1) I have read and understood the '*Local rules for the Safe Use of Lasers*' (available from

the SPIDER document store: docStore >> Physics >> ❑
safety - Laser Information >> all >> Local Rules) **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 2012

(To be returned by the student to Students Office JA 8.31 by 12 noon 28/09/12)

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 by Lauren Angus on Wednesday the 3rd of October 2012 – *Kevin O'Donnell*

Project Timetables

PH450

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

17th September 2012 Project booklet to students

Students will receive project handbook with project request page.

17th September 2012 –28th September 2012 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, JA8.33 (Lauren Angus).

12 Noon 28th September 2012 Last date for submission of Project choice form to JA8.31 (Lauren Angus)

3rd October 2012 Project allocations announced at 12 noon. Official start of Projects

19th October 2012 Literature review complete

Students submit literature survey for project (which will usually take the form of the Final Report's introductory chapter.)

30th November 2012 Completed safety form to be returned to JA 8.31 by this date

20th and 27th March 2013 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.

15th April 2013 Project reports submitted

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

Week beginning 29th April 2013 (revision week) Viva week

Project Information for Continuing 5th Year Students

PH 550

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

28th January – 1st February 2013 Mock viva voce examinations

The mock viva voce examination will give students a formative experience of a viva voce examination. The performance in the mock viva voce examination will not count towards the final assessment of the project.

20th and 27th March 2013 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.

15th April 2013 Project reports submitted

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

Week beginning 29th April 2013 (revision week) Viva week

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.tinyurls.co.uk/M8733 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