

PHY480 Project List, 2010 - 2011



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Synopses for Physics Projects

Excitons and photons in semiconductor microcavities

This project is an experimental one involving the study of coupled exciton photon particles in semiconductor cavities. Such particles exhibit many novel properties most notably condensation into a state with a macroscopic wavefunction. The project will involve the use of advanced optical techniques and low temperatures on timescales from seconds to 10 picoseconds. The subject is at the forefront of physics in the solid state.

Towards superman X-ray vision - Prof. M. S. Skolnick and Dr. A. J. Ramsay (experimental)

White paint on a glass slide is opaque because it is made up of Titanium nanoparticles that scatter light in random directions. The light can somehow find a path through the paint, but the interference between the multiple pathways results in the transmission of diffuse light only. Recently, Vellekoop and Mosk [Phys. Rev. Lett. 101 120601 (2008)] have demonstrated efficient transmission of a laser beam through an otherwise opaque glass slide painted white. This was achieved by programming the phase-front of the laser beam using a spatial-light modulator (a

liquid-crystal display), and using a search algorithm to find a path through the paint.

In this project, a team of up to two students will try to repeat these experiments, and demonstrate that a light beam can pass through an opaque medium.

Towards Terabit/second all-optical switches for high-speed internet (theoretical) - Prof. M. S. Skolnick and Dr. A. J. Ramsay

There is an exponential increase in internet traffic. In time there may be a demand for all-optical switches to process/route data at Terabit/sec speeds. All-optical switches require a strong optical nonlinearity, and in semiconductors the strongest nonlinearities are induced by the creation of real carriers. However, whilst carriers can be created on a sub-picosecond timescale, the potential repetition rate is limited by the slow 100-ps relaxation times of the carriers.

In this project, the student will explore a proposal for a new class of optoelectronic device based on quantum interference effects in semiconductor quantum dots.

Nano-imaging using nuclear magnetic resonance (NMR) - Dr. Alex Tartakovskii

Magnetic resonance has diverse applications in many branches of science including physics, chemistry, material science, biology, medicine, and very recently quantum computation. Nuclear magnetic resonance or NMR is based around properties of magnetic moments of nuclei in atoms. Among many applications of this technique, magnetic resonance imaging (MRI) is well known and is widely used in hospitals for imaging soft tissues in human body with sub-mm spatial resolution. In this project you will take NMR-based imaging much further: you will use it to study internal properties of semiconductor nano-structures – quantum dots. In particular, you will develop techniques for locating small groups of atoms inside an individual dot with resolution better than 10 nm. The project is computational, but the results will be directly compared with recent experiments of the Sheffield group, and will be used for future development of this advanced experimental study. If time permits you will carry out experiments on quantum dots using optically detected NMR (ODNMR).

Writing an SPH hydrodynamics code. Dr Simon Goodwin

Smoothed Particle Hydrodynamics (SPH) is a method for modelling fluid flows used in many areas of science and also in computer games and CGI. In this project we will write and test a simple SPH code.

Using atomic force microscopy to measure unexpected fluctuations in polymer crystal growth - Dr. Jamie Hobbs

Using state-of-the-art in-situ atomic force microscopy (AFM), we have recently shown that when polymers crystallize the growth rate fluctuates in an unexpected and currently unexplained manner when measured at high resolution. The aim of this project is to extend this work to a number of other polymers to find if the behaviour is general. If it is general, then it should be possible to find how the fluc-

tuations vary with temperature and hence gain an insight into the underlying physics. The large majority of commercial plastics are semicrystalline polymers, so an improved understanding of how they crystallize will lead to better control over properties in a wide range of materials. The project will involve extensive use of the AFM for nanometre resolution imaging of the process of crystal growth, as well as the subsequent analysis of the data obtained.

Constructing the largest scan area high speed atomic force microscope to date - Dr. Jamie Hobbs

Atomic force microscopy is one of the main tools of nanotechnology, allowing the imaging and manipulation of matter at the nanometre scale. However, its use in many applications is severely hindered by the time that it takes to collect an image. We have recently provided a partial solution to this problem with the invention of VideoAFM, the highest speed AFM technology to-date. However, the area that can be scanned is still rather limited, so preventing its widespread adoption. Very recently we have substantially increased the scan area (more than five-fold) by the use of a macroscopic resonator as the scan-stage. The aim of this project is to further extend this work by developing the scanner so as explore the maximum scan area obtainable. Having constructed the large area scanner the project will explore its use for possible applications in process control in semiconductor device fabrication.

Atomic force microscopy of the 'cytoskeleton' of red blood cells - Dr. Jamie Hobbs

Red blood cells are remarkable in that they have to travel through capillaries that are substantially smaller than their diameter and yet rapidly return to their conventional disc shape to enable free flow within blood vessels. The physical structure that enables this remarkable elasticity is a protein based network just inside the outer membrane that acts as a highly elastic cytoskeleton. The aim of this project is to try to gain a new understanding of the physics of this process by directly imaging the protein network as it undergoes mechanical deformation. Using atomic force microscopy (AFM) it is possible to image the network in specially prepared samples of red blood cells. In a previous project we have developed a method for mechanically stretching biological samples under the AFM. Here you will combine these methods to image the network as it deforms during stretching with the aim of separating out the contributions from individual proteins (i.e. linkers) and the nodes where multiple proteins meet and are linked to the membrane of the cell.

Design and construction of a spectroscopy suite - Prof. David Lidzey & Prof. David Mowbray

In this project, you will design and commission a new spectroscopic suite for the 4th year lab. This is a new lab-space that currently comprises an optics table and a number of spectrometers, light sources, detectors etc. Your job will be to write a lab-view script to control a monochromator and record data from an optical detector. You will then construct a spectroscopic system capable of performing a number of different measurements, including absorption, photoluminescence, photoluminescence excitation etc. If time permits, you will use the system to characterize a series of molecular materials as a

function of temperature using a cryostat.

This project will suit students who have good software skills together with an aptitude for practical 'hands-on' design and construction of mechanical systems.

The physics of light emitting diodes - Prof. David Mowbray

The ability to fabricate efficient Light Emitting Diodes (LEDs) whose emission spans the full visible spectrum (plus the near IR and UV) has resulted in increasing numbers of applications. These include general lighting, printing, communications, traffic lights etc. This project will look at the physics behind the design, fabrication and operation of LEDs. In addition to back ground reading students will study the properties of a wide range of LEDs. Measurements will include light-current characteristics, current-voltage characteristics and the spectral output. Measurements will also be performed as a function of temperature to assess the effect on performance of both high (up to 100C) and cryogenic (liquid nitrogen) temperatures.

Particle detection with Plastic Scintillator. Dr. Susan Cartwright

Scintillators are materials which emit light in response to ionising radiation. Particle physics experiments have a long history of using scintillators - the very first particle physics experiment, Geiger and Masden's study of alpha particles scattering off gold foil, used ZnS scintillator as the detector - and they are still used in many applications at the present time. In this experiment, you will study a long bar of plastic scintillator as used in the electromagnetic calorimeter of the T2K experiment. Using small photomultipliers to detect the scintillation light, you will design a readout system and study how the efficiency of light collection varies with position along the bar, for readout at one end only and for readout at both ends. The results may be compared with expectations from existing simulation programs.

Requirements: This is an experimental project, involving some building and configuring of hardware, some data acquisition and analysis, and possibly some use of existing simulation programs depending on the direction the work takes.

Supersymmetric Dark Matter - Dr. Susan Cartwright

The most popular model for the nature of dark matter is that the dark matter particle is the lightest of a family of supersymmetric "partners" to the known particles of the Standard Model. In this theory, the supersymmetric partners differ by half a unit of spin from their Standard Model equivalents, and are also more massive (the symmetry is "broken"). Discovering or ruling out supersymmetry is one of the main physics goals of the Large Hadron Collider.

Unfortunately, as no SUSY particles have yet been discovered, the parameters of the theory remain unknown. However, if we identify the lightest supersymmetric particle (LSP) as the dark matter, then limits can be placed on SUSY parameters by considering the observed dark matter density as deduced from WMAP data. In this project, you will use a standard simulation program (DarkSUSY) to investi-

gate the range of parameter space permitted by the WMAP data and study the implications for LHC.

Note: DarkSUSY is written in Fortran. If you feel reasonably comfortable with C, you should not have too much difficulty adjusting to Fortran (which is an older and simpler language) - but if you struggled with PHY225, this is probably not the project for you. Having taken PHY323 is useful, but not obligatory.

Development of readout electronics for multiwire proportional chambers. Dr. Ed Daw (RESERVED)

Multiwire proportional chambers contain, as the name suggests, hundreds of wires on to which are deposited small amounts (picocoulombs) of charged particles. The timescale for these charge depositions is around a microsecond, which sets the scale for the sampling rate of the digitization electronics necessary to write the datasets to disk for analysis. This project will explore modifications to the existing DRIFT electronics with the aim of reducing the noise level in the data, and reducing the level of undesirable artifacts such as pulse overshoot associated with the existing electronics. This work feeds in to a future design for a scaled-up DRIFT detector. The project requires some skill in electronics and electronic circuit fabrication.

Measurements of the Z boson background to the Higgs boson at the Large Hadron Collider - Dr. Stathes Paganis

The ATLAS experiment at the LHC will start collision data taking in November/2009. The main goal of ATLAS is to discover the Higgs boson. The major obstacle to the discovery in the 'golden' Higgs to 4 lepton channel is the proton-proton to Z-boson + jets background. In this project analysis techniques to measure this background from data will be developed. It is also expected that the student will analyze the first data reconstructing shower shapes from candidate electrons. Knowledge of these shapes are central to measuring the Z+jets background.

Proton interaction studies at the LHC. Dr. Davide Costanzo

Protons travel in opposite directions around the Large Hadron Collider grouped in bunches. When two bunches collide proton interact with a centre of mass energy of 7 TeV and the products of these interactions are recorded by the ATLAS detector.

By counting the number of interactions per bunch crossing we measure the intensity of the bunches and derive a measurement of the proton-proton cross section at the LHC.

Finite element studies of the MICE target actuator - Dr. Chris Booth and Paul Smith

The MICE experiment uses a small linear motor to drive a target into the circulating beam of the ISIS accelerator. The motor consists of a set of cylindrical magnets mounted on a long vertical shaft (carrying the target at its lower end) situated in a bank of cylindrical coils. The magnet and coils are nominally axially symmetric.

The project will involve building a computer model of the magnets and coils using commercial finite-element software. This will then be used to study the performance of the motor as a function of parameters such as the separation between magnets and coils. The magnitude of unwanted lateral forces will also be investigated for the case where axial symmetry is broken, e.g. by non-uniformities in the magnets or misalignment of the components.

Analysing MICE Target Data - Drs. Chris Booth & Paul Hodgson

The MICE experiment dips a small titanium target dynamically into the circulating proton beam in the ISIS accelerator, in order to generate pions (and eventually muons). Data have recently been taken recording the trajectory of the target and also the accelerator beam losses this has generated. There is an opportunity to study a variety of effects in the data stream. These include correlation between beam loss and target position and timing, uniformity of the target operation and stability of the accelerator beam over time. It may also be possible to correlate detector data with the records of protons and pions detected down the experimental beam line.

Langmuir Films of Calixarenes - Dr. Tim Richardson.

Calixarenes are amphiphilic monolayer-forming materials that are highly ordered when closed-packed into 2-dimensional arrays. This project concerns the measurement of surface pressure - area isotherms and surface potential - area isotherms of such ultra-thin films which reside at an air-water interface.

Frequency response of violins, guitars and drums - Dr. Tim Richardson & Prof. John Cockburn

The vibrations of the sound board in musical instruments such as violins, guitars and pianos determines the perceived quality of the instrument. For guitars, different parts of the soundboard vibrate with different amplitudes depending upon the layout of the bracing / strutting glued to its underside. Furthermore for all these instruments, these vibrations are frequency-dependent, that is resonances occur at certain frequencies which are governed by a complex mix of variables such as geometrical shape, wood composition, bracing design etc. This project involves exploring these phenomena mainly for a guitar and a violin, but possibly also for a drum.

Monte Carlo simulations of charge transport in organic semiconductors - Dr. Alasdair Buckley

Charge transport in disordered organic semiconductors can be thought as of hopping through a randomly distributed set of energy levels. The chance of a hop occurring between two sites depends on their energy difference. Such a model is partly successful at describing transport in organic materials but tends to break down at extremes of temperature and electric field. More advanced theoretical models include some degree of correlation of the energy of neighbouring sites. You will write a Monte Carlo simulation to initially replicate the so called "disorder model", and then proceed to investigate the influence of site correlation to the

transport properties. Competent programming is required, but the language you wish to implement the modelling in will not be prescribed.

Optical properties of Opal Multilayers - Prof. David Whittaker

Opals are gem-stones made out of stacked silica nano-spheres; their colours are produced by diffraction effects, which are determined by the sphere size, and so different stones have colours across the entire spectrum. Opals form a natural example of a three-dimensional photonic band-structure material, with their periodic lattice creating ranges of wave-vectors and frequencies at which light cannot propagate in the material.

We can make high quality opals in the laboratory, but these are typically thin layers, of ~10 spheres thick. The aim in this project is to use existing software to model the reflectivity properties of such opal films, and to try to understand how the features we see are related to the photonic band-structure of the bulk material. The final task links to the 'modelling birefringent materials' project; we shall investigate how the reflectivity of an opal structure is affected if the material it is made from exhibits circular dichroism.

Modelling Birefringent Materials- Prof. David Whittaker

Birefringent materials, such as calcite, have different refractive indices depending on the direction and polarisation of the light propagating through them. The main aim of this project is to develop a computer code which will implement a transfer matrix treatment of the reflectivity of a multi-layer structure where some of the materials are birefringent. We shall consider cases both of simple birefringence and circular dichroism.

The final task links into the 'optical properties of opal multilayers' project; we shall investigate how the reflectivity of an opal structure is affected if the material it is made from exhibits circular dichroism.

Coherence of the Microcavity OPO. Prof. David Whittaker (RESERVED)

Semiconductor microcavities are structures which confine light to propagate in a thin slab of material which contains a nonlinear absorbing quantum well layer. Under the right conditions, we can make such a microcavity act as an optical parametric oscillator (OPO). When the structure is illuminated with a laser, coherent emission occurs at two new frequencies, known as the signal and idler. This project is concerned with learning the quantum theory of an OPO, and applying it to work out the coherence for the microcavity system. We shall look at both the temporal properties (how long the emission remains coherent with itself) and the spatial properties (how coherent is light emitted from different regions of the structure).

Pattern Formation in the Semiconductor Microcavities. Prof. David Whittaker

Semiconductor microcavities are structures which confine light to propagate in a thin slab of material which contains a nonlinear absorbing quantum well layer. We have found experimentally that the light in these cavities can form optical vortices

- states with finite angular momentum. It seems that for some parameters these vortices may form spontaneously; if we create a light field which is uniform, this is unstable and may collapse to form vortices and possibly other spatial structures. This is a numerical project, the aim of which is to produce a computer code which solves the non-linear equations for the system. We shall use this to investigate the unstable region and see what sort of patterns evolve.

A ferromagnetic semiconductor: growth and properties: - Professor Gillian Gehring & Prof. Mark Fox

Computers store information magnetically on the hard disc and manipulate information using semiconductors. Hence there is great interest in making a ferromagnetic semiconductor so that these two functions can be combined in one unit. There are many reports of semiconducting oxide films having weak ferromagnetism and also reports of magnetism of small cobalt particles. This project is to develop an optimized material which is magnetic at room temperature and furthermore keeps its magnetism when the applied magnetic field is removed. We shall make a film that has both metallic and oxide magnetism which builds on recent studies by the Sheffield oxide group. Thin films will be made by pulsed laser deposition and their magnetisation measured as a function of temperature and applied magnetic field. Finally the results will be analysed using standard theories of magnetism and a route established for optimal performance.

Nanoplasmonic-semiconductor hybrids - Dr. Luke Wilson

Reducing the size of metallic particles below the wavelength of light leads to dramatic changes in the response to optical excitation. The most striking effect is the emergence of new collective electron oscillation modes (localised plasmons) with resonance wavelengths which can be tuned across the visible to mid-infrared range by varying the size of the metallic particles. In this project you will develop hybrid inorganic semiconductor–metal nanoparticle devices with unique modes of operation provided by the nanoparticle plasmon resonances. The effects you will exploit arise from confinement of optical fields over lengthscales less than the diffraction limit, providing large enhancements of the local electromagnetic field and density of electromagnetic states. New device developments such as highly efficient light emitting diodes and single photon emitters, intense near-field sources and polarisation sensitive detectors can be expected from the research you will undertake. You therefore have a real chance to make an impact in the highly topical research area of nanoplasmonic photonics where new phenomena and technologies are being developed which go far beyond those possible using conventional photonics and electronics.

Semiconductor nanowires - Dr. Luke Wilson

Multijunction solar cells constructed using III–V semiconductors provide the highest efficiency operation (>40%) of any present photovoltaic (PV) approach. III–V Semiconductor nanowires offer a promising route to reducing costs whilst maintaining high efficiencies. Semiconductor materials combinations with a large lattice mismatch that in planar systems would result in dislocations can be grown without such problems in the form of nanowires. Thus the restrictions on choice of materials combinations that are normally present no longer apply when consid-

ering nanowire-based devices. New multijunction designs can therefore be envisaged, with optimised spectral coverage and the real potential for higher efficiency operation.

In this project you will work in our research group, studying III-V nanowires for PV applications. The aim is to develop materials combinations that will allow the production of highly efficient nanowire-based multijunction solar cells. You will take advantage of our recently developed capability of catalyst-free semiconductor nanowire growth. This approach avoids nanowire contamination found in the more common metal-catalyzed nanowire growth and provides excellent uniformity of the nanowires (~5% variation) which permits more straightforward nanowire array PV device fabrication.

Coupling diamond NV centres to photonic crystal cavities. Prof. Mark Fox

Nitrogen vacancy (NV) centres in diamond are a promising candidate for the implementation of solid state quantum bits and room temperature single photon sources. The spontaneous emission dynamics can be controlled by coupling the emitter to the optical mode of a photonic crystal (PhC) cavity. Conventional semiconductor processing of diamond is very challenging because of difficulties in the growth of high quality single crystal diamond and in etching diamond films. For this reason there is growing interest in coupling NV centres embedded in diamond nanocrystals to PhC cavities fabricated in a different material.

In this project you will use finite difference time domain techniques to design photonic crystal cavities in III-V semiconductor materials suitable for coupling to diamond nanocrystals and investigate the effect of diamond nanocrystal on the properties of the PhC. The optimised designs will be fabricated in the National Centre for III-V technologies cleanroom and characterised using optical spectroscopy techniques.

Dynamic photoconductivity - Dr. Martin Grell

Most semiconductors – organic and inorganic- are photoconductors: Conductivity increases under illumination due to photogeneration of mobile charge carriers. However, when illumination stops, conductivity does not immediately return the dark level: It takes some time, τ_{ex} , to extract all photocarriers from the sample. τ_{ex} will depend on applied voltage as well as the charge carrier mobility, μ . Measurement of τ_{ex} hence gives access to μ . Here, you shall build and test a dynamic photoconductivity system, using pulsed illumination in the form of an LED driven with variable frequency, f , from a signal generator. The photocurrent of a sample shall be measured under pulsed illumination by driving a current through it and dropping it across a serial measurement resistor, R_M . Both photocurrent and the LED's drive voltage shall be displayed on an oscilloscope, and compared. At low f , photocurrent will follow drive voltage, but as f approaches $1/\tau_{\text{ex}}$, a time lag between drive and response shall become apparent. Hence, sweeping f allows determination of τ_{ex} . You shall build such a system and first test it with a conventional photodiode, then apply it to organic semiconductor samples. Time permitting, you shall replace the signal generator by feedback of the photocurrent signal to the

LED, resulting in an oscillator that locks itself at $f = 1/\tau_{\text{ex}}$, thus measuring τ_{ex} automatically. The described system would have a variety of applications for measurements on organic semiconductor devices, e.g. sensor systems where μ may change under certain 'odours', organic transistors where μ changes with charge carrier density, or the characterisation of photovoltaic blends. Students will need no background in organic semiconductors, but some experience with electronics (Op Amps, potis, 'scopes, signal generators) is desirable.

Synopses for Astronomy Projects

Anthropic limits on the IMF. Dr. Simon Goodwin

The Initial Mass Function (IMF) is the distribution of stars by mass at their birth. That we exist means that there are enough stars massive enough to produce the heavy elements we need, as well as enough low-mass stars to provide long-term homes for life. In this project we will build a chemical evolution model of a galaxy and examine how we can change the IMF and still have the right elements for life.

Terraforming Mars. Dr. Simon Goodwin

Mars is the best option for human colonisation, but conditions are not really right for humans. We will examine various strategies for changing conditions on Mars by writing a climate model for Mars and applying several proposed terraforming strategies.

Collisions during star formation. Dr. David Hubber & Dr. Simon Goodwin

When they are young stars tend to be far more densely packed than when they are older. This means that collisions between stars could be common in some extreme environments. We will use a hydrodynamics code to examine the interactions and collisions between massive stars and/or star forming cores in dense environments.

To the edge of space - Prof. Vik Dhillon

No. of students: 4 (working in 2 pairs).

Prerequisites: For dual Physics and Astrophysics students who are keen on playing with bits of kit.

Abstract: Your primary task will be to design, construct and launch balloon-borne experiment to take a photograph or video showing the curvature of the Earth from the edge of space (~30 km), and measure the variation of temperature and pressure with altitude in the Earth's atmosphere. In the process of doing this, you will learn how to design and manage a project within a specified budget and timescale - extremely valuable real-world skills. Your first task will be to design a payload containing a camera and some form of altitude/longitude/latitude/temperature/pressure sensors. This payload will also have to include some form of tracking system, be able to withstand low temperatures and pressures, and have some means of landing without damaging itself and others. It is hoped that all electronic components used will be off-the-shelf items and that they will be recoverable on landing. Your second task will be to design the launch system, which will include a

helium-filled meteorological balloon, some form of parachute and a stable mounting for the payload. At the end of this design stage (at the end of the first semester), the two teams of students will present their fully costed designs and, following presentations and detailed questioning, a winning solution will be chosen by the students and academics that offers the best chance of success given the budget of £500. Construction of the payload will commence in the second semester, followed by a launch at a suitable date/place towards the end of the semester.

Wolf-Rayet stars in the Milky Way: Database and spatial distribution. - Dr. Paul Crowther

This project aims to provide a complete database of known Wolf-Rayet stars in the Milky Way, to be made available electronically to the massive star community through a dedicated website, plus analysis of the resulting census. Wolf-Rayet stars are chemically evolved massive stars whose numbers have grown enormously over recent years through dedicated infrared surveys which penetrate the high Galactic disk dust extinction at optical wavelengths. The project will involve a mixture of web database construction, plus subsequent analysis of the resulting known Wolf-Rayet populations from which the global WR population will be estimated, and subtype distribution versus galactocentric distance will be investigated.

Understanding the nature of the central engines in low luminosity (FRI) radio galaxies. Prof. Clive Tadhunter

The properties of low luminosity (FRI) radio galaxies differ markedly from their high luminosity (FRII) counterparts, but it is currently uncertain what causes this fundamental difference. The aim of this project is to determine whether the FRI/FRII dichotomy is caused by different accretion processes in the nuclear regions. It will involve the analysis of spectra taken using the Hubble Space Telescope.

Outflows in rapidly evolving galaxies in the local Universe. Prof. Clive Tadhunter

There has been much speculation, but little direct observational evidence, that AGN-induced outflows can directly affect the evolution of the AGN host galaxies. The main aim of this project is to establish the importance of AGN-induced outflows in rapidly evolving galaxies in the local Universe. It will involve the analysis of spectroscopic data taken with the 4.2m William Herschel telescope.

Searching for dwarf novae in outburst - Dr. Stuart Littlefair

Dwarf Novae are interacting binary stars which undergo regular outbursts, during which they can brighten many times over. These outbursts are caused by sudden collapses of the accretion disc, and are actively studied by professional observers around the world. In this project you will use the robotic telescope on the Hicks Building roof to monitor a sample of Dwarf Novae for outbursts, and obtain light-curves of the stars in outburst.

Measuring mass in binary stars. Dr. Stuart Littlefair

Measuring stellar masses requires the application of many novel techniques. You will use the newly commissioned 16" telescope and spectrograph to measure the motions of stars in a binary system, and use these motions to measure the relative masses of the stars.