Senior Physics Special Projects

Semester 2, 2006

Version 3 (June 5, 2006)

What is a Special Project? See the Senior Physics Web page for details on the aims and assessment:
`http://www.physics.usyd.edu.au/ugrad/sphys/projects.html`

How do I enrol? You must first arrange a supervisor and a project. Once you have reached an agreement with your supervisor, please complete a Special Permission form (available from the Student Support Office in Physics). This must be signed by the Senior Physics Coordinator (Dr Tim Bedding, Room 554, `bedding@physics.usyd.edu.au`) and then taken to the Science Faculty Office (Carslaw) to allow you to enrol.

Suggested projects: The following compilation of project topics is not complete. It is intended to give you a flavour of the kinds of research being done in the School. You are invited to discuss these and other projects with the supervisors listed here. You can also look at the Web pages describing Research Activities in the School:
`http://www.physics.usyd.edu.au/research.html`

How do I contact supervisors? Unless indicated otherwise, all staff have e-mail addresses of the form
`I.Name@physics.usyd.edu.au`
where `I` is the initial letter of the person's first name, and `Name` is their surname.

What is new in this version?

Version 2: One new project has been added: 8.1

Version 3: Two new projects have been added: 12.3,12.4

1 APPLIED & PLASMA PHYSICS

1.1 A Phasor and Particle Model for coupling between an auto-matching network and electrical plasma (Dixon T. K. Kwok)

In most of the semiconductor fabrication processes such as plasma doping, plasma-enhanced chemical vapor deposition, and plasma etching, electrical plasma (ions and electrons) are involved. To generate the plasma, it is common to use radio-frequency (RF) coupled inductive or capacitive discharge with an external matching network. Verboncoeur et. al. developed a simultaneous potential and circuit solution for 1D bounded plasma particle simulation. Gauss's law was applied to the plasma system and the second order finite difference equation was derived for the second order Kirchoff's voltage law for a general voltage-driven RLC circuit. However, an external matching network is more complicated than a simple RLC circuit. In plasma processes such as plasma doping, several matching networks with different frequencies may be applied to the electrodes. Solving the second order Kirochoff's voltage equations pertinent to these complicated matching networks is very difficult. An RF signal going through a general matching network can be described by its absolute amplitude and phase. Based on the phasor analysis, any complicated circuits can be described by several linear equations that can be solved directly.

A model combining the plasma particle model and electrical phasor model is developed, so that the coupling of the plasma with any external matching network can be effectively simulated. The aim of this project is to use this model to investigate the amplitude and phase of the voltage/current of the external matching network when coupled to different electrical plasma conditions.

Students will learn in this project;

a) the basic principle of a matching network; b) programming in Microsoft Managed C++ .net; c) numerical simulation of using Particle-in-cell (PIC) model; d) the working principle of low pressure electrical plasma.

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1.2 Monte Carlo simulations for Fibre Optic Dosimetry (David McKenzie, Jamil Lambert, Natalka Suchowerska)

Fibre optic dosimetry is a new way of measuring dose in radiotherapy and in environmental montioring. A scintillator is attached to a fibre optic and measures the dose locally. Cerenkov radiation is produced when a high energy electron passes through a medium faster than the speed of light in that medium. This radiation creates a large unwanted background signal in optical fibres used in radiation therapy dosimetry. The purpose of this project is to design and write a function of the Egs4 Monte Carlo program to calculate the path of electrons through an optical fibre when exposed to a high energy electron or photon beam. This will help to explain the observed Cerenkov radiation and be used to optimise the design of radiation detectors that use an optical fibre.

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1.3 Dye Sensitised Solar Cells (Ned Ekins-Daukes)

Dye sensitised solar cells represent a new approach to the problem of converting sunlight into electricity. Inspired by the process of photosynthesis, organic dyes are used to absorb sunlight and generate charge carriers. The key to successful solar cell operation is to extract the charge carriers from the dye with the minimum energy loss. This is typically performed using a nanostructured TiO_2 semiconductor, that collects electrons and a redox electrolyte that replenishes the dye ground state. The best power conversion efficiency achieved using this solar cell technology is 11%. In this project dyes derived from fruit and artificial laser dyes will be compared, both in terms of their solar absorption and electron transfer properties. In addition, the efficacy of home made TiO_2 films and commercial samples will be assessed. The project will involve some chemical preparation, optical spectroscopy and electron microscopy and serves as a good introduction to the physics of solar energy conversion.

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1.4 Super-elasticity and shape-memory in disordered carbon (Nigel Marks, David McKenzie)

Disordered carbon has an amazing ability to recover its shape after deformation. This ability is thought to be connected with the crumpled sheet-like topology of the material. We will perform atomistic simulations in which we compress a carbon structure by as much as 10-20%, far beyond the elastic limit of most materials. The calculations will show how the carbon material is able to remember its original shape, even after new bonds have formed. This project will bring together computer simulation and indentation experiments performed in the School. Should the project be successful, the results will be presented to the SMAC (Specialist Meeting on Amorphous Carbon) international meeting.

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1.5 Temperature-accelerated dynamics of radiation damage (Nigel Marks)

Molecular dynamics (MD) simulation provides powerful insight into atomistic systems, but calculations are limited in scale to the picosecond or nanosecond. Temperature accelerated dynamics (TAD) is a recently proposed scheme which extends the capabilities of simulation to the laboratory scale, that is, seconds, minutes and even hours. This project will apply the TAD method to the investigation of radiation damage as experienced by materials in extreme environments, such as nuclear reactors and spacecraft. The student will learn the use of the cutting-edge TAD computer code from the Voter group at Los Alamos National Laboratory, and will gain insight into the world of materials science at the atomic scale.

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1.6 Molecular Simulation for Quantum Computer Fabrication (Oliver Warschkow, Nigel Marks, David McKenzie)

Controlling and manipulating individual atoms is a key skill in the atom-by-atom construction of nanotechnological devices such as quantum computers. In order to do this effectively, we must understand the quantum mechanical behaviour of atoms and molecules on a surface. This project will use computer simulations to explore how the ammonia molecule interacts with the silicon surface. The calculations will be compared to high-resolution scanning tunneling microscopy (STM) images which remain unexplained.

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1.7 Object Oriented Programming and Molecular Simulation (Oliver Warschkow)

This project is aimed at students with an interest in both scientific computing and software engineering, as both aspects will be covered. The scientific computing objective of this project is to implement the equations of molecular dynamics into a simple computer code using an object-oriented programming language (C++ or Java). The software design objective (or obstacle depending on viewpoint) is to do this is in a way that reuses components of an existing software library for molecular simulation and adds new components to the library. This project has scope to accommodate a students particular interests in this field; some familiarity with object-oriented programming techniques is required.

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1.8 Exploring Chemical Reactions using Metadynamics (Oliver Warschkow, Nigel Marks)

First-principles molecular dynamics solves the Schrödinger equation for an ensemble of atoms, providing an accurate description of the vibrational and rotational motion. However, the simulations are restricted to picoseconds, many orders of magnitude smaller than the typical timescale on which atomic rearrangements occur. Metadynamics is a complementary technique which biases the simulation in such a way that chemical reactions become commonplace. This project will explore the use and limits of metadynamics in the context of quantum computer fabrication.

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1.9 Surfaces for attachment of biomolecules (includes a number of project areas) (M.M. Bilek and other members of the team as appropriate)

The attachment of bioactive proteins to surfaces underpins the development of biosensors and diagnostic arrays for detecting disease. We have developed and patented a plasma technology utilising high energy ions for activating polymer surfaces to attach proteins and retain their activity. We have demonstrated the technology with three enzymes and developed a theory for the chemical and physical mechanisms responsible for their enhanced attachment. In the next phase of the project we seek to test our theory by studying the effects of modifications to the surface chemistry on interactions with a new set of proteins. The interactions of the proteins with the new surfaces will be examined using a range of methods including surface plasmon resonance, ellipsometry, neutron reflectometry and biological activity assays. There are a number of student projects available, all of which will allow the student to learn about the physics governing the response of protein molecules to surfaces and to become familiar with one or more of these analysis methods. In the course of the project students will interact directly with our research partners in biochemistry, anatomy, CSIRO and ANSTO and learn the research skills required to function effectively in a vibrant, multidisciplinary research environment.

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1.10 Development of Spectroscopic Methods for Protein Detection (D.R.McKenzie, M.M. Bilek and A. Kondyurin)

Proteins are polymer macromolecules folded into an approximately spherical shape. The area of physics that is concerned with the behaviour of matter of this type is "soft condensed matter physics". Proteins carry out the functions that enable a living cell to carry on its activities. Certain proteins are characteristic of disease states and detection of these is useful for medical diagnosis. Antibodies exist to each protein which "recognize" the protein by a binding process to a specific binding site. We are developing an "on chip" medical diagnostic by creating surfaces suitable for attachment of antibodies to produce antibodies arrays. In this project we will experiment with the use of several spectroscopic methods to detect the attachment of a protein in body fluid simulating solution to its antibody and to a surface. The methods we will explore are ellipsometry, surface plasmon resonance, fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy. We have state of the art equipment for all of these spectroscopies. In ellipsometry, the detection occurs via the effect of the molecule on the refractive index of the solution. We will test a new method of increasing the sensitivity of the ellipsometry by coupling to surface plasmons in an island metal film. In FTIR, the molecules are detected by their characteristic vibrational frequencies and the shape of the peaks can be used to infer structural information about the proteins conformation on the surface.

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1.11 Surface treatment of complex shapes for medical and automotive industries (D.R. McKenzie M.M. Bilek)

Ion implantation by immersing the object, whose surface is to be treated, in plasma is used to improve its surface properties. A problem arises in practice when objects of complex geometries are treated because due to the dynamics of the plasma sheath the dose is not uniform around sharp points and deep hollows. This is a major issue hampering the treatment of prosthetic devices such as artificial joints and automotive components such as gears. A mesh approximately conforming to the shape but not in contact with the surface could provide a way of modifying the dose distribution by refocusing ion trajectories using curved surfaces and by masking. This project aims to understand the ion focusing effects of various mesh topographies. The ion dose distribution will be measured by using polyimide membranes which show increases in optical opacity in proportion to the ion dose. Complex shaped workpieces simulating medical prosthetic devices and automotive components of interest will be made and coated with the polyimide membranes for plasma treatment and optical dose measurement. The results will be compared with existing calculations of the dose from simulations of the plasma as a collection of positive and negative particles.

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1.12 Characterisation of a Novel High Density Plasma Source (M.M. Bilek and D. Andruczyk)

The Applied and Plasma group has recently developed and commissioned a high current (1–5 kA) pulsed cathodic arc plasma source. This source is the only one of its kind in the world and produces a much higher instantaneous ion flux than any other deposition system currently available. The range of parameters which can be accessed make it an ideal instrument for investigating the basic physics of plasma transport in magnetic and electric fields. This project will utilize high-tech plasma diagnostic equipment, such as time resolved Langmuir probes, microwave and laser interferometry and tomography, and CIS spectroscopy) developed in collaboration with the fusion research group at the ANU, Canberra, on a two million dollar ARC infrastructure grant awarded to the consortium. The questions to be investigated include the identification of instabilities associated with transport of a high density fully ionized drifting plasma in magnetic fields, the development of enhanced charged states in the rapidly expanding plasma region of the high current cathodic arc and the effect of transport through a magnetic filter on ion charge and energy distributions. Recent simulation work has predicted that the charge state distribution is coupled to the energy distribution in a specific way and we are now in a unique position to test this. There are two to three separate projects available in this general area.

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1.13 Synthesis of MAX phases using a high powered pulsed plasma (R. Tarrant, M.M. Bilek)

The MAX phases are made up of an early transition metal M, an element from the A groups, usually IIIA and IVA, and a third element, X, which is either nitrogen or carbon, in the composition Mn+1AXn, where n is 1, 2 or 3. The MAX phases represent a new class of compounds which have unique properties that can be related to their layered (nanolaminate) crystal structure. They have high thermal and electrical conductivities and are machineable like metals, but are also highly resistant to oxidation and thermal shock like ceramics. To fabricate a thermodynamically stable MAX phase material it is necessary to obtain the correct stoichiometry and so a means of combining elements with high degree of accuracy is required. This project aims to fabricate Ti2AlC and Ti3AlC2, and possibly also V2AlC, and Cr2AlC, using the high current pulsed cathodic arc in the School of Physics. This is a unique deposition tool allowing highly reproducible, sub-monolayer quantities of material to be ablated into a plasma during each pulse. A ternary cathode source has been built, calibrated , and interfaced with control software. The plasma parameters and film properties will be measured and correlated to develop an understanding of the synthesis process.

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1.14 Reactive deposition of thin films from a pulsed cathodic arc plasma (R.N. Tarrant, S. Lim and M.M. Bilek)

To make ceramics such as metal oxides and nitrides using a cathodic arc plasma, it is necessary to operate the arc in a background pressure of the gas. The gas is then ionised by its interaction with the metallic cathodic arc plasma. This interaction varies with gas pressure, flow rate and injection point in the vacuum chamber. In a pulsed cathodic arc the interaction also varies as a function of time throughout the pulse. Depending on the time between pulses cathode poisoning or total gettering of the gas molecules can occur blocking completely the metal plasma from reaching the substrate. This complex system of dependencies means that the stoichiometry of films deposited in the reactive mode is difficult to control. This project will utilise a mass selective energy analyser, time resolved Langmuir probes and other plasma diagnostic methods to map the parameter space associated with the reactive mode. The use of a secondary ion source to pre-ionise the gas will also be explored. The stoichiometry of deposited films will be determined by SNMS (secondary neutral mass spectroscopy) and optimum deposition conditions for ceramic materials will be identified.

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1.15 Computer Simulation of Stress and Preferred Crystallographic Orientation (D.R. McKenzie and M.M. Bilek)

A number of theories based on different physics are proposed to explain the formation of preferred crystallographic orientation in microcrystalline thin film materials. The competing ideas are based on energy minimization on the one hand and dynamic effects associated with energetic ions during the growth process on the other. Although a lot of experimental data exists showing how various plasma parameters used during the growth phase affect the preferred orientation of the resulting materials, the data on elastic constants which determine the minimum energy orientation in a biaxial stress field are is scant. In this project the student will use quantum mechanical computational methods to determine the anisotropic elastic constant tensor for a number of well studied materials and using this data calculate the orientation minimizing the elastic energy for each phase. The results will be compared to the experimental data to assess the two prevailing theories and hopefully resolve the prevailing controversy. A definitive resolution of the controversy will certainly result in a landmark publication.

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1.16 Thin Film Deposition Using 2-D Linear Scanning RF plasma (Y. Yin, D.R. McKenzie)

A novel 2-D scanning RF plasma system was developed in this group. The patented and unique technology opens a way to provide flexibility in plasma control and thus materials properties manipulation. The scanning method allows the deposition of thin films layer by layer; typically each layer is within a few nanometres or as thin as one nanometre. This project aims to optimise and study silicon oxide thin films deposited using this scanning plasma method. Technologically important properties such as stress and optical constants as a function of wavelength will be measured and correlated against the plasma discharge parameters. The physical effects of the scanning method on the properties of the thin films deposited will be studied.

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1.17 Monte Carlo modelling of Cerenkov radiation in optical fibres (J. Lambert, D.R. McKenzie)

Cerenkov radiation is produced when a high energy electron passes through a medium faster than the speed of light in that medium. This radiation creates a large unwanted background signal in optical fibres used in radiation therapy dosimetry. The purpose of this project is to design and write a function of the Egs4 Monte Carlo program to calculate the path of electrons through an optical fibre when exposed to a high energy electron or photon beam. This will help to explain the observed Cerenkov radiation and be used to optimise the design of radiation detectors that use an optical fibre.

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2 ASTRONOMY & ASTROPHYSICS

2.1 Extreme radio galaxies in the Phoenix Deep Survey (Andrew Hopkins)

Radio galaxy spectral shape has traditionally been used to differentiate between two broad populations: (1) steep spectrum objects, often the extended lobes of radio jets, and (2) flat spectrum objects, often an active nucleus at the core of a radio galaxy. The radio spectral slopes for several hundred radio galaxies in a deep radio survey called the Phoenix Deep Survey have recently been measured. The aim of this project will be to explore the nature of the objects with extreme spectral slopes, making use of existing complementary imaging at optical and near-infrared wavelengths, as well as optical spectroscopy.

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2.2 Oscillating stars (Laszlo Kiss, Tim Bedding)

A star is a sphere of gas that can oscillate in many modes simultaneously. By studying the properties of the oscillations, we can learn about the internal structure of the star. This process, called asteroseismology, is analogous to the way in which geologists use earthquakes to study the interior of the earth. We have several projects in mind, most of which involve analysing observations of stars using Fourier transforms and similar methods. We would be happy to discuss possible projects with interested students.

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2.3 Investigating our Galaxy with the Molonglo Galactic Plane Survey (Tara Murphy, Anne Green)

Our Galaxy is full of strange phenomena, from supernova remnants to planetary nebulae. We have almost finished the Molonglo Galactic Plane Survey which will give us a unique view of the plane of our Galaxy. At radio frequencies we can see through the dust that obscures optical observations, revealing many new objects. The data from this survey is relatively unexplored, so in this project you will have a chance to find and identify new objects.

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2.4 Compact, Isolated High Velocity Hydrogen Clouds (Tara Murphy)

Observations of Neutral Hydrogen are a powerful tool for understanding the nature and distribution of gas in our galaxy. The Galactic All Sky Survey (GASS) is mapping the Hydrogen in our Galaxy with the Parkes radio telescope. Objects of particular interest are compact isolated clouds of gas that lie away from the Galactic Plane. Finding these is difficult due to the massive amount of data in the survey. This project involves developing an algorithm to detect these objects so we can create the most comprehensive catalogue of them to date.

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2.5 Martian Radio Emissions (Zdenka Kuncic, Iver Cairns)

This project involves predicting the levels of radio emissions associated with small-scale magnetic anomalies on Mars. Such radio emissions could be used in practice as a remote sensing tool to locate magnetic anomaly sites favourable for establishing Martian biospheres. The project uses an existing code that may need to be modified slightly for application to Mars.

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2.6 The Interstellar Medium, Star Formation, and Magnetic Fields in the Milky Way (Peter Barnes, Anne Green, Andrew Hopkins, Bryan Gaensler)

We have a number of projects available in the structure and evolution of the interstellar medium. These include problems in the details of star formation (eg, enhancing an interstellar medium database to find likely sites of current and future star formation; measuring the temperature evolution of individual massive protostars on their way to the Main Sequence; mapping ammonia emission from a sample of medium-mass protostars; analysing the chemistry and dynamics in dense molecular clouds forming low- or high-mass stars), and larger-scale questions of galactic structure (eg, analysing the radio and far-infrared emission from a part of the galactic plane to look at the interaction between newly forming stars and the interstellar medium; examining the physics of variable radio sources in the galactic plane; exploring the global properties of the multiwavelength emission from star-forming regions in order to find the connections between SF rates and SF luminosities; radio polarisation observations to explore the galactic magnetic field). Please contact any of us for more details.

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2.7 Radio galaxies in the Hubble Deep Field (Elaine Sadler, Tom Mauch)

In this project, you will explore some deep radio images of an area of sky which has also been studied by the Hubble Space Telescope and several other telescopes around the world. The goal is to identify rare, distant galaxies which are powerful sources of radio emission. This radio emission may arise either from regions of violent star formation, or from processes related to a supermassive black hole at the galaxy's centre. By studying the parent galaxies of the radio sources, you should be able to estimate which of these mechanisms is more common.

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3 BIOPHYSICS

3.1 Simulating protein unfolding at high temperatures (Serdar Kuyucak, Turgut Bastug)

Proteins are produced in a string form in cells and fold to their 3-dimensional native states within seconds. How this happens is one the most interesting problems in biophysics today. While it is still beyond our reach to simulate the folding process in the native environment of a cell, we can learn from the reverse process of unfolding by speeding it up using higher temperatures than the body temperature. The project involves molecular dynamics simulations of some simple proteins at several different temperatures and analysing their structural properties to assess the degree of unfolding.

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3.2 Simulating protein unfolding (Serdar Kuyucak, Turgut Bastug)

A second way to speed up unfolding of proteins (see the above project) is to fix one end of the polypeptide chain and apply a force on the other. This is realized in labs using optical tweezers. This process can also be simulated on computers using steered molecular dynamics with harmonic pulling forces. The work done on the protein, and hence the free energy change during unfolding can be calculated using Jarzysnki's equality. The project involves molecular dynamics simulations of some simple proteins subjected to harmonic pulling forces, and calculating the free energy change during unfolding which will be contrasted with the structural changes in the protein.

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3.3 Ion permeation in carbon nanotubes (Serdar Kuyucak, Turgut Bastug)

Carbon nanotubes have many potential applications in biotechnology, medicine, electronics and materials science. An interesting question that may have important ramifications in biotechnology and medicine is whether they can be made to function like ion channels. The project will investigate the permeation properties of carbon nanotubes using molecular dynamics simulations. Steered MD simulations and/or umbrella sampling method will be used to caclulate the free energy profiles of ions crossing a nanotube. Issues to be addressed include: size (radius and length of the nanotube) dependence of ion conduction and modification of the nanotube structure so as to make it charge selective.

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3.4 Memory effects in Brownian dynamics simulations of ion permeation (Serdar Kuyucak, Turgut Bastug)

Brownian dynamics (BD) simulations provide the only reliable method that allows calculation of conductance of ion channels at present. In all applications of BD to ion channels so far, the random forces used in the Langevin equation are assumed to have no memory (i.e. Markovian). This approximation is fine in a purely diffusive motion of ions but its validity has not been tested in the presence of potential energy barriers, which are quite common in ion channels. The project involves BD simulations of identical model systems using Markovian and non-Markovian random forces with the aim of finding out the domain of validity of the Markovian assumption. For this purpose, the width and height of a potential barrier in a schematic model will be systematically varied and the conductance results from the two BD simulations will be compared. Deviations between the two results in a certain range of barrier parameters will signal the break down of the Markovian assumption, and will compel the use of non-Markovian random forces in future BD simulations of ion channels that have similar energy barriers.

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3.5 Polarizable force fields in molecular dynamics simulations (Serdar Kuyucak, Turgut Bastug)

Practically all the force fields employed in molecular dynamics simulations of biomolecules neglect polarization interactions among the atoms. Computational expense used to be the main reason for this approximation but this is no more an excuse. Nevertheless lack of compelling evidence showing the importance of polarization effects is hindering development of polarizable force fields. One area where one may find such evidence is the temperature dependence of the transport coefficients of ions (conductance and diffusion), which are grossly underestimated by the traditional force fields. The project involves calculation of the transport coefficients of ions using a polarizable force field at several temperatures. An improved agreement with the experimental data will provide a clear signal for the importance of polarization effects and thus will help to stimulate development of polarizable force fields.

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4 BRAIN DYNAMICS

4.1 Modelling of Brain EEG response with layered cerebral cortex (Peter Drysdale and Peter Robinson)

Electroencephalograms (EEGs) measure electrical activity of the brain via scalp electrodes. They have diverse applications in medicine and understanding of brain function. The Brain Dynamics group has developed successful models of EEG, which reproduce the observed major features of EEGs. Each of these models contains a number of neural populations modelling parts of the brain. In particular, the cerebral cortex in each of these models is approximated as a homogeneous mixture of excitory and inhibitory neurons. In fact the human cortex is divided into six layers of neurons each with different properties and characteristic length scales of connections. This project will explore how the addition of layered structure in the cortex alters the predictions of EEG models. In this project the existing estimates of the properties of these layers will be found from the published literature and used as input to run simulations of neural activity using an existing computer program. Exploration of this layered structure will ultimately allow greater insight into EEG responses.

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4.2 Chaos in Continuum Models of Brain (Jong-Won Kim, Peter A. Robinson)

We aim to understand dynamical behaviors of brain activities by analyzing models based on coupled differential equations. In particular, steady states and limit cycle solutions and their bifurcation properties are to be investigated using basic chaos theory. Broad background knowledge on brain and chaos theory will be studied as well. We consider models where a cell-body potential is activated by a sigmoidal function and an external driving. In case the external driving is given as a sinusoidal function, it becomes similar to the well-known Duffing equation. We thus use the same techniques which have been developed to analyze the Duffing equations although detailed dynamical results may vary due to the differences between the sigmoidal and the polynomial function. The analyed properties of models should be interpreted with respect to physiological observations of brain activities. New insights on complex brain dynamics will be expected to be unveiled through this approach.

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5 COMPLEX PLASMAS

5.1 Physics of complex plasma (Alex Samarian, Brian James)

Complex plasma contains micrometre-sized particles which usually acquire a huge net negative charge (billions of electron charges). They form crystal-like structures (called plasma crystals) which exhibit phenomena such as wave propagation, vortex motion, instabilities and phase changes. Complex plasmas occur naturally in outer space in the form of planetary rings and comets. Plasma etching used in semiconductor processing can generate dust particles which are a source of contamination. In the laboratory, complex plasmas are produced by sprinkling small particles into a discharge. The plasma crystals formed from these charged particles are illuminated by a laser and their motions are recorded for later analysis using a CCD camera. This project involves the experimental observation of plasma crystal consisting of several layers of dust particles trapped in a planar radio frequency discharge. The structure and dynamics of such plasma crystals will be investigated.

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5.2 Symmetry-breaking, phase transitions and group theory in a complex plasma. (Sergey Vladimirov, Alex Samarian)

The nature of particle arrangements in systems containing large number of particles (Plasma Crystals) can be easily understood by considering simplified systems of just a few (e.g., two) particles. In a typical experiment the dust particles levitate in the sheath, where the strong plasma (ion) flow to the electrode is established. The plasma flow naturally provides a prevalent direction and reduces the symmetry of the system. One of the striking observations is the symmetry-breaking disruption of arrangement in two particle systems in which particles change their arrangement from the horizontal to the vertical when the plasma parameters are changed. The symmetry breaking appears initially as a continuous change of position of one particle, then followed by an abrupt (discontinuous) change of the symmetry. The project involves the the analysis of the symetry breaking during the structural phase transition dust structures in complex plasma.

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5.3 Plasma treatment of living cells (Brian James, Alex Samarian)

The effect of atmospheric discharge plasma (ionized gas) on biological material has received much attention in recent years due to its possible application as a sterilization device that is fast, simple, and operates at low temperature. While atmospheric plasma has been shown to be very effective for sterilization and decontamination, non-lethal effects on cells were minimally studied. For example, it has been suggested that plasma treatment might affect adhesion between cells. Therefore, the plasma can be useful in fine surgery where some tissue can be removed without damage to adjacent cells or inflammatory reaction. There is also the possibility of the plasma variance depending on the differences between cells. This will allow the discharge to kill targeted cells. Thus the gas plasma can be used, for example, for the treatment of blood plasma. The project will use low power atmospheric glow discharge and involves the establishment of the procedures for producing differential effects on cells of the same kind that are infected/not infected, cancerous/non-cancerous.

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6 CONDENSED MATTER THEORY

6.1 How Attractive Are You? : Relevance of the concept of electronegativity for surface adsorption (Cathy Stampfl, Mira Todorova and Aloysius Soon)

Rational design of materials will ultimately rely on an atomic-scale understanding of the targeted functionality. Corresponding theory must then accurately describe the behaviour of electrons and the resulting interactions that govern the elementary processes among the atoms and molecules in a system. Dnsity-functional theory, which does not rely on empirical or fitted parameters making it predictive and applicable to a wide range of problems and various conditions, is well suited for such a purpose.
To aid the fundamental understanding of chemisorption, the relevance of the concept of electronegativity is to be examined. Electronegativity, owes its modern definition to Linus Pauling and is understood to be *the power of an atom in a molecule to attract electrons to itself.* Flourine, oxygen and nitrogen are considered to be some of the most electronegative elements. This project will investigate their adsorption behaviour on two distinct metal surfaces by means of density-functional theory calculations, as carried out on high-performance computers.

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6.2 Noble and Rare? The Xe/Pb(111) (Cathy Stampfl, Mira Todorova and Aloysius Soon)

Rare-gas atoms adsorbed on metal surfaces represent a paradigm of weak adsorption, i.e. physisorption. There has been a long-standing debate about the on-surface site that rare-gas atoms will adsorb at. Initially, it was assumed to be one of the highly coordinated hollow sites (e.g. face-centred-cubic or hexagonal-close-packed). Recent studies have shown, however, that Xenon atoms actually prefer to adsopb in an on-top site. New low-energy electron diffraction studies for Xe atoms on the Pb (111) surface once more raise the question about the site at which a Xe-atom would preferentially sit.
The project involves performing ab initio quantum mechanical calculations for the Xe-Pb system in order to shed light on this question. Various adsorption sites and geometries will be studied to establish the prefered adsorption site, and detailed analysis will be used to propose why it is so.

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6.3 Wires in the nanoworld (Damien Carter, Catherine Stampfl)

There is much current interest in the optical properties of semiconductor nanowires, due to their possible role as important nanoscale building blocks for future optoelectronic, high-temperature/power and spintronic device applications. Gallium nitride (GaN) nanowires are one such system of interest, as gallium nitride is a wide-bandgap semiconductor widely used in ultraviolet-blue light-emitting diodes, lasers and photodetectors.

While holding exciting potential, little is known about the properties of nanowires and of the behaviour of defects and dopants. This project will use state-of-the-art ab initio density functional calculations to examine the atomic and electronic properties of key point defects in GaN nanowires of various sizes.

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7 CUDOS (Centre for Ultra-high Bandwidth Optical Systems)

7.1 Analytic model for side-coupled photonic crystal cavity (Martijn de Sterke and Lindsay Botten (UTS))

Photonic crystals are structures in which the refractive index varies periodically with position, with a period of a few 100 nm. The periodicity can lead to Bragg reflection, and associated (photonic) bandgaps for visible and near-infrared light. A number of different photonic crystal-based devices have been considered, but most analyses have been purely numerical, which provides only limited physical insight. We have developed an analytic method which does provide some of this insight, and which we are now refining, and we want to apply this method to various different geometries. The aim of this theoretical and numerical project is to use this method, including parameters that are found from rigorous numerical calculations, and apply it to a side-coupled cavity, which consists of a waveguide that is weakly coupled to a resonant cavity.

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7.2 Slow light solitons in chirped fibre gratings (Martijn de Sterke, Eduard Tsoy, and Joe Mok)

"Slow light," a hot topic in optics, refers to the fact that the group velocity of light can be widely manipulated. This allows light pulses to propagate very slowly, much slower than the speed of light in vacuum. One of the main problems with these schemes is that the group velocity depends strongly on frequency, leading to severe broadening of the pulses. We get around this problem by using *solitons*, in which dispersion is cancelled by nonlinear effects in the glass. We believe that extremely low velocities can be achieved in chirped fibre Bragg gratings: gratings in which the period slowly changes with position. The aim of this numerical project is to study the propagation of these solitons and to ascertain how these low velocities can be achieved, keeping in mind what is feasible in the lab.

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7.3 Efficient four-wave mixing in highly nonlinear chalcogenide nanowires (Ben Eggleton, Hong Nguyen, Eric Magi)

At high light intensities, materials such as glass respond "nonlinearily", which means that the refractive index depends on intensity and that the glass can generate light at new frequencies. This project will investigate nonlinear processes in highly nonlinear chalcogenide optical fibres that have been tapered to very small (sub micron) dimensions. In the waist of the tapered fibre, ultra-high nonlinearities can be achieved, leading to a range of fascinating and very useful processes. Furthermore, the tapering allows us to engineer the group velocity dispersion, which means that we can achieve new frequencies very efficiently. This project will investigate this process theoretically using analytic equations and nonlinear simulations and will perform measurements through such tapers.

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7.4 Parabolic pulses in highly nonlinear fibres (Ben Eggleton, Hong Nguyen, Libin Fu, Alex Fuerbach [Macquarie])

Under certain conditions parabolically-shaped optical pulses (known as similaritons) can propagate without changing shape in spite of strong dispersive effects. These pulses require a careful interplay between dispersion, nonlinearity and gain which is difficult to obtain in conventional optical fibres. CUDOS is pioneering a new class of optical fibre based on a highly nonlinear material known as chalcogenide that possesses the properties to generate and propagate parabolic pulses. This project will investigate theoretically and experimentally the propagation of parabolic pulses through highly nonlinear chalcogenide fibres. Sophisticated experiments will be performed using ultra-fast picosecond pulsed lasers and pulse diagnostics.

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7.5 Monitoring noise in ultra-high bandwidth 160 Gb/s optical transmission systems (Ben Eggleton, Mark Pelusi)

This project will investigate schemes that can monitor noise in ultra-high bandwidth optical communication systems, specifically in-band "noise", which limits the distances that data can be transmitted. The problem is that at 160 Gb/s, which involves light pulses that are only a few picoseconds long, electronics cannot process the information sufficiently fast. CUDOS is pioneering all-optical methods to monitor noise in high-speed optical communication systems. It relies on a "nonlinear" process occurring in a nonlinear waveguide, so that very fast fluctuations in the signal, i.e. noise, can be monitored on a slow, and thus cheap, detector. This project will investigate new schemes at 160 Gb/s on our newly established facility. We will analyze simple designs using theory and simulations, which will subsequently be tested on the facility.

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7.6 Supercontinuum generation with preconditioned sources (Dane Austin, Jeremy Bolger, Martijn de Sterke, Ben Eggleton)

Supercontinuum generation is a spectacular nonlinear optical process that can occur in optical fibres; starting with a short pulse with a pulse length that is a fraction of a picosecond, the process leads to a wide continuum that covers 100's of nanometers, and that looks white to the eye. The process has many applications in metrology and imaging. Some of the applications benefit from spectrally narrow high-intensity peaks on the otherwise featureless background. We recently discovered that this can be achieved using input pulses that are preconditioned by manipulating their amplitude or phase. The aim of this project, which is experimental, theoretical or a combination, is to study this process in more detail and to devise novel methods of preconditioning.

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7.7 Coated photonic crystal fibres: analysis of hybrid guidance mechanisms (Boris Kuhlmey, Ross McPhedran)

Photonic crystal fibres (PCF) are a new kind of optical fibre in which light is guided by microscopic air holes running along the fibre. Compared to conventional optical fibres they offer exciting properties, most of which still remain to be explored. PCFs can guide light by a variety of physical effects, notably total internal reflection, Bragg reflection and antiresonant or ARROW effects. While so far these various mechanisms were reasonably clearly separated according to the geometry of the PCFs, new types of PCFs having coated holes exhibit characteristics of more than one guidance effect. In this project, we will clarify the interplay between the various guidance mechanisms in coated PCFs through numerical studies, using our in-house modeling tools (http://www.physics.usyd.edu.au/cudos/mofsoftware/).

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7.8 Surface waves in photonic crystals (Mike Steel, Snjezana Tomljenovic-Hanic, Martijn de Sterke)

Photonic crystals are structures in which the refractive index varies periodically with position. Since the period is a few $100\ \mu\mathrm{m}$, visible and near-infra red light can be Bragg reflected by these structures, leading to bandgaps for light ("photonic band gaps"). The aim of this numerical project is to study the fields that can occur at the interface between two different photonic crystals (a "heterostructure"), or between a photonic crystal and a uniform medium. This is not only interesting in its own right, but also sheds light, so to speak, on the properties of double heterostructures, currently the most promising route to achieving novel, photonic crystal based, lasers with ultra-low threshold.

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8 ELECTRON MICROSCOPE UNIT (EMU)

8.1 Three-Dimensional Imaging of Atoms in Advanced Titanium Alloys (Prof. Simon P. Ringer, Dr Tomoyuki Honma & Dr David Saxey)

The new Local Electrode Atom Probe (LEAP) at the Electron Microscope Unit allows us to see the three dimensional (3-D) arrangement of atoms in solids. The atoms at the tip of a needle-like specimen are ionized and drawn out by the local electric field. The ionized atoms are removed one-by-one and their precise 3-D positions are recorded. The mass spectrometer in the LEAP can identify the ionized atoms to a very high resolution. Therefore, one can get 3-D images at the nanometre scale showing the position and type of each atom. This project is concerned with the development of new advanced titanium alloys for aerospace applications where there is a need to understand the alloy structure and chemistry down to the atomic level. The student working in this program will develop new specimen preparation techniques for these advanced alloys.

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9 HIGH ENERGY PHYSICS

9.1 Visualisation of B meson interactions. (Kevin Varvell, Andrew Bakich)

The Belle experiment is located at the KEK laboratory in Tsukuba, Japan, and studies the decays of B mesons (subatomic particles containing a b quark), using a data set of in excess of 500 million pairs of such decays. Much can be learned about particle interactions if they can be visualised, and we would like to develop a simple 3D display of these decays based on CERN's "ROOT" package, an interactive data analysis package for high energy physics. In doing this you would not only learn about computer graphics and ROOT, but also the way that Belle detects particles, and some high energy physics as well. This project would most suit a student with a little bit of experience in programming (particularly C++) and an interest in computer graphics.

Contact: `K.Varvell@physics.usyd.edu.au`

9.2 Decays of B mesons to charmed mesons. (Kevin Varvell)

The Belle experiment mentioned in the previous project has a huge number of B meson decays, over 500 million pairs of them. B mesons decay in many, many ways, some of them very rare, and we can even study the rare ones with so much data. In this project you will use Belle data to look for decays of B mesons to charmed mesons known as D^* mesons, along with an electron or muon and an accompanying neutrino. How often this decay occurs is not as precisely determined as it should be and you can help us try to improve that situation. A little bit of programming experience (particularly in C++) or a desire to gain some would help you in tackling this project.

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10 PLASMA NANOSCIENCE

10.1 Self-organized large-scale patterns in a nano-world: What is behind the origin of symmetry? (K. Ostrikov and I. Levchenko)

Modern nanotechnology can provide an effective control of nano-scale assembly processes. One can now move individual atoms about the surface and create exotic nano-objects of the required shape and structure. Now the time came to think of a long-range "self-organized" order in the nano-world. Is it possible to control the nano-assembly deterministically and place the nano-objects into the requered place, in addition to properly shaping them? Can one control mutual orientation of the nano-objects in a large array? What physical effects, forces and fields could make this possible? This project aims to answer some of these questions by using specific examples of ordered, symmetrical and self-organized patterns consisting of a large number of the nano-scale objects. By using advanced multi-scale numerical simulation model and codes, this project will enable you to investigate the dynamics of the selected nanoassembly processes and elucidate possible reasons behind the origin of the long-range symmetry in the nano-world. You are expected to show that the plasma environment is the best control tool of the long-range order on plasma-exposed nanostructured surfaces. The project is expected to result in producing "real-time" movies that will visualize the origin of the symmetry in our stochastic world and, potentially, in a research paper to a prestigious physics journal.

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11 OFTC (Optical Fibre Technology Centre)

11.1 Design and fabrication of photonic bandgap fibres (Alex Argyros, Maryanne Large)

Photonic bandgap fibres have the unique ability of guiding light efficiently in a hollow core. The light is prevented from leaving the core by a surrounding 2D lattice of holes, which has a photonic bandgap at certain wavelengths and thus reflects the light back into the core. The exact details of the lattice can have a huge impact on the quality of the bandgaps. What this project aims to do is to optimise a common design for the lattice of holes through numerical simulations. At the OFTC we have the unique facilites to fabricate such fibres using polymers, so once an optimal design is found an opportunity exists for the fabrication and experimental testing of bandgap fibres.

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11.2 Fabrication and characterisation of an optical fibre mode shape transformer (Martijn van Eijkelenborg, Alexander Argyros)

Providing a low loss connection between optical fibres of different geometries is not a trivial task. The difference in mode field diameters or shapes can be large, and a direct connection between them can lead to large losses. In this project a mode shape transformer ('a ferrule') is fabricated and characterised to create a fibre-to-fibre connector with an efficient transformation of the fibre core shape and size in order to reduce these mode matching losses. The connector will be based on recently developed circular- and rectangular-core microstructured polymer optical fibre (mPOF). The ferrule is made by inserting rectangular-core mPOF into a circular-core mPOF preform and drawing it down, effectively making the rectangular core mPOF fibre the core of the drawn circular-core fibre. The tapered shape of the neckdown then provides a potentially loss-less mode transformation. Both fabrication and optical characterisation of the mode shape transformer is to be carried out in this project.

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11.3 Exploring the role of periodicity in photonic crystal fibres (Maryanne Large, Boris Kulmey & Alex Argyros)

Photonic bandgap fibres (normally taken to mean fibres with a 2 dimensional lattice structure) and Bragg fibres (which use a '1D' structure of concentric rings) have revolutionized optical fibres by allowing light to be guided in low index material, such as air, or aqueous solutions. The latter has profound implications for biosensing. Surprisingly, there is still fundamental argument about the nature of the physical processes that give rise to photonic bandgaps. In particular, the need for periodicity of the lattice has been questioned. We aim to explore this question, both theoretically and experimentally, in Bragg-like fibres. For example, we aim to discover whether we could extend the width of bandgaps by introducing chirping to the structure.

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11.4 Developing a New Fibre Optic Based Dosimeter (Sue Law, David McKenzie, Alex Argyros and Natalka Suchowerska)

We have a team of researchers developing a new type of miniature dosimeter for radiotherapy. The new dosimeter is very accurate and is small enough to be inserted into the body to give dose measurements in real time during treatments. It is being developed for clinical use in conjunction with Royal Prince Alfred Hospital in collaboration with our industry partners the Bandwidth Foundry, CMS Alphatech and The Sydney Cancer Centre. In this project we will study the effects of radiation on the properties of the polymer used in the optical fibre. This will involve measurements of optical absorption and infrared absorption and an assessment of their effects on fibre performance. Using the results of the measurements, a model of the radiation effects on this material will be developed and an assessment of the performance of the dosimeter in high radiation intensities will be made.

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12 SPACE AND SOLAR PHYSICS

12.1 Do solar flares occur sympathetically? (M.S. Wheatland)

There has been a lot of discussion in the solar astrophysics literature about solar flare sympathy, i.e. the triggering of a flare in one region on the Sun by a flare in another region. However, the question of whether flare sympathy is real remains controversial. If flare sympathy is confirmed, it may shed light on the mechanism or mechanisms by which flares are initiated, which is of obvious importance for solar flare prediction. Recently a new statistical test for flare sympathy has been devised (Wheatland 2006), which examines the time history of flare occurrence in two regions on the Sun, and decides if the sequences of events are independent or not. The method improves on previous techniques in that it can cope with variations in the mean rates of flaring in the two regions. The method has been applied to two flare catalogs with ambiguous results.

In this project the method will be applied to a variety of different flare catalogs including flares selected from observations at different wavelengths. There is also scope for testing the method to assess its sensitivity, based on Monte Carlo simulations. The project will involve data analysis and programming in the Interactive Data Language (IDL), a programming environment similar to Matlab.

Wheatland, M.S.: 2006, to appear in Solar Physics

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12.2 Electron beam and plasma waves in type III solar radio sources (Bo Li, Peter Robinson and Iver Cairns)

Type III solar radio bursts are produced via energetic electrons which are accelerated locally in solar flares and then ejected as beams into the solar atmosphere. The beams then propagate through the solar atmosphere and persist far into interplanetary space, where they generate plasma waves and type III radio emissions. The aim of this project is to predict the effects of plasma temperature variations on electron beam propagation and plasma wave generation. The project will involve extending an existing numerical simulation code to include varying plasma temperature.

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12.3 Bursty Langmuir Waves in Space (Iver Cairns, Peter Robinson)

The European Space Agency's Ulysses spacecraft has observed localized packets of Langmuir waves between Mars and Jupiter. A new and larger sample of wave packets will be obtained and analyzed (primarily using existing software) in order to answer outstanding questions concerning their origin.

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12.4 Resistance of Antennas in Space (Iver Cairns, Peter Robinson)

An antenna immersed in a plasma has a resistance (actually a complex impedance) that depends on the wave frequency and the properties of the plasma. The resistance is needed in order to calibrate flux of natural signals observed. Here numerical calculations of existing theoretical expressiona are used to predict the resistance of antennas on NASA's Wind spacecraft and compared with recent observational data. Predictions for NASA's upcoming STEREO spacecraft will also be developed.

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13 THEORETICAL PHYSICS

13.1 Coherent radio emission from cosmic-ray air showers (Qinghuan Luo, Don Melrose)

High energy cosmic rays induce a cascade in the Earth's atmosphere producing pairs (electrons and positrons) in copious numbers. These relativistic particles can emit 'coherent synchrotron radiation' as they propagate in the Earth's magnetic field. Study of their radio emission, such as the radio spectrum can provide an important clue to the properties of the primary cosmic rays. This project will involve analytical or numerical calculation of the coherent synchrotron spectrum. The plan is to compare the predicted spectrum with observational data.

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14 SUPER (Sydney University Physics Education Research group)

What is a project in physics education research about?

Physics education research (PER) provides an opportunity to investigate qualitative research methods and to understand the interpretation of results from such methods. A variety of research methodologies are available including action research, phenomenology, phenomenography and grounded theory. The research can involve mapping how certain concepts are learned and the stages in conceptual development involved in the learning. You will find that you learn about learning, and indeed, do learn a lot of physics while deciphering the complex and intricate processes. The research is discipline specific and is done within the physics department. An honours project in PER can lead to a PhD and postdoctoral positions. A project in PER will provide you with the necessary tools and experience to conduct qualitative research, frequently used when working with people.

A range of projects is available in physics education research. Three projects are presented below and we invite you to contact Manju Sharma for other projects.

Contact people in SUPER are:
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14.1 Facets of gravity and freefall (Manjula Sharma, Ian Sefton)

A pilot investigation has shown that first year students use various strategies to explain gravity and freefall [1]. In this project you will compare how first year Advanced and Fundamentals students answer this question and the reasoning pathways used.

1. M. D. Sharma, R. Millar, A. Smith and I. Sefton (2004) Students' understandings of gravity in an orbiting space-ship. Research in Science Education, 34, 267–289.

14.2 Student understandings of quantum tunnelling (Manjula Sharma)

Derek Muller, a PhD student with SUPER, has surveyed how students conceptualise changes in energy with barrier height and width. The findings are that students' have diverse ways of understanding the real and imaginery parts of the wavefunction and their associated probabilities. In this project you will interview students and observe the strategies they use for conceptualising quantum tunnelling.

14.3 Multimedia in teaching and learning of complex physics processes (Manjula Sharma)

Technology is increasingly being used in educating people about the complex discoveries being made in science. Effectively utilizing the potential of multimedia is not a trivial task, however, and requires research informed by extensive disciplinary knowledge. Researchers continue to debate the merits of dynamic visual representations versus static text and picture displays. Students undertaking this project would enter into this debate and explore the challenges of communicating the real science behind complex phenomena from lighting storms to special relativity and quantum tunneling.