School *of* Physics and Astronomy

BSc/MPhys
Senior Honours Year

Physics
Computational Physics
Physics and Music
Physics with Meteorology
Astrophysics
Theoretical Physics

Project Guide
2013/2014

August 2013

Contents

This section contains a list of Honours Projects. Each project has a short description, typically one or two references and the name of the supervisor. It should be noted that because some projects share common equipment, it is not possible to offer all projects at once. Also some projects may be withdrawn, substituted, or added to at short notice. Additional projects will be posted on the Senior Honours Notice Board.

SENIOR HONOURS PROJECTS

The aim of the Senior Honours projects is to provide an introduction to a longer term and more open ended style of working which characterises Physics as it is practised at the professional level.

At the end of the course you should:

- have learnt how to conduct a comprehensive search of the literature relevant to a research topic and to select and summarise the crucial aspects of the relevant literature
- have gained experience of the organisation and completion of an extended project where the results and outcomes are not fully defined at the beginning
- have learnt how to organise, keep and use a comprehensive log book of the work done in the project
- have learnt how to write a full report including a concise summary of the relevant literature, the pertinent aspects of the method and a critical discussion of the results and conclusions
- have gained experience of the preparation of scientific posters and the oral reporting of results

Senior Honours Project Organiser

The *Senior Honours Project Organiser* is Professor Franz Muheim (5422 JCMB, f.muheim@ed.ac.uk, telephone 650 5235).
For *Astrophysics Senior Honours Projects* the local contact is Professor Andy Taylor (U15 ROE, ant@roe.ac.uk).
For *Meteorology* and *Geophysics* projects (available to Physics with Meteorology students) the local contact is Dr David Stevenson (314 Crew Building, david.s.stevenson@ed.ac.uk).

Selection of Project

Project work is a major element of the Senior Honours programme, both in terms of your time and in terms of its contribution to your final degree. Project work is your main chance to work on your own on a topic of interest to you and to show your own initiative and experimental or computational skill.

The projects in this booklet are arranged in three lists corresponding to the three degrees followed (Physics, Computational Physics and Physics and Music).

It is essential that you discuss the proposed project with the supervisor and discuss what it involves prior to starting. Once you have selected a project, tell the supervisor and fill in the green Project Start Form (available from the Teaching Office, the Senior Honours laboratory technician or the Senior Honours Notice Board) which must be returned to the Teaching Office before you start the project. At the start of the semester a large number of people are trying to start projects, so try and make up your mind quickly.

Physics with Meteorology Project choices are available to view on the web at
http://xweb.geos.ed.ac.uk/~dstevens/teaching/GP_Projects_2013-14.pdf

Students taking these projects should still return a green form to the Physics Teaching Office, to ensure we have a record of your project choices.

Astrophysics Projects choices are available to view on the web at
http://astroprojects.roe.ac.uk/bin/view/Projects/WebHome
Astrophysics project are only available to Astrophysics students. Students will have a few days to review the projects and talk to potential supervisors before selecting their three top choices. Allocation will be on a first-come first-served basis. As many projects are oversubscribed, some discussion beforehand may be useful.
Note that Astrophysics students should adhere to all the procedures and deadlines detailed below. More details will be given on the first day of this semester.

Please note that some projects rely on the operation of specialist equipment and, if located in a research laboratory, space being available. These projects are subject to cancellation at short notice. In most cases the original supervisor is able to offer an alternative project in that same subject area, but this cannot be guaranteed.
If you book a project well ahead of time, check with the supervisor a week before you intend to start to ensure that the project is available.

The degree programme tables place the following constraints on your choices.

BSc Physics
You must take one project from the Physics list (or the Science Education Placement). You may take a second project or substitute 20 points of other courses from Schedule Q.

BSc Computational Physics
You must take one project from the Computational Physics list (or the Science Education Placement). You may take a second project or substitute 20 points of other courses from Schedule Q.

BSc Physics and Music
You must take one project from the Musical Acoustics list. You may take a second project or substitute 20 points of other courses from Schedule Q.

BSc Physics with Meteorology
You must take one project from the Physics with Meteorology list. You may take a second project or substitute 20 points of other courses from Schedule Q.

BSc Mathematical Physics
You may take one project from the list.

BSc Astrophysics
You must take one project from the Astrophysics list (or the Science Education Placement).

BSc Theoretical Physics
You may take one or two projects from the list

MPhys Physics
You must take one project from the Physics list (or the Science Education Placement).

MPhys Computational Physics
You must take one project from the Computational Physics list (or the Science Education Placement).

MPhys Mathematical Physics
You may take one project from the list.

MPhys Theoretical Physics
You may take one or two projects from the list.

MPhys Astrophysics
You must take one project from the Astrophysics list (or the Science Education Placement).

MPhys Physics with Meteorology
You must take one project from the Physics with Meteorology list. You may take a second project or substitute 20 points of other courses from Schedule Q.

Background Reading

As with all aspects of science, the more background you know about the subject, the more likely you are to understand what is going on and the more likely that you will do a good project. A thorough search of the relevant literature and the selective presentation of the relevant material should form an important part of the introduction section of your report. Most projects have some initial references or background material, but this should be regarded as a starting point only, and it is *your* task to find other material, with the assistance of the supervisor, **and** by use of the library and through web databases such as Web of Knowledge (http://wok.mimas.ac.uk).

Background Skills

Some projects require specialist skills such as computing or electronics.
In most cases these skills will be stated in the project synopsis, or will be identified for you by the supervisor. Remember that the levels of skills expected are not in excess of what is normally obtainable in your previous years of study. For example if a project asks for computing skills it is expected that you completed *Computational Methods* successfully, and well. If you are in any doubt, ask the supervisor - preferably before you actually start the project.

Planning the Project

All projects, even those that initially appear to be fairly well determined, need to be planned and where possible, a time schedule and checkpoints set out. Remember you have limited time. Planning what you are going to do will help to keep a project on schedule and ensure that you do not run out of time at the end. It is important for your other studies that you do not let a project drag on beyond its allotted time. Students should produce a one-page project outline with a time schedule.

Laboratory Note Book

During all experimental or computational work you **must** keep a *Laboratory Note Book* which is to be submitted with the Report. This book should be used to record the project plan, day to day experiments, list of results, graphs, short notes from references, and any other information you think may be helpful when it comes to writing your report. If you produce graphs on a computer, attach a copy of the graph into the Note Book to ensure you have a record. The Note Book must be written **during** the laboratory time; it is not useful if it is “written-up”' afterwards.

The Note Book **must** be a book, not a loose leaf folder from which things tend to get lost or out of order. Suitable books are available for approximately £2.

Supervision

The role of the project supervisor is to aid and guide you in your project and not to stand over you and tell you what do. For most projects the supervisor has a fairly clear idea of where the project should go and what the outcomes should be. Almost all projects are closely related to the supervisor's research interests and expertise, and they will be able to help you in all aspects of the project. If you think of a way that the project could be improved, then say so.

All staff have other teaching duties and will not be available at all times during laboratory days. Additionally many staff have external commitments that take them away from the School. Discuss suitable times for meetings with your supervisor and periods when they will not be available. There are no fixed rules about how often meetings are required. Some projects which require the learning of a specialised technique will involve frequent and extended meetings, while some projects require only occasional contact. You **must** meet with your supervisor at least once a week, and inform him/her of any periods of absence. Remember, ultimately, it is **your** project, and if you do not seek advice and discuss problems with the supervisor, or ignore advice given, then don't be surprised if the project runs into trouble.

Most projects go smoothly, and most students enjoy their project work. However problems can occur. If, for some reason the project work is going badly, see your supervisor at the earliest opportunity and discuss what should be done. If you feel that there is still a problem, or would just like to discuss your project with somebody else, see the *Senior Honours Project Organiser*.

If, for any reason, you decide to abandon a project and start another one, you must inform the *Senior Honours Project Organiser*, and complete a new *Project Start Form*.

Laboratory Times

The standard laboratory times for experimental projects are Mondays and Thursdays from 10.00 am to 5.00 pm, in Weeks 2-11 of Semester 1 and Weeks 1-10 of Semester 2. Access outwith these times **may** be available with agreement from the supervisor or technician in charge of the laboratory, provided that there is safety supervision available. Such access **must** be arranged in advance.

Undergraduate student access to **any** experimental laboratory is **strictly limited** to Monday to Friday 9.00 am to 5.00 pm.

School or University public access computing areas, such as the *CP Lab*, *JCMB PC-Labs* etc. are available at times posted on the appropriate notice boards.

Safety

Senior Honours students are expected to work with a considerable degree of independence and be familiar with the contents of the School Safety Leaflet and *Keynote Guide.*
You should have a copy from the Junior Honours (Third Year) laboratory; additional copies can be obtained from Mr George Hughes, Room 4207. It is **vitally important** to consult the project supervisor about any hazards associated with the project and to follow the recommended working practices. This is of particular importance when working with hazardous chemicals, radioactive materials, X-rays or lasers. Some projects involve experimental procedures that require training or close supervision to be carried out safely: these procedures **must** be carried out as recommended by your supervisor. Remember also that one of the greatest dangers in the laboratory is the 230/240 Volt mains supply. A copy of the School procedures for supervisors, *Safety Procedures*

for Honours Projects is posted on the Senior Honours Notice Board, and any variation in this procedure should be notified to the *Project Organiser*.

If you are in any **doubt** about the safety of any procedure, ask before you do it.
You can obtain advice from your project supervisor, the technician in charge of the laboratory where you are working, the *Project Organiser* or the Senior Honours Year Laboratory technician, Mr George Hughes (Physics) or Mr Jim Boulter (Astrophysics).

Report any accidents, **however minor**, immediately to your supervisor, to George Hughes or, in the case of research laboratories, to the technician in the laboratory.

Report

You are required to submit a separate report for each project. If you are working with a partner, this report must make it clear which parts of the project were your work, and which parts were carried out by your partner. The report **must** contain a signed declaration; details of this will be available on-line in due course.

Report Preparation

A guide to assist in the preparation of Senior Honours project reports will be available on-line in due course. The style suggested is that of the formal laboratory report. Clearly one report style is not appropriate for **all** possible laboratory projects, but the basic layout is common. If you find this style does not fit your particular project feel free to modify it, but major variations should be discussed with your supervisor.

When planning and writing a report, be selective about what you include. There are no fixed rules regarding how long, or short a report should be, but remember you are writing a **concise technical document**, not a diary or novel, so you don't get any marks for size. Good reports are typically 15 to 20 pages; reports significantly longer than this are frequently too wordy. Technical documents are traditionally written in the third person and in the rather impersonal passive voice. This is no longer considered mandatory. While the first person active voice (I/we) is still considered somewhat radical (in scientific circles), it is gaining respectability. However an arbitrary mixture is not acceptable.

The *Poster* has been added as an exercise in presenting your work to a non-specialist.

It is *expected* that reports are typed or word processed. The \LaTeX\ template for the guide referred to above will be made available on the CP lab machines, once finalised.

Workshops on Literature Review, and Report and Poster Preparation

There will be SH Workshops on the following dates:
Week 1 - 18/09/13, between 2pm and 4pm, room 6301 JCMB.
Week 3 - 02/10/13, between 2pm and 4pm, room 5326 JCMB.
Week 7 - 30/10/13, between 2pm and 4pm, room 5326 JCMB (if necessary)

Report Submission

Physics, Computational Physics, Physics with Meteorology and Musical Acoustic project reports must be submitted to the *Teaching Office* in JCMB.
Astrophysics project reports must be submitted to the *Teaching Office* in the ROE.

The submission deadline for Semester 1 Projects (Report: Hardcopy & turnitin, Laboratory notebook and Poster) is
Tuesday 3rd December 2013 – 12:00 NOON

The submission deadline for Semester 2 Projects (Report: Hardcopy & turnitin, Laboratory notebook and Poster) is
Tuesday 1st April 2014 – 12:00 NOON

Deadlines for laboratory reports must be adhered to. If you submit your report after the deadline, your project mark out of 100 will be reduced by 5 marks for each weekday by which the deadline is exceeded. If, for good reason, you are unable to meet a deadline you, or your supervisor, should contact the *Project Organiser* and the *Teaching Office* immediately. Note that only the Senior Honours Project Organiser can grant extensions to the deadline, not your supervisor.

Poster Presentation

Most national and international scientific conferences have a poster session. This provides an efficient means to communicate results to other interested scientists. As part of the project, a poster session will be held in Semester 2 at 3pm **on Thursday 3rd April 2014** and will be attended by the project supervisor and second marker for each project. The aim of a poster is to provide enough information to understand the basic sense of the project (the reason for doing the work, the method used and the principal results) which can then be amplified by discussion in front of the poster.

Project Assessment

The work done during the project, the poster presentation, the logbook, and the report itself will be assessed according to the criteria specified on the *Project Mark Sheet*, a copy of which will be available on-line in due course. The final *Senior Honours Project* mark will be formed from a weighted average of the project work, your poster presentation and report marks.

1. Physics

1.1 Optics

Fluorescence lifetime imaging
Contact: Jochen Arlt (Room 2601, extn. 50 5121, email: j.arlt@ed.ac.uk)

Optical microscopy is a major research tool in a wide range of scientific disciplines despite its apparent simplicity. Using fluorescent labels very high contrast images can be acquired, using instrumentation such as laser scanning confocal microscopy. But rather than just monitoring the intensity of the fluorescence signal it is also possible to measure its fluorescence lifetime. As this lifetime is less susceptible to artefacts this enables much more quantitative measurements.

You would be working with a state of the art fluorescence lifetime detector and characterize its performance. Aim is to precisely measure the dissolved oxygen distribution within fluid samples.

1.2 Nuclear Physics

Quantum physics: illusion or reality? (4 projects available in both semesters)
Contact: Tom Davinson (Room 8205, extn. 50 5250, email: t.davinson@ed.ac.uk)

In 1935 Albert Einstein, Boris Podolski and Nathan Rosen published a paper (referred to now as the EPR paper) which brought into question the completeness of quantum mechanics. Their main concern was associated with the predictions that quantum mechanics made concerning the influence that two particles had on each other once they were physically separated outside their interaction range. This called into question the whole concept of external reality in the physical world. In an effort to make quantum theory more complete, the idea of hidden variables was investigated. In 1969, Bell showed that it was possible to identify an experimental test for deciding between conventional quantum mechanics, with its holistic view of reality, or a theory that was based on a more localised concept of reality.

The idea behind the project is to undertake such an experimental test for two correlated gamma rays from the annihilation of a positron emission of Na^{22} radioactive source.

Development of a solar spectrometer (1 project in semester 1 & 1 in semester 2)
Contact: Alan Shotter (Room 8205, extn. 50 5298, email: alan.shotter@ed.ac.uk)

The idea behind this project is to calibrate and help develop a modest telescope spectrometer that is capable of measuring the optical absorption spectra of the Sun and possibly a few of the brighter stars. The method for the measurement of the absorption spectra is similar to that used on larger research telescopes to determine stellar element distributions across the galaxy.

A tracking 4" aperture refractor telescope projects the image of the sun onto an image plane. An optical fibre transports light from part of the Sun's image to an Omni-X 300 spectrometer. This spectrometer is capable of measuring optical spectra with a wavelength resolution of about 1 in 5000. The spectra are recorded by a CCD detector and processed by a computer.

The main objective of the current project will be to develop a procedure to calibrate the telescope, optical fibre and spectrometer so that the relative solar absorption intensities across a range of wavelengths can be deduced. This will require working with CCD cameras, optical spectrometers, black body radiation sources and image processing software. Depending on progress it may be possible to work with actual solar spectra.

1.3 High Energy Physics

Muon Lifetime Measurement
Contact: Franz Muheim (Room 5422, extn. 50 5235, email: f.muheim@ed.ac.uk) **or Matthew Needham** (Room 5415, extm 506769, email: matthew.needham@cern.ch)

The muon is one of the elementary particles and a very clean probe to study the weak interaction. Cosmic ray muons are produced in the upper atmosphere. Some of these muons reach sea level such that their properties can be measured in the laboratory.
The aim of this project is to measure the lifetime and/or the mass of the muon. Muons are stopped in a large block of scintillator, where they subsequently decay into an electron or positron and two neutrinos. A short light pulse is produced by the stopping muon which is detected and amplified by a photomultiplier tube. When the muon decays a second light pulse is produced by the emitted electron or positron. The scintillation light is detected by a the photo multiplier which converts it into an electronic signal. These signals are fed into an electronic circuit which determines the time delay between the two pulses. The circuit is connected to a PC which is used to read out the data. The experiment involves the set-up of the equipment, performing the actual measurement and the subsequent data analysis.
You can also determine the mass of the muon by measuring the energy of the electron or positron emitted in the decay of the muon. This can be achieved by recording the pulse height of the photo multiplier signals.

References:
http://www.ph.ed.ac.uk/~muheim/teaching/projects/index.html
• T.K. Gaisser & T. Stanev, *Cosmic rays*,
in Particle Data Group, Reviews, Astrophysics and Cosmology,
http://durpdg.dur.ac.uk/lbl/2007/reviews/contents_sports.html#astroetc
• W.R. Leo, *Techniques for Nuclear and Particle Physics Experiments*,
2nd edition, Springer Verlag (1994) Berlin, Heidelberg
• P.R. Bevington & D.K. Robinson, *Data Reduction and Error Analysis for the Physical Sciences*, 3rd edition, McGraw-Hill (2003)

1.4 Condensed Matter

Phonons in 1D Periodic, Aperiodic and Quasicrystal Systems
Contact: Malcolm McMahon (Room 3804 (CSEC), extn. 50 5956, email: mim@ph.ed.ac.uk)

Phonons are the quantised modes of vibration of a crystalline lattice, and play an important role in the physical properties of materials, such as their thermal conductivity and the speed of sound. In this project, a taut steel wire loaded with carefully positioned small masses is used to model a 1D crystal. A digital lock-in amplifier is then used to measure the normal modes (eigenvalues) of the system. After investigating the acoustic and optical phonons in a monatomic and diatomic system (which repeats the experiment of Luerssen, below), one can then choose to investigate the properties of either a 1D aperiodic system, a 1D random system, a Fibonacci chain (a 1D quasicrystal), or look at the effects of an impurity on the behaviour of phonons.

References:
S. He and J.D. Maynard, *Detailed Measurements of Inelastic Scattering in Anderson Localisation*, Phys. Rev. Lett. 57, 3171 (1986).
D. Luerssen et al, *A Demonstration of Phonons that Implements Linear Theory*, Am. J. Phys. 72, 197 (2004).

How does the environment affect an intrinsically disordered protein?
Cait MacPhee (Rm 2613, Ex. 505291, email: cait.macphee@ed.ac.uk) with Marieke Schor (email: m.schor@ed.ac.uk)

Intrinsically disordered proteins (IDPs) – protein polymer chains that lack a well-defined structure under the conditions found in cells and organisms – seem to be critically important for a wide range of cellular functions. Their role in essential cellular processes including signal transduction, DNA transcription and regulating protein assembly means that many IDPs are associated with diseases such as cancer and neurodegenerative disorders. However, despite their vital biological role, the importance of their inherent flexibility and lack of well-defined structure to their function remains a mystery.

Due to their lack of structure, IDPs are very sensitive to their environment and changes in temperature, pH or salt concentration can have a pronounced effect on the behaviour of the protein. In this project you will perform molecular dynamics (MD) simulations and advanced enhanced sampling methods in order to obtain a molecular level understanding of the effects of temperature and salt concentration on a representative IDP. Prior knowledge of biology is not required.

Emulsion drolets & microuidics
Contact: Simon Titmuss (Room2504, extn 505267, email: simon.titmuss@ed.ac.uk)

Emulsions are structured uids in which droplets of one liquid are dispersed in another (typically oil/water) that are important in foodstu_s, oil recovery and drug delivery. The high energy interface between the two phases can be stabilised by surfactants or colloidal particles.
In this project microuidics will be used to produce monodisperse emulsion droplets. The narrow size distribution of droplets opens up the possibility of using arrays of the droplets as containers in which the contents are con_ned to dimensions comparable to cells.

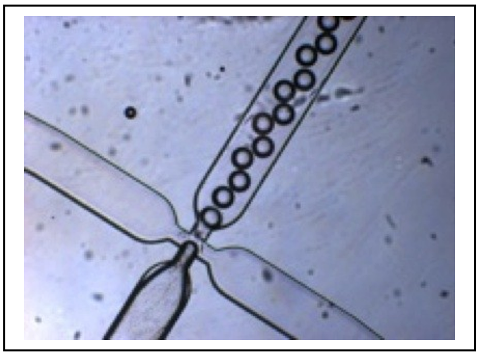

Figure 1: Emulsion drops of diameter ~ 80 μm produced in microuidic chip.

Possible lines of enquiry for this project include:
- design of microuidics for emulsion droplet production & storage
- investigating the mechanical properties of surfactant & nanoparticle stabilized emulsion drops
- using droplets as cell-sized containers for self-assembly experiments

References:
N. Bremond & J. Bibette, Soft Matter 2012 DOI:10.1039/c2sm25923k

An unexpected interaction – why are solid particles at water-oil interfaces relatively far apart?
Contact: Job Thijssen (Room 2621, extn. 50 5883, email: j.h.j.thijssen@ed.ac.uk)
Soft condensed matter, second semester preferred
Emulsions consist of droplets of a liquid A dispersed in an immiscible liquid B. An everyday example is milk, which is a dispersion of micron-sized oil droplets in water. Usually, a third component is required to stabilize the emulsion against separation of the two liquid phases, e.g. mustard in a vinaigrette of olive oil and vinegar. These stabilizers are usually surfactants, i.e. molecules similar to those in washing-up liquids. Recent years have seen an increasing interest in emulsions stabilized instead by solid microparticles (Fig. 1a), as they are i) model arrested systems and ii) promising for applications in the food, personal-care, agricultural, pharmaceutical and petrochemical industries.
In previous undergraduate projects, we have studied the stability of emulsions stabilized by hard-sphere particles under compression; these results have recently been published in the journal *Soft Matter* [1]. Essentially, the particles form a close-packed layer around the droplets, preventing them from merging upon contact. In recent experiments with the same particles at *flat* rather than curved water-oil interfaces, we have noticed that the particles are not close-packed at all. Instead, they are up to two diameters apart, suggesting an unexpected (long-range) repulsion between the particles!
In this project, you will use microscopy to investigate the packing and movement of solid particles at flat water-oil interfaces. Using and/or adapting image-analysis software, you will track the movement of these particles in time, from which the interaction between the particles can be deduced. Successful completion of this project may well lead to your results being incorporated in a scientific paper.

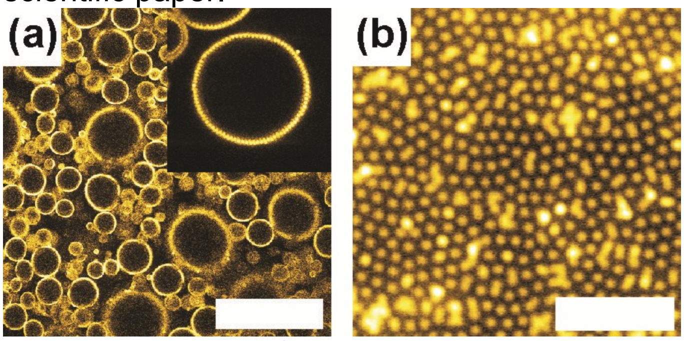

Figure 1: micrographs of micron-sized PMMA particles (yellow) at water-oil interfaces. (a) Water-in-oil emulsion stabilized by PMMA particles. Inset: the PMMA particles appear close-packed at the droplet interface. (b) Similar PMMA particles at a flat water-oil interface; the particles are relatively far apart. Scale bar: (a) 200 μm and (b) 20 μm.

[1] L. Maurice, R. A. Maguire, A. B. Schofield, M. E. Cates, P. S. Clegg and J. H. J. Thijssen, *Squeezing particle-stabilized emulsions into biliquid foams – equation of state*, Soft Matter **9**, P7757 (2013)

1.5 Acoustics

Stereoscopic sound localization
Contact: Clive Greated (Room 7306A, extn. 50 5232, email: c.a.greated@ed.ac.uk)
This project investigates the ability of humans to localize auditory events on the horizontal plane using two ears. Rayleigh's duplex theory of inter-aural time and intensity differences will be investigated through a series of experiments on a dummy head in the anechoic room and the limitations of the theory examined. Spectral position cues will be analyzed using head-related transfer functions. A stereoscopic loudspeaker configuration will be used to implement different ways of panning virtual sound images.

References:

J Blauert "*Spatial Hearing: The Psychophysics of Human Sound Localistion*" MIT Press 1997
F Rumsey "*Spatial Audio*" Focal Press, Elsevier 2001

F R Moore "*Elements of Computer music*" Prentice Hall 1990
W Hartmann "*Signals, Sound and Sensation*" Springer 1997

Input impedance of musical wind instruments
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

The acoustical resonances of a musical instrument can be measured by injecting a known oscillating volume flow into the mouthpiece and measuring the resulting pressure fluctuation. The ratio of pressure to volume flow is known as the input impedance. In this project the input impedance of a range of different wind instruments can be studied, and experimental measurements can be compared with numerically simulated input impedance curves. It is also possible to explore the optimisation of musical wind instrument bore profiles using input impedance targets.

Reference:
Braden, A.C.P., Newton, M.J., Campbell, D.M., *Trombone bore optimisation based on input impedance targets*, J. Acoust. Soc. Am. 125, 2404-2412 (2009).

The vibration of piano strings
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

On a well tuned piano, the fundamental frequencies of two strings an octave apart have a frequency ratio slightly greater than 2. This “stretched tuning” is related to the fact that the normal mode frequencies of a stiff string depart in a systematic way from the harmonic series which characterises an ideal flexible string. In this experiment the inharmonicity of real strings on grand and upright pianos is compared with theoretical predictions. The decay rates of single and multiple strings can also be investigated.

References:
H. Fletcher, *Normal vibration frequencies of a stiff piano string*, J.Acoust.Soc.Am. 36, 203-209, 1964.
G. Weinreich, *Coupled piano strings*, J.Acoust.Soc.Am. 62, 1474-1483, 1977.
N.H. Fletcher and T.D. Rossing, *Physics of Musical Instruments*, 2nd ed., Springer, 1998.
M. Campbell and C. Greated, *The Musician’s Guide to Acoustics*, Oxford University Press, 1987.

Vibrations of bars and plates
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

Impulsively excited long thin bars have natural mode frequencies which are far from harmonic. For a uniform bar, the theory is straightforward; for non-uniform bars, numerical predictions can be made. Glockenspiels, xylophones and tubular bells provide musical examples. Two dimensional plates have more complicated sets of natural modes than bars. Square and circular plates can be investigated; the small tuned cymbals known as crotales would make an interesting study.

Studying sound generation in brass instruments using artificial lips.
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

The lips of a brass instrument player act as a pressure-controlled valve, modulating the flow of air from the player's mouth into the instrument. The interaction between the lips and the air column of the instrument is an interesting example of nonlinear dynamics. In this project the mechanical response of a pair of artificial lips is measured, and the behaviour of the lips when playing a trombone is compared with the predictions of a computer model.

Nonlinear sound propagation in musical wind instruments.
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

When a musical wind instrument is blown loudly, the amplitude of the pressure fluctuations inside the pipe can reach 10 kPa (10% of atmospheric pressure). At such high levels the normal linear acoustic equations are inadequate to describe a propagating sound wave. This project explores some of the physical and musical consequences of nonlinear sound propagation in brass instruments.

Data acquisition using Labview in experimental physics
Contact: Jochen Arlt (Room 2601, extn. 50 5121, email: j.arlt@ed.ac.uk)

LabVIEW is a powerful programming environment to integrate the control of test equipment as well as acquisition, processing and display of data. In this project you first will go through a guided process of learning to independently use LabVIEW on the scale needed for the assigned data acquisition task. This also will provide you with sufficient techniques, understanding and overview to approach different or more complex tasks on your own thereafter.

This project then will ask you to investigate a fairly simple experimental task, such as characterizing a Loudspeaker. You will be given the required data acquisition equipment and will have to come up with a LabVIEW program which handles the interfacing and control of the hardware, the data acquisition and the signal analysis in 'real-time'. That, in turn, can be used as feedback to adjust the experimental parameters.

A variety of experiments could be considered, one example being the investigation of the AC characteristics of a loudspeaker. The goal is the automatic characterisation of the frequency response of the loudspeaker. You will also have to discuss the experimental and systematic uncertainties of the employed method and the obtained results.

1.6 Physics Education

To sketch or not to sketch, that is the question
Contact: Ross Galloway (Room1615, extn.508614, email:ross.galloway@ed.ac.uk)

The development of strong problem solving skills is a central objective of a Physics degree. Accordingly, one of the main areas of Physics Education Research is the study of how the development of problem solving skills can be supported, and what approaches characterise expert problem solvers. It has long been established that one of the features of expert problem solving is the use of 'multiple representations', i.e. expressing physics ideas or information in multiple ways, e.g. in equations, in words, as a diagram or graph, etc.
Given the widespread use of diagrams to aid problem solving, it is common for undergraduate students to be encouraged or required to draw diagrams when attempting to tackle problems, and for example diagrams to be given.
Some recent research [1] has suggested, perhaps surprisingly, that providing a ready-made diagram may actually inhibit problem solving compared to when no diagram at all is used.
In this project we will investigate the influence of diagrammatic representations on student problem solving success, using an experimental method. Suitable problems will be developed where diagrams form an important element of the solution process. These problems will then be given to students under a number of conditions: pre-made diagram provided; no diagram provided but students requested to draw one; no diagram provided but students requested not to draw one; and a control condition (no provided diagram and no special instructions). By deploying this investigation to a large number of students we will be able to explore in a robust statistical manner

the impact of diagrammatic representations and look for correlations with other measures (such as diagnostic test results).

[1] A. Maries & C. Singh, "Should Students be Provided Diagrams or Asked to Draw Them While Solving Introductory Physics Problems?", Proceedings of the
2011 Physics Education Research Conference (2011).

Modelling online PeerWise learning networks
Contact: Judy Hardy (Room 1617, extn 506716, email : j.hardy@ed.ac.uk)

PeerWise is an online tool that enables students to write multiple-choice questions and associated explanations, share them with their peers, and answer, rate and comment on each other's questions. The interactive design of the system means that students can collaborate and engage in both peer and self-assessment and feedback. Such interactions lead to the development of online learning networks among the cohort.

The development of student learning networks in face-to-face settings (a physics learning centre) have been studied using the tools of social network analysis.[1,2] More recently, the same techniques have been applied to online PeerWise learning networks.[3] In this project, social network analysis will be used to characterise PeerWise networks in Physics 1A/1B, compare these to 'idealised' networks created from synthetic data and investigate how such networks develop over time.

You will use the social network analysis software packages UCINET and NETDRAW; some programming will also be needed.

References

[1] E. Brewe, L.H. Kramer, G.E. O'Brien, C. Singh, M. Sabella, and S. Rebello, AIP Conference Proceedings **1289**, 85 (2010).

[2] E. Brewe, L. Kramer, and V. Sawtelle, Physical Review Special Topics - Physics Education Research **8**, 010101 (2012).

[3] J. Hardy, A.E. Kay, and R.K. Galloway, AIP Conference Proceedings (n.d.).

2. Computational Physics

2.1 Computer Simulations

The motion of asteroid 3753 Cruithne -- Earth's second Moon?
Contact: Arjun Berera (Room 4411, extn. 50 5246, email: ab@ph.ed.ac.uk)

The near-Earth asteroid 3753 Cruithne is now known to be a companion, and an unusual one, of the Earth. This asteroid shares the Earth's orbit, its motion 'choreographed' in such a way as to remain stable and avoid colliding with our planet. This relationship was revealed in a paper by Paul Wiegert, Kim Innanen and Seppo Mikkola, and published in Nature on June 12, 1997. However, Cruithne's path is much more complicated than simple satellite motion. The aim of this project is to write a program (probably in C) to simulate the orbit of Cruithne and to investigate its stability.

Relevant Physics: Computer Programming, orbital dynamics.

Emergence of combinatorial communication in a fluctuating environment
Contact: Richard Blythe (Room 2505, extn. 50 5105, email: r.a.blythe@ed.ac.uk)
Semester 2 preferred

Many species communicate, but only a few do so by combining signals together to make more complex signals: examples include humans (using language), putty-nosed monkeys (using audible calls) and possibly bacteria (using chemical signals). Evolutionary game theory can furnish a set of autonomous differential equations ("equations of motion") that describe the emergence of signalling strategies. We have used these equations to derive some fundamental principles for the emergence of combinatorial communication, but these apply only for infinite populations of agents who can all interact with each other. The aim of this project would be to determine using computer simulations whether these principles apply also to finite populations interacting in a spatial setting where strong fluctuations in space and time - ignored by this theory - may be present.

This project would suit a student with strong computational skills and an ability to think creatively about modelling complex interacting systems.

Reference: T C Scott-Phillips and R A Blythe (2013) to appear in J Roy Soc Interface, http://arxiv.org/abs/1308.4780

Computational approaches to the analysis of neutron scattering data from soft and biological matter
Contact: Simon Titmuss (Room2504, extn 505267, email: simon.titmuss@ed.ac.uk)

Cold neutrons represent the perfect probe of soft and biological matter, which is characterized by structural units comparable in size to the wavelength of the neutrons (~ nm) and the interactions are dominated by thermal energy (kT), which is comparable to the neutron energy. This means that both structural and dynamical information is accessible on length scales from Angstrom to 100's nm and time scales from ps to microseconds.

My experimental programme uses: neutron reflectivity to assess the structure of model bacterial membranes and their interaction with antimicrobial agents being investigated as replacements for antibiotics; small angle neutron scattering to investigate the kinetics of insulin self-assembly as prototypical amyloid forming protein; neutron spin echo to assess the dynamical properties of virus capsids.

The analysis of this data requires computational approaches of varying degrees of sophistication, eccompassing: writing simple macros to encode physical prior knowledge into the fitting of neutron reflectivity data from membranes; coding analytic models for the fitting of small angle neutron scattering data; running molecular dynamics and scattering calculations on HPC resources to understand the spin echo data on nanosecond time scales and nanometre length scales.

Depending on interest and prior experience this Semester 2 project could be based on any one of these aspects

The Quantum Harmonic Oscillator on a Computer
Contact: Tony Kennedy (Room 4404, extn. 50 5272, email: adk@ph.ed.ac.uk)
or: Roger Horsley (Room 4419, extn. 50 6481, email: rhorsley@ph.ed.ac.uk)

Quantum mechanics can be described in several different ways: wave mechanics, operator formalism and sum over particle histories. The latter method, due to Feynman, when analytically

continued to imaginary time becomes suitable for numerical simulations using statistical Monte Carlo methods.
The aim of this project is for the student to understand the basic principles behind path integrals and Markov chain methods and how they can be applied to find energy and wavefunctions for the one-dimensional harmonic and anharmonic oscillator.

References:
M. Creutz and B. Freedman, A Statistical Approach to Quantum Mechanics, Annals of Physics, 132 (1981) 427.
R. MacKenzie, Path Integral Methods and Applications, quant-ph/0004090.

Devising a fair system of trials

Contact: Graeme Ackland (Room 2502, extn. 50 5299, email: gja@ph.ed.ac.uk)
1 project offered in semester 2, may be 1 in semester 1

In many experimental situations, one is interested in obtaining the maximum possible data from the minimum number of trials. Designing a good experimental protocol is important, and depends upon what the desired outcome is. In some cases an equal test of all samples is needed, while in others development of the most promising candidate for a specific application is preferred.
A similar dilemma is faced by those devising sports tournaments. In football for example, there is the prosaic all-play-all English Premier League system, the slightly more sophisticated Scottish PL where best play best in the second half, the English Championship system where third place is determined by a post season mini-tournament, World Cups with mini-leagues and knockouts, cups with straight knockout, and the US sport system where teams play a partially randomised selection of opponents. In this project you will examine which of these systems gives results most representative of the actual abilities of the teams.
Specifically, this will be done using computer simulation with code you will develop from scratch. Teams will be assigned a variety of strengths, and probabilities for winning will be determined by these strengths. The test for the system is whether the results of the competition are in agreement with the known prior expectation.

You will primarily need skills in programming, probability and statistics.

1D condensation transformation in sports

Contact: Graeme Ackland (Room 2502, extn. 50 5299, email: gja@ph.ed.ac.uk)

In a number of racing sports, it is advantageous to be alongside other competitors. In some cases, e.g. triathlon cycling and orienteering, this is against the "spirit" and competitors do not start in a group. A model for this process was developed several year ago in a JH project "Pack formation in cycling and orienteering" G.J.Ackland and D.Butler, Nature, 413, 127 (2001).
There are similarities to shock wave physics, to shallow water waves, and to traffic flows where the leading edge of a feature moves more slowly than the material behind it.

The model was applied in "The effect of pack formation at the 2005 world orienteering championships" G.J.Ackland Scientific Journal of Orienteering 17 12 (2005)

Since then, huge amounts of data have been obtained in various events. In this project you will analyse this data, and use it to parameterize and improve on the Butler/Ackland model.

The project will be entirely computational. You will write a code to simulate the pack formation process, and you will gather and format data from various online sources to test the model against.

Title: DNA unzipping and overstretching
Contact: Davide Marenduzzo (Room 2506, extn. 505289, email: dmarendu@ph.ed.ac.uk)

DNA is made up of two complementary strands, which are kept together by hydrogen bonding. When the DNA molecule is heated up, or subjected to external stresses, it can open up, or unzip. A simple and effective statistical physics model for DNA unzipping (also called denaturation) is provided by a pair of random walks interacting with a short range interaction mimicking hydrogen bonding. This model cannot be solved exactly and its analysis requires computer simulations.
In this project you will become familiar with similar statistical physics models for DNA unzipping, and study via computer simulations the effect of sequence heterogeneity in the physics of melting.

Relevant physics: Computer Programming, Statistical Physics, Biological Physics

Modelling chromosome dynamics
Contact: Davide Marenduzzo (Room 2506, extn. 505289, email: dmarendu@ph.ed.ac.uk)

Human chromosomes are arguably among the most important biopolymers. While we know in exact details the sequence of human genomes, we still know very little about how chromosomes fold in 3D space, or how chromosomes change their conformations during the different times of the cell cycle. In this project you will study via a molecular dynamics code which we have used in our lab a simple model of a chromosome as a long polymer subject to suitable simple interactions, which is suggested from experiments performed by our biology collaborators. We will then compare the results we obtain in our simulations with the real conformations of chromosomes in human nuclei. No prior knowledge of biology is required for the project, but you will need to be ready to engage with biophysics ideas which are new to you.

Relevant physics: Computer Programming, Statistical Physics, Biological Physics

3. Musical Acoustics

3.1 Acoustics

Stereoscopic sound localization
Contact: Clive Greated (Room 7306A, extn. 50 5232, email: c.a.greated@ed.ac.uk)

This project investigates the ability of humans to localize auditory events on the horizontal plane using two ears. Rayleigh's duplex theory of inter-aural time and intensity differences will be investigated through a series of experiments on a dummy head in the anechoic room and the limitations of the theory examined. Spectral position cues will be analyzed using head-related transfer functions. A stereoscopic loudspeaker configuration will be used to implement different ways of panning virtual sound images.

References:
J Blauert "*Spatial Hearing: The Psychophysics of Human Sound Localistion*" MIT Press 1997
F Rumsey "*Spatial Audio*" Focal Press, Elsevier 2001
F R Moore "*Elements of Computer music*" Prentice Hall 1990
W Hartmann "*Signals, Sound and Sensation*" Springer 1997

Input impedance of musical wind instruments
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

The acoustical resonances of a musical instrument can be measured by injecting a known oscillating volume flow into the mouthpiece and measuring the resulting pressure fluctuation. The ratio of pressure to volume flow is known as the input impedance. In this project the input impedance of a range of different wind instruments can be studied, and experimental measurements can be compared with numerically simulated input impedance curves. It is also possible to explore the optimisation of musical wind instrument bore profiles using input impedance targets.

Reference:
Braden, A.C.P., Newton, M.J., Campbell, D.M., *Trombone bore optimisation based on input impedance targets*, J. Acoust. Soc. Am. 125, 2404-2412 (2009).

The vibration of piano strings
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

On a well tuned piano, the fundamental frequencies of two strings an octave apart have a frequency ratio slightly greater than 2. This “stretched tuning” is related to the fact that the normal mode frequencies of a stiff string depart in a systematic way from the harmonic series which characterises an ideal flexible string. In this experiment the inharmonicity of real strings on grand and upright pianos is compared with theoretical predictions. The decay rates of single and multiple strings can also be investigated.

References:
H. Fletcher, *Normal vibration frequencies of a stiff piano string*, J.Acoust.Soc.Am. 36, 203-209, 1964.
G. Weinreich, *Coupled piano strings*, J.Acoust.Soc.Am. 62, 1474-1483, 1977.
N.H. Fletcher and T.D. Rossing, *Physics of Musical Instruments*, 2nd ed., Springer, 1998.
M. Campbell and C. Greated, *The Musician’s Guide to Acoustics*, Oxford University Press, 1987.

Vibrations of bars and plates
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

Impulsively excited long thin bars have natural mode frequencies which are far from harmonic. For a uniform bar, the theory is straightforward; for non-uniform bars, numerical predictions can be made. Glockenspiels, xylophones and tubular bells provide musical examples. Two dimensional plates have more complicated sets of natural modes than bars. Square and circular plates can be investigated; the small tuned cymbals known as crotales would make an interesting study.

Studying sound generation in brass instruments using artificial lips.
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

The lips of a brass instrument player act as a pressure-controlled valve, modulating the flow of air from the player's mouth into the instrument. The interaction between the lips and the air column of the instrument is an interesting example of nonlinear dynamics. In this project the mechanical response of a pair of artificial lips is measured, and the behaviour of the lips when playing a trombone is compared with the predictions of a computer model.

Nonlinear sound propagation in musical wind instruments.
Contact: Murray Campbell (Room 7306, extn. 50 5262, email: d.m.campbell@ed.ac.uk)

When a musical wind instrument is blown loudly, the amplitude of the pressure fluctuations inside the pipe can reach 10 kPa (10% of atmospheric pressure). At such high levels the normal linear acoustic equations are inadequate to describe a propagating sound wave. This project explores some of the physical and musical consequences of nonlinear sound propagation in brass instruments.

Data acquisition using Labview in experimental physics
Contact: Jochen Arlt (Room 2606, extn. 517066, email: Jochen.Arlt@ed.ac.uk)

LabVIEW is a powerful programming environment to integrate the control of test equipment and the acquisition, processing and display of data. In this project you first will go through a guided process of learning to independently use LabVIEW on the scale needed for the assigned data acquisition task. This also will provide you with sufficient techniques, understanding and overview to approach different or more complex tasks on your own thereafter.

This project then will ask you to investigate a fairly simple experimental task, e.g. investigating the AC Characteristics of a Loudspeaker. You will be given the needed data acquisition equipment and will have to come up with a LabVIEW programme which handles the interfacing and control of the hardware, the data acquisition and the signal analysis in 'real-time'. That, in turn, can be used as feedback to adjust the experimental parameters.
The goal is the automatic characterisation of the frequency response of the loudspeaker. You will also have to discuss the experimental and systematic uncertainties of the employed method and the obtained results.