DEPARTMENT OF PHYSICS

MSci PROJECT BOOKLET
2005/06

Course P4100 — Project in Physics

Contents

Project in Physics

(M.Sci) Course P4100

1. INTRODUCTION

This booklet contains information on the Fourth Year (M.Sci) Project in Physics course P4100 which is worth one course-unit. The procedures listed here are applicable to single honours physics students and to joint honours students who choose to take a project offered by the Physics Department.

All students in the fourth year physics M.Sci class are *required* to take a project course. Single honours physics students will take a project offered by the Physics Department. Joint honours students may choose a project offered by either of their departments. Projects in the Physics Department involve 250 hours of work in total, including 120 hours of laboratory or equivalent work. Experimental, Theoretical and Computational projects are available.

The following few pages deal with the way in which the project work is organised. Guide-lines for writing the project report are given in Appendix (1). Appendix (2) is a listing of the projects which are offered by members of staff in the Physics Department of King's College. Students are expected to choose a project offered by the College at which they are registered for the M.Sci degree.

A *Wheatstone Prize*, is normally awarded annually for the best P4100 project submitted by a King's College student who is progressing to a higher degree (see p5).

2. ORGANISATION, SAFETY, PROJECT WORK AND ASSESSMENT

In this section the various elements of the project work are detailed in chronological order.

2.1 Organisation

The list of projects available is published to all fourth year students at the start of the session. The list for the session 2005/6 is contained in Appendix (2) of this booklet.

All the students are required to return a form — the ‘Project Selection Form’ *by the end of the second week of the first semester*

Students are *strongly encouraged* to arrange themselves which project they will do by consulting with staff members (see p3). Any students who are unable to arrange their project in this way should select up to five projects from the list giving their order of preference.

Projects will be allocated by the Departmental Project Committee to any students who have not pre-selected their project by consultation with a staff member. The project preference will be taken into account as well as the load on individual members of staff. Please note that there is no guarantee that you will be allocated your first choice (a number of students may have given the same first choice), or indeed any of the projects you have selected.

2.2 Safety

It is of paramount importance that all work in the Physics Department is carried out safely. For that reason, staff have carried out a risk assessment for every M.Sci project. For theoretical and computational projects the risks are normally minimal; nevertheless there are general safety issues with which every student must be familiar. For experimental projects there may be a number of potential hazards, and to ensure safe working it is essential that students are made aware of these. **Students must not start work on a project until they have received instruction in general safety and have also discussed the risk assessment for their project with the supervisor.** Students must sign a document to say that this safety information has been provided, and that they will conduct their project in a safe and responsible manner.

2.3 Project Work and the Project Notebook

Work on the project will begin in the fourth week of the session. Your supervisor will discuss your own work schedule with you and arrange a time for a weekly review of progress. The supervisor's duty is to advise you on the conduct of the project and assist with the provision of any apparatus or facilities needed. Do not expect the supervisor to do project work for you: the supervisor awards a mark for your own enterprise and approach to the work and it is important during the weekly discussion that you keep him or her aware of exactly what you are doing.

Students must maintain a **Project Notebook** which contains all of the analyses and data arising from work carried out for the project. This ‘notebook’ may be in loose-leaf form if desired. The report will be prepared from work in the notebook. The notebook must be submitted with the two copies of the final report for the examiners' inspection.

Most of the scientific work for the project should be completed by the end of the first semester – do not underestimate how long it will take to write your report. In any research project, analysis of data, preparation of figures, and the actual writing, takes just as long to do as the science which is to be reported. (120 hours have been assigned to laboratory or equivalent work leaving 130 hours for preparation of the report — p1). Most of the marks for the course are awarded for the report.

At the end of the first semester you must submit a one-page progress report to your supervisor.

2.4 The Final Report

You should begin preparing your final report at the start of the second semester. Detailed guide-lines for writing the final report are given in Appendix (1) of this booklet. It is a good idea to prepare a list of section headings as a preparation to the actual writing of the report and to discuss this with your supervisor. Do not rely on being able to print-out the final report on the last date for submission. This particularly applies if your report contains a number of graphical images which will require a long time to print out!

On or before the *deadline* of the last week of the second semester you must present *two copies* of your final report, the project notebook, and the three evaluation forms (one for your supervisor, one for your project and one for the M.Sci programme) to the departmental secretary (see p5). The project notebook may be collected from the departmental secretary after the examination period. The final report will be marked by the supervisor and a second examiner. The reports have the status of examination papers and will be retained for inspection by the External Examiners and teaching quality assessors. They will not be returned to you so you should make a copy for yourself before submitting the report for marking.

2.5 The Oral Examination

At the beginning of the third semester you will be given an oral examination on your project by a panel of three or more staff members. The appointed external examiners have the right to be present. Students must attend their examination at the time allocated on a published timetable. A provisional timetable will be given to you when you submit your final report to the departmental secretary. At the beginning of the third semester you should check (by consulting the notice board outside room Q122) that the date and time for your oral examination has not had to be changed.

In the examination you will give a talk on your project work lasting for 25 minutes. This will be followed by about 15 minutes of questions from the panel members. IMPORTANT - Note that not all the panel members will be familiar with the subject matter of your talk and only your supervisor and second examiner will have seen your written report. Take particular care to give an introduction to your talk at an elementary level to set the scene. Your project will probably be concerned with a very specialised research area. If some of the examiners do not understand your talk you are likely to score a low mark. In the oral exam your aim should be to present an outline of what you have done which could be understood by undergraduate students at the third year B.Sc. level.

An overhead projector and/or a computer data projector will be available for the talk.

- Students may obtain materials (pens and transparencies) for their presentation from the departmental secretary (Room Q122). *Please note that one day's notice is required if you want material photocopied to overhead transparencies by the secretary*.
- If you wish to use the data projector you must ensure that your presentation file is loaded into the computer and runs successfully before the appointed time for

your talk. Please consult the departmental secretary (Room Q122) to find out when the projector can be made available for testing your presentation.

A mark will be given for the oral examination which will represent 20% of the final mark for the project course.

3. STAFF PROJECTS.

Appendix (2) of this booklet is a listing of projects which have been proposed by members of King's College physics staff. All these projects are of research standard, and a well-written project report should provide the basis for a publication in the scientific literature.

A typical project heading in the listing is as follows.
ABC_04. Measurement of Microwave Magnetic Fields. (EC)

project reference code *project title* *project nature*

The project reference code is to be entered on the project Selection Form to identify your choice of project.
The project nature is an indication of the type of work involved in carrying out the project. The following literals are used —

E indicates an experimental project,

T indicates a theoretical project,

C indicates a computational project,

Combinations of these literals may be used in the description.

You are *strongly encouraged* to discuss individual projects in the list with the staff before making your choice. Each member of staff is allowed to allocate his/her project to a named student. Clearly such projects are then not available to other students. If you are very intent on taking a particular project, you should ask the appropriate member of staff if he/she is prepared to nominate you. If he/she agrees to do so, he/she must sign your project selection form. You should then enter only this one project on the Selection Form. Otherwise the form does not require a signature.

4. THE PROJECT SELECTION FORM.

Both single and joint honours students must return the project selection form **by the end of the second week of the session.** This form is the official departmental record of the work you are undertaking and will be used by the Project Committee to allocate projects to those students who have not arranged one themselves. If, as is usual, a member of staff has agreed to nominate you for his or her project, he or she must sign the selection form before you submit it.

5. SUBMISSION OF REPORTS AND THE DEADLINE.

The *deadline* for submitting your project work is the last day of the second semester (Friday, March 24 2006).

Your submission must include ***all*** of the following elements:

- ***two*** copies of the project report
- the project notebook
- ***three*** completed evaluation forms (one for the project work, one for the supervisor and one for the entire M.Sci. programme)

The three evaluation forms will be given to you by your supervisor.

The complete submission must be handed to the departmental/undergraduate secretary (Room Q122), ***not*** to the supervisor. Submissions will be accepted during the normal working week — Monday to Friday between the hours of 10am and 5pm. The secretary will make a note of the date of submission.

The secretary will not accept any submissions after 5pm on the day of the deadline.

Any late submissions must be made directly to the P4100 Project Committee Chairman (currently Prof. A.T. Collins, Room Q19) or to the Head of the Department if the Chairman is not available.

A late submission must include a ***written statement*** *and* ***documentary evidence*** *(such as a medical certificate) supporting the reasons for failure to meet the deadline*.

The fate of late submissions (**including consideration of whether they should be marked at all**) will be decided by the Project Committee in consultation with the project supervisor. You should **not** assume that a late submission will automatically be marked.

6. THE WHEATSTONE PRIZE.

A cash prize will normally be awarded for the best fourth-year project submitted by a student proceeding to study for a higher degree. However, the Department reserves the right not to award the prize and to vary the monetary value.

Appendix (1)

A1.1 THE PROJECT REPORT.

The length of the final report should be 10,000 — 12,000 words. There should be good reasons for the length of any report being outside these normal ranges. You should make a copy of the report for yourself because submitted reports will be retained for inspection by the External Examiners and will not be returned to you.

The report should be on A4 size paper and bound in a simple folder. The report should normally be prepared using a word processor with 1½ line spacing, 12 point type, a single-column format and 1 inch margins. However, a manuscript will be accepted if it is neat and legible.

The report should conform to the standards of published work except that *figures* need not meet the very high standards of presentation required by a scientific journal. Figures must, however, be neat, and, if hand-prepared, should have smooth curves with axes and axis labels drawn in ink.

Note that published papers consist only of text (with appropriate numbered headings and sub-headings), tables and figures. *Graphs*, *Photographs*, *Plates* and *Diagrams* are '*figures'*. Each table and figure must be numbered, labelled and referred to in the text.

Do not use bizarre fonts – 'Times Roman' or a Swiss font such as 'Arial' are normally used for papers submitted to scientific journals.

References to previously published work form an extremely important part of any research report. References to published work consulted in the course of the project should be given in the text in the Harvard form *name (year)* or *(name, year)* (e.g. ... as discussed by Smith (1997b) or ... as reported in the literature (Smith, 1997b).) and the complete reference given in an alphabetically ordered list at the end of the report. All references in this list must be cited in the text.

Any supporting material (such as computer program listings) should be presented in appendices and not included in the word count.

Guidance on the standards and style expected of published work can be obtained by study of a few original research papers – for example, those published in the *Journal of Physics A: Mathematical and General* or in *Physical Review*. You may also wish to consult a book giving guidance to the writing of scientific papers such as R. A. Day's *"How to Write and Publish a Scientific Paper"* (Cambridge University Press, 1989).

A copy of the marking scheme and guidelines used by the examiners is given in the next section of this appendix and summarised below.

The pages of the report and individual sections and sub-sections must be numbered and the report should include —

(a) a separate title page containing the **course number** (P4100), the **title**, **author's name** and **supervisor's name.**
(b) an abstract summarising the report (typically 150—250 words).
(c) an introduction setting the project work in context.
(d) a discussion of any relevant published work.
(e) a description of the work actually done.
(f) results of the work with an analysis of the data obtained.
(g) a discussion of the significance of the results.
(h) a final summary and conclusions.
(i) a list of the references cited in the text.
(j) any appendices.

Your attention is drawn to the following extract from the University Regulations for Internal Students — **"Where the Regulations for any qualification provide for part of an examination to consist of work written in the candidate's own time, the work submitted by the candidate must be his** [or her] **own and any quotation from the published or unpublished works of other persons must be acknowledged"**. Failure to observe this Regulation is regarded by the University Examination Board as a very serious matter. Note that the regulation includes unacknowledged quotations or the paraphrasing of published material.

A1.2 THE MARKING SCHEME AND GUIDELINES USED BY YOUR EXAMINERS.

The main points the examiners will be looking for are detailed below. The project supervisor will award marks for items 1-7. The second examiner will award marks for items 2-7. All of the examiners in attendance at the oral presentation (except the supervisor) will award a mark for item 8 and this mark will represent 20% of the final mark. A total of 250 marks are available, distributed as indicated below.

1) Student performance and initiative.
   [30 marks from supervisor]

- Did the student show skill and initiative or did he/she require a lot of help?
  (Factors considered will include the way the student acquired any new experimental, theoretical or computational skills, the way the student developed equipment, theory or programs, and how the student coped with unexpected difficulties.)
- Did the student successfully schedule the work for maximum productivity?

2) Context of the work.
   [10 marks each from supervisor and second marker].

- "What is the scientific interest in carrying out this work?"
  (Examiners will look for evidence of a satisfactory literature search, of an understanding of work already published in the area, a clear understanding of the initial objectives of the work, and (possibly) of how the final outcome differed as a result of the evolution of the work.)

3) Description of the methods used.

[15 marks each from supervisor and second marker].

- In a project with experimental aspects, is the equipment explained adequately, and are any samples which were used described?
- In a project with computational or theoretical aspects, are the techniques used explained and justified?
- In all projects, examiners will be looking for new developments made by the student, and careful consideration of the advantages and limitations of the techniques used compared to other possible techniques.

4) Results and their analysis.

[30 marks each from supervisor and second marker].

Results:–
- Are the results presented clearly?
- Is the quality of the results good, and have sufficient results been obtained?
- Have cross-checks been made to ensure the accuracy of the results?
- Have errors and uncertainties in the results been discussed adequately?
- Have the new results been compared to any relevant earlier results?

Analysis:–
- Is the analysis appropriate?
- Have cross-checks been made on the methods used?
- Are the final conclusions justifiable in terms of the methods used in the work?
- Have comparisons been made with existing theoretical or experimental results?
- Are there further conclusions the student could have drawn from the work done?

5) Summary of the work.

[10 marks each from supervisor and second marker].

- Are the final conclusions clearly stated?
- Are suggestions made for the future development of this line of work?
- Are any problems with this work clearly stated and discussed?

6) Impact of the work.

[10 marks each from supervisor and second marker].

- In the judgement of the examiners, how close is the work presented to being a published research paper?
  (Full marks will be awarded if minimal additional work is required, down to zero marks if there are no prospects of publication.)

7) Technical presentation of the report.

[10 marks each from supervisor and second marker].

- Does the style conform to that of published scientific papers?
- Is the report presented in a logical order?

- Are figures and tables numbered, do they have suitable captions, and are the references given clearly?
- Is the general quality of presentation good?

8) Oral Examination.

[50 marks in total awarded by all members of the examining panel, excepting the supervisor]

- Has the student given a clear description of the aims and results of the project?
- Were the graphs and diagrams legible, comprehensive and explained well?
- Did the student appear to have a confident knowledge of the material?
- Did the student pace the talk well and complete the presentation in the allotted time?
- Were questions answered competently?

9) The Final Mark

The maximum number of marks available is 250. The final percentage mark is calculated as the sum of all the marks awarded (as above) divided by 2.5.

Appendix (2) – Listing of Staff Projects

Dr J Alexandre (Room 2AA) (jean.alexandre@kcl.ac.uk)
JA_05: Exact Renormalization equations in two-dimensional theories (T)

The aim of this project is to study two-dimensional quantum field theories, relevant in String Theory, using exact renormalization equations (derived with the Wegner-Houghton procedure). A important model that will be studied is the Liouville Theory on a flat world-sheet.

The renormalization group transformations are introduced so as to set up the explicit dependence of the parameters of a theory on the observational scale. This procedure helps generate the quantum theory corresponding to a classical theory. Differential equations defining the evolution of the system with the scale of observation will be studied. These equations will be integrated analytically when possible and numerically otherwise.

This project includes a large component of bibliographical work and analytical computations for the student to get used to the basic ideas underlying the theory. These studies will be original and the student is expected to develop his/her own results.

The structure of the research project is the following:

(1) Starting from the definition of partition function that the student knows, the functional integral will be introduced qualitatively. This introductory part is based on the tools developed in Analytical Mechanics.

(2) Infinitesimal renormalization group transformations will be defined in Fourier space and the corresponding (well known) differential equations, showing the scale dependence of the theory, will be derived by the student.

(3) These differential equations will be integrated analytically in the simplest approximations.

(4) A numerical study will be performed in order to discuss the validity of the different approximations. The student can use the language and method of his/her choice for this numerical analysis.

Professor Alan Collins (Room Q19) (alan.collins@kcl.ac.uk)
ATC_05. Interfacing optical spectrometers and the study of brown diamonds. (E)

Some spectrometers, in the Solid State Physics Group, employed for measuring absorption, photoluminescence and cathodoluminescence spectra, currently use plug-in cards, DOS-based software and custom-built electronic interfaces to control the spectrometers and input analogue signals from the detectors.

The initial purpose of this project is to modernise these systems, using a computer with a USB bus and a miniLAB 1008 from the Measurement Computing Corporation. This device provides analogue input and output channels as well as digital input/output lines. New software will be written using Visual Basic to perform the same functions as those carried out by the present software, and the miniLAB will be configured to provide timing pulses for stepper motors, input trigger signals from external timers and input the analogue signal from the detector. Some electronic construction will be required make the miniLAB signals compatible with the existing hardware.

The completed system will be used to study cathodoluminescence spectra from natural brown diamonds, following a series of thermal annealings in the temperature range 800 to 1600 °C. The colour enhancement of brown diamonds by high pressure, high temperature annealing is currently a very topical issue. The changes, with annealing temperature, in the concentration of an optical centre with a zero-phonon line at 490.7 nm may provide a better understanding of the plastic deformation process believed to be responsible for the brown colour.

Skills required - Programming using Visual Basic; good understanding of analogue and digital electronics; electronic construction; ability to use a variety of instruments and techniques; careful and methodical experimental spectroscopy.

Dr A De Vita (Room Q23) (alessandro.de_vita@kcl.ac.uk)
ADV_05: Modelling long-range interactions in rubrene on gold (111) [TC]

This project is concerned with the self-assembly of supramolecular nanostructures. As in biological systems, non-covalent bonds (mainly hydrogen bonds) mediate the controlled assembly and hierarchical growth of instructed, fully integrated and connected man-made supramolecular systems. An impressive variety of structural motifs using various self-assembly protocols has been designed to date, including helicates, catenates, grids, cages, dendrimers, rosettes, chains, ladders and “magic clusters”. Crucially, recent studies have shown that theoretical simulations performed in conjunction with scanning tunnelling microscopy (STM) allow for unprecedented insight in complex molecular architectures, much needed to design manipulation protocols down to the single molecule level.

The goal here is to investigate the higher-level supramolecular assembly behaviour of rubrene molecules physisorbed on the Au(111) surface. STM experiments on these systems have shown that rubrene molecules self-assemble on the surface giving rise to a number of supramolecular geometries including, in particular, pentagonal five-molecule clusters which, in turn, assemble in a stereoselective way to yield self-avoiding 1D structures. A number of theoretical and experimental results suggest that the rubrene pentagons may be in a positive charge state. Although a direct experimental confirmation of this hypothesis is still missing, it is likely that the charging effect has a primary role in determining the final supramolecular structures observed.

The project will consist of a theoretical investigation of the aggregation of rubrene pentagons, using a model interaction Hamiltonian which will be developed to incorporate long-range electrostatic effects. The primary scope of the project is to rationalize the appearance of the self-avoiding 1D structures seen in the experimental STM images in a range of surface coverages, by means of a molecular dynamics simulated annealing technique.

Lev Kantorovich (Room Q127) (lev.kantorvitch@kcl.ac.uk**)**
LNK_05. Atomic processes during nano-scale friction: a microscopic approach (TC)

Understanding of microscopic processes happening during sliding of two crystal surfaces with respect to each other are important in numerous number of applications related to friction and wear (e.g. in tyre industry). These processes can be studied on various length scales from micrometers to nanometers and down to atomic scale when protrusions of one surface contact with those of the other. Friction forces and extent of wear depend on the hardness of the surfaces, their smoothness, the speed of sliding and applied load.

In this project, which is envisaged to be done in close collaboration with experimental groups in Basel (Switzerland) and McGill University (Canada), a student will study these processes using an atomistic simulation technique. The load and the pull will be simulated by springs attached to the upper and front sample surfaces, respectively, the corresponding spring constants will be taken from those implemented in actual experiments. The interactions between atoms in the system will be modelled using semiclassical force fields. Temperature effects can be taken into account by means of molecular dynamics simulations. The goal of the project is to study the friction force and the amount of wear as functions of the applied load and the velocity of sliding for a number of different surfaces.

The project is based on existing modelling tool, developed at King's (the Sci-Fi code), but will require some additional programming using FORTRAN language in the UNIX environment.

Dr. Alison Mainwood (Room Q129) (alison.mainwood@kcl.ac.uk)
AMM_05. Theoretical modelling of the nucleation of growth of diamond. (TC)

Diamond can be grown by a process called Chemical Vapour Deposition (CVD) in which a mixture of hydrogen and methane gases are activated by a microwave plasma, and carbon is deposited on the surface of a substrate to build up the diamond. This is done at temperatures and pressures where graphite is the stable form of carbon and the role of the hydrogen is to etch away any graphite so that just the diamond phase grows. One of the problems in this process is the nucleation of the first tiny crystallites, and some recent work (reported at a conference in September 2003) showed that on an iridium substrate, the first tiny islands of diamond form a fairly regular pattern of evenly spaced and evenly sized islands. This can be understood if the carbon atoms arriving on the surface can move across it, and adhere to any which are already there.

In the project you will set up a model of this process, with carbon atoms arriving randomly at the surface and either sticking, moving or detaching from it, until the islands and finally a full layer of diamond builds up. You will change the probabilities of these processes and compare the “crystallites” that you predict with the experimental images. At the same time, conventional molecular dynamics software will be used in combination with the results of chemical modelling of the processes that have already been published, to simulate the first stages in the growth of CVD diamond.

Skills: Computer programming using C (or another language)

Dr N.E. Mavromatos (Room Q21) (nikolaos.mavromatos@kcl.ac.uk)
NEM_05: Neutrino Oscillations in Noisy Media: a preliminary study (T)

In recent years there is mounting experimental evidence that the neutrino is massive. This evidence has been gathered by essentially measuring oscillations of neutrino species (flavours) in a diversity of experiments (solar, atmospheric and nuclear reactor experiments), for instance , disappearance of electron neutrinos due to their transformation into muon neutrinos etc. Indeed, the probabilities for such flavour transformations during the neutrino flight from production till observation have an oscillatory time dependence, and are unavoidable if the neutrinos are massive particles. In many neutrino experiments the neutrinos are produced in noisy environments, such as the Sun or nuclear matter, where the density of the medium (say the density of electrons) is itself a time dependent function. One of the important features of the passage of neutrinos through matter is an induced difference in the mass among the various neutrino flavours, even if the neutrinos were degenerate in mass in vacuo.

The project will be dealing with a preliminary study of such effects, both oscillations and induced mass differences among flavours in the case of media where the electronic density of the medium will be assumed to vary stochastically in time (i.e, Gaussian fluctuations about an average (mean) density). The pertinent quantum mechanical Schroedinger-like evolution equation, describing the passage of neutrinos through such media, which will involve the interaction with the stochastic environment , will be constructed and solved with respect to the oscillation probabilities in the simplified case of two flavour oscillations. In such a case the pertinent quantum mechanical system is a two-level system.
The necessary information from particle physics on the detailed form of the interaction Hamiltonian with the medium, and other relevant properties, will be provided to the student as background input. The task will be then to solve the associated temporal Schroedinger equation for the neutrino species in the stochastic medium.

The problem will require semi analytical (iterative) methods for solving the stochastic temporal equations involved, supported by numerical methods for obtaining the relevant probabilities of neutrino oscillations, and the associated matter-induced mass differences between flavours.

Skills required: Excellent knowledge of advanced quantum mechanics, in particular quantum mechanics of open systems interacting with an environment, and good knowledge of numerical methods for solving quantum mechanical Schroedinger-like temporal equations. Some basic knowledge of particle physics is also a prerequisite. The project will also require an extensive literature search to provide the necessary background information.

Professor AG Michette (Room Q25)

AGM_05: Optics for keV X-Rays [CT]

Optics such as the mirrors and lenses common for visible light cannot readily be used for manipulating or focusing beams of x-rays since the refractive indices of all materials are very close to unity. This means that refraction angles are very small, leading to extremely long focal lengths, and reflectivities at near-normal incidence are essentially zero.

Despite these difficulties there are several modern x-ray applications that require beams of x-rays to be focused to small (sub-micrometre) spots. One of these is the study of x-ray induced radiation damage of biological material. Previous work in this area has used low energy (284 eV) x-rays, which can be focused reasonably well using diffractive optics, i.e., zone plates. However, such x-rays are not very penetrating and so the studies have been limited to isolated cells, and the results may not be directly applicable to living organisms. To provide better penetration studies should be carried out using higher energy x-rays, but these are harder to focus. Optics for x-ray energies of a few keV would find application in many areas of research, including that carried out at synchrotron sources.

The purpose of this project is to compare optical systems suitable for focusing titanium K (4.5 keV) x-rays. Possibilities include zone plates, various arrangements of grazing-incidence optics and linear arrays of refractive components (compound refractive lenses, CRLs). The first part of the project will be to survey the possibilities, followed by the selection of two of them for further study. This will include comparisons of focal spot sizes, focal lengths, depths of focus, aberrations and the effects of manufacturing inaccuracies. If required the optical design programme ZEMAX is available, but this may only be used on a specified computer in the Department.

Dr. G Morrison (9A/B) (graeme.morrison@kcl.ac.uk)

GRM_05 Simulation and characterisation of Brownian ratchets.(CT)

The random walks executed by small particles suspended in a fluid are the result of Brownian motion, a series of randomly-induced movements arising from molecular collisions with the particle. Brownian ratchets are micro-structured arrays of asymmetric obstacles that effectively bias the random walk in particular directions. They have been used as sieves and sorters that can very effectively sort microscopic particles, such as soot particles, or biological material such as viruses or DNA fragments, since Brownian motion displaces small particles further than larger ones [1,2]. Computer simulation of such ratchets allows the effect of changing various ratchet parameters to be tested and compared in a quick and relatively direct manner, without the need for access to microlithographic facilities. This allows a range of different designs and configurations to be considered before resorting to the careful and time-consuming experimental work needed to characterise a promising design. The specific aims of the project are as follows:

(i) To develop computer programmes that allow the simulation of biased random walks through asymmetric 2-D arrays of microscopic obstacles.

(ii) To compare the effectiveness of different obstacle arrays in separating small particles of different sizes, and perhaps also shapes.

Skills: Computer programming, mathematics, theoretical physics.

Dr David Richards (Room Q117) (david.r.richards@kcl.ac.uk)
DRR_05. Nanostructure Measurement by Atomic Force Microscopy. (E)

The development of *nanostructures*, structures with dimensions less than 1 µm fabricated for an ever increasing range of application, relies critically on the ability to characteriise with nanometre accuracy the size and shape of such systems. One important technique for such measurements is that of atomic force microscopy (AFM), in which a sharp needle maps out the relief of a surface with nanometre resolution.

This project will be concerned with the preparation of a range of nanostructures, and their characterisation by AFM. It will involve a detailed understanding of the underlying principles and limitations of AFM.

One system to be considered is that of gold nanostructures deposited on glass surfaces, which have application in optical sensors for chemical and biological detection. Thin metal films will be deposited by evaporation. If the evaporation conditions are chosen corrrectly, this should lead to a rough ‘nanostructured’ surface and the nature of the surface and the length-scales of the surface roughness will be investigated by AFM. It is also possible to create metallic nanostrutures by metal evaporation through a mask of a layer of sub-micron latex beads, and it is proposed to also investigate such systems with AFM. Depending on progress with the project, AFM will also be employed for the characterisation of individual semiconductor nanoparticles, or clusters of nanoparticles, deposited on a glass surface.

Skills: careful experimental work and data analysis; the ability to use a variety of instruments and techniques.

Prof. Sarben Sarkar (Q27) (sarben.sarkar@kcl.ac.uk)
SS_05. The emergence of gauge fields in classical mechanics (T)

Gauge fields are important in the description of fundamental interactions in nature such as electromagnetism and general relativity. They are associated in these cases (within a quantum context) with particles, viz. the photon and the graviton. However recently it has been found that gauge fields emerge in effective descriptions of physical situations such as that of a springboard diver and a falling cat. In both these cases change of shape is used to affect rotation. The connection between shape and rotation is given by gauge fields which represent Coriolis forces. In this project the kinematics of the introduction of such gauge fields will be studied. The symmetries of these systems are translational and rotational invariance. Separating the internal motion from those associated with these symmetries leads to the construction of shape co-ordinates and shape space. Explicit construction of shape space in both 2-dimensional situations (for both connected systems of rods of fixed lengths hinged at one end and point particles) as well as the 3-body problem in 3-dimensions will be performed. The angular momentum will be constructed in terms of these co-ordinates and associated gauge fields. For zero total angular momentum the relation between shape and rotation will be constructed. The models will be in addition regarded as giving explicit examples of fibre bundles and the constructions will be interpreted in terms of base space, group actions on fibres and sections. Situations where monopoles arise will be considered.

Skills: Classical mechanics, mathematical methods, theory of angular momentum, tensor analysis, differential geometry

Klaus Suhling (Room Q17) (klaus.suhling@kcl.ac.uk)
KS_05. Photon counting imaging

The use of a photon counting image intensifier coupled to a CCD camera is an established method to acquire images at a low-light level. The Hubble Space Telescope's faint object camera, and the optical monitor of the recently launched x-ray multi-mirror mission (XMM) are both based on low light level photon counting imaging devices. Linearity, a high dynamic range, large active area and high sensitivity in the UV are particular strengths of this technique. Photon counting imaging is not restricted to astronomy, its advantages have also recently been harnessed in fields such as autoradiography, bioluminescence and fluorescence imaging.

One characteristic feature of this method is a centroiding technique, where the intensity distribution of each individual photon event is converted into positional information. The resolution lost in the amplification and readout stages of the detector can thereby be recovered and subpixel resolution be obtained. An important factor to consider in the design of a photon counting imaging system is the choice of a suitable centroiding algorithm.

The project will focus on the optimization of software-based centroiding algorithms, and it is envisaged that this will be tested on biological samples under a fluorescence microscope.

*Skills required***:** programming in C++