DEPARTMENT OF PHYSICS AND ASTRONOMY

4th Year
Course Descriptions

Including link to
4th Year Intercollegiate MSci Courses

2014/15

INTRODUCTION

This handbook contains details about all the constituent courses for 4th year full-time masters undergraduate programmes which are planned to be offered by the Department of Physics and Astronomy in Session 2014/15. For example, for each course you will find aims and objectives, the syllabus and its teaching and assessment methodology. Additionally, at the end of the booklet, information is given on courses provided by other London Colleges, as part of the Intercollegiate MSci programmes. The handbook should be consulted in conjunction with another Departmental publication *BSc/MSci Programme Structures 2014/15.* If you do not have a copy of this, one may be obtained from the Undergraduate Teaching pages on the departmental website The latter handbook gives information on how these courses fit into particular degree structures as well as brief descriptions of the courses themselves. Please note that it cannot be guaranteed that all courses offered will run and that only the most usual pre-requisites for courses are given.

If you need guidance on your choice of course(s) please contact the Departmental Programmes Tutor, Dr. S. Zochowski (s.zochowski@ucl.ac.uk).

A copy of this Handbook can be found on the Departmental Web site:
http://www.ucl.ac.uk/phys/admissions/undergraduate/.

CONTENTS

PHASM101 - Astrophysics Project (Term 1 & 2)

Prerequisites

Normally PHAS3330 and PHAS3331 or PHAS3332

Aim of Course

The aim of the course is to transfer and encourage independent research skills in the student, by requiring them to undertake and complete a research project over two full terms. At the end of the project, the student is required to submit a detailed project report, written in the same style as a scientific paper, and to give a 20-minute audiovisual presentation of their results.

Objectives

At the end of the course the student should have:

- increased skill and confidence to plan and work independently, or with a single partner
- improved skills in conducting a complex, open-ended scientific investigation, in an active research environment
- increased ability to seek out information as required from a variety of sources
- become accustomed to developing ideas in discussion
- have further developed the reporting skills practiced in earlier lab courses by distilling the notebook record of work of the lengthy project into a concise, but precise and complete formal report of the experiment in word-processed form
- have become more aware of the demands of oral presentation by making an oral report of the project

Course Contents

- *Project Assignment:* Students normally work singly on an Astrophysics project, spending about ten hours per week for two terms conducting an open-ended investigative project. After the completion of examinations at the end of the third year, students are given a list of staff and their research interests and are told to approach those whose fields interest them, in order to select and agree upon a research topic. Wide scope is allowed for the nature and topic of the project. The project may consist of the analysis and interpretation of recently acquired data, a laboratory-based instrumentation development, an observational project at the University of London Observatory, or may mainly consist of theory and computation. Each student is given a reading list for the summer break and the project proper commences on the first day of term at the beginning of the fourth year.
- *Project outline:* A deadline of the last day of summer term in the 3rd year is given for handing in to the course coordinator a title and abstract for the agreed-upon research project, to be signed by both student and supervisor.
- *Project Supervision:* Each student has a project supervisor, who should be skilled in the chosen research topic, and whose task it is to define a project whose goals are capable of being achieved over two full terms of work. The supervisor will advise the student on suitable techniques and packages that are needed for the research project. The supervisor and student will meet regularly (at least once a week) in order to facilitate the learning of research skills by the student and to monitor the progress of the project.
- *Progress report:* Towards the end of the first term, each student has a formal interview with the course coordinator in order to assess progress and during the second week of second term an interim 2-page report must be written by the student (and signed by the supervisor)

describing the results achieved to date, any problems encountered, and what remains to be done by the end of the project.

- *Project Oral presentation:* Two weeks before the deadline for submission of the final project report, each student must deliver a 20-minute audiovisual presentation on the background to and results from their research project.
- *Project Final Report:* The final project report, normally not more than 50 typed pages in length, is expected to have been word-processed and to contain full referencing.

Assessment

The different course components contribute to the total assessment with the following weights:

- Literature survey – 15%
- Progress report – 5%
- Progress interview – 5%
- Project presentation – 15%
- Project dissertation – 60%

Three assessors are involved; the supervisor, a second marker who will normally be familiar with the subject of the project, but not involved in it, and a moderator. The task of the moderator is to harmonise the results of the individual examiners in the light of the moderator's own assessment and a comparison with other projects. In cases of significant discrepancies between the marks of the first and second examiners, the task of the moderator is to produce a final mark which can be agreed upon by both examiners.

In assessing a project, attention will be paid to a demonstration of the context and relevance of the work to the rest of the field. Inadequate referencing will be penalised. The bulk of the assessment hinges on the quality of the scientific work carried out and what has been achieved. If some of the initial goals of the project could not be achieved through no fault of the student, then this should be made clear. The actual work done by the student should be clearly distinguished in the report.

PHASM201 - Physics Project (Term 1 & 2)

Prerequisites

Normally PHAS3440 Experimental Physics. Theoretical Physicists require Mathematica training.

Aim of the Course

All Physics Laboratory courses within the Department contribute to a continuing development of students' practical skills extending throughout the four/three years of the MSci/BSc degrees. Collectively the courses have the overall aim of equipping the student with those practical skills which employers expect to find in graduates in physics whether they are employed in scientific research or development, or in a wider context. Intended for students following Physics-related in their final year of study, PHASM201 contributes to this aim by bringing the skills acquired in earlier years to bear on an open-ended project of two-term duration with the following objectives.

Objectives

At the end of the course the student should have:

- increased skill and confidence to plan and work independently, or with a single partner
- improved skills in conducting a complex, open-ended scientific investigation, in an active research environment
- increased ability to seek out information as required from a variety of sources
- become accustomed to developing ideas in discussion
- have further developed the reporting skills practiced in earlier lab courses by distilling the notebook record of work of the lengthy project into a concise, but precise and complete formal report of the experiment in word-processed form
- have become more aware of the demands of oral presentation by making an oral report of the project

Course Contents

- *Project:* Students working in pairs on experimental projects, or singly in the case of theory projects, spend about ten hours per week for two terms conducting an open-ended, investigative project. They are required to keep a detailed lab notebook of their work. Each project is supervised by the member of the academic or technical staffs who has suggested the project which is normally derived from their own research work. It is normally carried out partly in the supervisor's research lab and utilising research group resources.
- *Project outline:* After an initial discussion with the supervisor and assessment of the project requirements, each student must present a short plan for the way they intend to proceed.
- *Progress Report:* At the mid-point of the project, each student presents a short report summarizing progress.
- *Project Report:* At the end of the project, each student must present formal word-processed report, normally not more than 50 typed pages in length, summarising the work on the project.
- *Project Oral Presentation:* At the end of the project, a project pair must make a joint oral presentation of their work lasting 30 minutes. Students working alone present their work singly in a report of 20 minutes duration.

Methodology and Assessment

Assessment is continuous. Students meet at regular intervals with their project supervisors to discuss progress and plan further work. Supervisors are also expected to be available on an ad hoc basis to help with difficulties as they arise. During these meetings the supervisor forms an opinion of the student's scientific abilities which is an important element in their assessment. In the project outline, presented after about three weeks of the first term, the student is expected to show evidence of understanding of the problem to be solved, a considered approach to the planning of the project backed up, if necessary, by preliminary calculations, and with possible areas of difficulty identified. The progress report at the mid-point of the project is intended to monitor how closely this initial plan has been followed, how much progress has been achieved at the half-way stage towards achieving the ultimate aim of the project, and what direction future work will take. Further assessment of the scientific merit of the students' work is derived from the lab notebook they keep of their activities and the formal report. Assessment of their ability to communicate their work is derived from the formal written report and oral presentation. The preparation of the report is time consuming and students are instructed to finish their investigative work well before the end of the second term to give adequate time for this. The supervisor is expected to spend some time reiterating advice given to students in earlier years on the content and qualities of good reports. Students making joint presentations are instructed to share the task in a way which reflects their individual contributions to the project. All assessed work is both first and second marked. The different course components contribute to the total assessment with the following weights.

- Literature survey – 15%
- Progress report – 5%
- Progress interview – 5%
- Project presentation – 15%
- Project dissertation – 60%

PHASM312 – Planetary Atmospheres (Term 2)

Prerequisites

Knowledge of mathematics is required including the basic operations of calculus and simple ordinary differential and partial differential equations.

Aims of the Course

This course aims to:

- compare the composition, structure and dynamics of the atmospheres of all the planets, and in the process to develop our understanding of the Earth's atmosphere

Objectives

On completion of this course, students should understand:

- the factors which determine whether an astronomical body has an atmosphere
- the processes which determine how temperature and pressure vary with height
- the dynamic of atmospheres and the driving forces for weather systems
- the origin and evolution of planetary atmospheres over the lifetime of the solar system
- feedback effects and the influence of anthropogenic activities on the Earth

Methodology and Assessment

30 lectures and 3 problem class/discussion periods. Lecturing supplemented by homework problem sets. Written solutions provided for the homework after assessment. Links to information sources on the web provided through a special web page at MSSL.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

(a) Planetary atmospheres and atmospheric physics:

- *The Physics of Atmospheres*, John T Houghton, Cambridge
- *Theory of Planetary Atmospheres*, J.W. Chamberlain and D.M. Hunten
- *Fundamentals of Atmospheric Physics,* by M. Salby
- *Planetary Science* by I. de Pater and JJ Lissauer (Ch 4: Planetary Atmospheres)

(b) Earth meteorology and climate

- *Atmosphere Weather and Climate* , RG Barry and RJ Chorley
- *Fundamentals of Weather and Climate,* R McIlveen
- *Meteorology Today* **OR** *Essentials of Meteorology* (abridged version), CD Ahrens
- *Meteorology for Scientists & Engineers*, R Stull (technical companion to Ahrens)

Syllabus

(The approximate allocation of lectures to topics is shown in brackets below)

Comparison of the Planetary Atmospheres (2)

The radiative energy balance of a planetary atmosphere: the competition between gravitational attraction and thermal escape processes; The factors which influence planetary atmospheres: energy and momentum sources; accretion and generation of gases; loss processes; dynamics; composition

Atmospheric structure (7)
Hydrostatic equilibrium, adiabatic lapse rate, convective stability, radiative transfer, the greenhouse effect and the terrestrial planets

Oxygen chemistry (3)
Ozone production by Chapman theory; comparison with observations; ozone depletion and the Antarctic ozone hole

Atmospheric temperature profiles (3)
Troposphere, stratosphere, mesosphere, thermosphere and ionosphere described; use of temperature profiles to deduce energy balance; internal energy sources; techniques of measurement for remote planets

Origin of planetary atmospheres and their subsequent evolution (3)
Formation of the planets; primeval atmospheres; generation of volatile material; evolutionary processes; use of isotopic abundances in deducing evolutionary effects; role of the biomass at Earth; consideration of the terrestrial planets and the outer planets

Atmospheric Dynamics (4)
Equations of motion; geostrophic and cyclostrophic circulation, storms; gradient and thermal winds; dynamics of the atmospheres of the planets; Martian dust storms, the Great Red Spot at Jupiter

Magnetospheric Effects (1)
Ionisation and recombination processes; interaction of the solar wind with planets and atmospheres; auroral energy input

Atmospheric loss mechanisms (1)
Exosphere and Jeans escape; non-thermal escape processes; solar wind scavenging at Mars

Observational techniques (3)
Occultation methods from ultraviolet to radio frequencies; limb observation techniques; in-situ probes

Global warming (3)
Recent trends and the influence of human activity; carbon budget for the Earth; positive and negative feedback effects; climate history; the Gaia hypothesis; terra-forming Mars

PHASM314 – Solar Physics (Term 2)

Prerequisites

This is a course which can accommodate a wide range of backgrounds. Although no specific courses are required, a basic knowledge of electromagnetic theory and astrophysical concepts (e.g. spectroscopy) is required.

Aims of the Course

This course will enable students to learn about:

- the place of the Sun in the evolutionary progress of stars
- the internal structure of the Sun
- its energy source
- its magnetic fields and activity cycle
- its extended atmosphere
- the solar wind
- the nature of the heliosphere

The course should be helpful for students wishing to proceed to a PhD in Astronomy or Astrophysics. It also provides a useful background for people seeking careers in geophysics-related industries and meteorology.

Objectives

On completion of this course, students should be able to:

- explain the past and likely future evolution of the Sun as a star
- enumerate the nuclear reactions that generate the Sun's energy
- explain the modes of energy transport within the Sun
- describe the Standard Model of the solar interior
- explain the solar neutrino problem and give an account of its likely resolution
- describe the techniques of helio-seismology and results obtained
- discuss the nature of the solar plasma in relation to magnetic fields
- explain solar activity - its manifestations and evolution and the dynamo theory of the solar magnetic cycle
- describe the solar atmosphere, chromosphere, transition region and corona
- explain current ideas of how the atmosphere is heated to very high temperatures
- describe each region of the atmosphere in detail
- explain the relationship between coronal holes and the solar wind
- explain a model of the solar wind
- indicate the nature of the heliosphere and how it is defined by the solar wind
- describe solar flares and the related models based on magnetic reconnection
- explain coronal mass ejections and indicate possible models for their origin

Methodology and Assessment

This is a 30-lecture course and Problems with discussion of solutions (four problem sheets). Video displays of solar phenomena will be presented. Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

- *Solar Astrophysics*, P. Foukal, Wiley-Interscience,1990. ISBN 0 471 839353
- *Astrophysics of the Sun*, H. Zirin, Cambridge U P, 1988. ISBN 0 521 316073
- *Neutrino Astrophysics*, J. Bahcall, Cambridge U P, 1989. ISBN 0 521 37975X
- *The Stars; their structure and evolution* by R.J. Taylor, Wykeham Science Series - Taylor and Francis, 1972. ISBN 0 85109 110 5
- *Guide to the Sun*, K.J. H. Phillips, Cambridge U P, 1992. ISBN 0 521 39483 X
- *The Solar Corona*, Leon Golub and Jay M. Pasachoff, Cambridge U P, 1997. ISBN 0 521 48535 5
- *Astronomical Spectroscopy,* J. Tennyson, Imperial College Press, 2005. ISBN 1860945139

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below)

Introduction [1]
Presentation of the syllabus and suggested reading, a list of solar parameters and a summary of the topics to be treated during the course

The Solar Interior and Photosphere [8]
Stellar structure and evolution; Life history of a star; Equations and results; Conditions for convection; Arrival of the Sun on the Main Sequence; Nuclear fusion reactions; The Standard Solar Model; Neutrino production and detection - the neutrino problem; Solar rotation; Photospheric observations; Fraunhofer lines; Chemical composition; Convection and granulation; Helio-seismology - cause of solar five-minute oscillations, acoustic wave modes structure; Description of waves in terms of spherical harmonics; Observing techniques and venues; Probing the Sun's interior by direct and inverse modeling; Recent results on the internal structure and kinematics of the Sun

Solar Magnetic Fields/Solar Activity [6]
Sunspot observations - structure, birth and evolution; Spot temperatures and dynamics; Observations of faculae; Solar magnetism - sunspot and photospheric fields; Active region manifestations and evolution; Solar magnetic cycle - Observations and dynamics; Babcock dynamo model of the solar cycle; Behaviour of flux tubes; Time behaviour of the Sun's magnetic field

The Solar Atmosphere – Chromosphere and Corona [9]
Appearance of the chromosphere - spicules, mottles and the network; Observed spectrum lines; Element abundances; Temperature profile and energy flux; Models of the chromosphere; Nature of the chromosphere and possible heating mechanisms; Nature and appearance of the corona; Breakdown of LTE; Ionisation/recombination balance and atomic processes. Spectroscopic observations and emission line intensities; Plasma diagnostics using X-ray emission lines Summary of coronal properties

The Solar Atmosphere – Solar Wind [2]
Discovery of the solar wind; X-ray emission and coronal holes – origin of the slow and fast wind; In-situ measurements and the interplanetary magnetic field structure; Solar wind dynamics; Outline of the Heliosphere

Solar Flares and Coronal Mass Ejections [4]
Flare observations; Thermal and non-thermal phenomena; Particle acceleration and energy transport; Gamma-ray production; Flare models and the role of magnetic fields; Properties and structure of coronal mass ejections (CMEs); Low coronal signatures; Flare and CME relationship; Propagation characteristics; CME models and MHD simulations

PHASM315 – High Energy Astrophysics (Term 1)

Prerequisites

Algebra and some calculus (differentiation, integration); basic knowledge of mechanics and electromagnetic theory; basic astrophysical concepts (e.g. spectra)

Aims of the course

This course aims to:

- provide a practical rather than mathematical introduction to General Relativity and the properties of black holes
- derive a simple mathematical formulation of the mechanisms which lead to the production of high energy photons in the Universe, and of the absorption processes which they undergo on their path to Earth
- provide a quantitative account of cosmic sources and phenomena involving the generation of high energy photons and particles
- train students to apply the mathematical formulations derived in the course to realistic astrophysical situations, to derive parameters and properties of cosmic sources of high energy radiation, in a fashion similar to that commonly applied in research projects

Objectives

On successful completion of this course students should be able to:

- derive, using practical considerations and a simple mathematical treatment, the expression of the space-time metric appropriate in the vicinity of a non-rotating mass and the properties of non-rotating black holes, and demonstrate knowledge of the properties of rotating black holes
- derive a mathematical formulation of the mechanisms that lead to the production of high energy photons and of those that cause their absorption on their path to Earth
- describe, with the aid of diagrams and the application of basic mechanics and electromagnetic theory, the characteristics of celestial sources of high energy radiation, such as cosmic ray sources, supernova remnants, pulsars, Galactic and extra-galactic X-Ray sources; deduce their physical parameters by practical application of physical laws and formulae

Methodology and Assessment

This is a 30 lecture course. Students progress is monitored by their performance in homework problems (3 to 4 papers are set throughout the course) and by the final, written examination. The marked problem sheets are returned one week after submission and the solutions are discussed in the class by the lecturer encouraging student intervention.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

The numbers in round brackets correspond to the syllabus topics listed below. Students should note that no single text book covers all the topics included in the course. The extensive reading list given below (including some research papers) is proposed **for consultation,** so that students can check and expand on the notes taken at lectures.

- *Principles of Cosmology and Gravitation*, M. J. Berry, Institute of Physics Publishing Ltd; 1989 (2)
- *High Energy Astrophysics*, vol. 1, M Longair, Cambridge University Press, 2nd edition; 1992 (3,4,5)
- *High Energy Astrophysics*, vol. 2. M. Longair, Cambridge University Press, 2nd edition; 1994 (3,5,6,8)
- *X-ray Astronomy*, R. Giacconi and H. Gursky, Reidel; 1974 (3,8)
- *Astrophysical Concepts*, M. Harwit, Springer-Verlag, 2nd edition; 1988 (3,9)
- *Cosmic Rays and Particle Physics*, T.K. Gaisser, Cambridge University Press; 1990 (5)
- *Supernova Remnants*, Ann. Rev. Astron. Astrophys., **10,** 129; 1972(6)
- *Pulsar Astronomy*, A. G. Lyne and F. Graham-Smith, CUP; 1990(6,7)
- *Neutron Stars*, Ann. Rev. Astron. Astrophys., **8,** 179; 1970 (7)
- *On the Pulsar Emission Mechanisms*, Ann. Rev. Astron. Astrophys., 13, 511; 1975 (7).
- *The Nature of Pulsar Radiation*, Nature, 226, 622; 1970 (7)
- *Accretion Power in Astrophysics*, J. Frank, A.R. King and D.J. Raine, Cambridge University Press; 1985 (8)

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below)

1. ***The scope of High Energy Astrophysics; Pre-requisites, units***

2. General Relativity and black holes [5]
A simple approach to the Schwarzschild metric; Properties of the event horizon; The Kerr solution for rotating black holes; Ergospheres

3. Radiation processes [8]
Cyclotron and synchrotron radiation, inverse Compton, thermal bremsstrahlung, free-bound (thermal recombination) and bound-bound (line emission) processes

4. Interaction of radiation with matter [2]
Photoelectric absorption, Thomson and Compton scattering, pair production, synchrotron self-absorption

5. Cosmic rays [2]
Isotrophy, mass spectrum and origin

6. Supernovae [3]
Origin of the collapse, observational properties; Supernova remnants: Evolution, X-ray properties

7. Pulsars [4]
Observations and models; Neutron stars

8. Accretion onto compact objects [4]
Eddington limit, galactic X-ray binaries, active galactic nuclei

9. Jets [2]
Radiosources, Galactic (e.g. SS433) and extragalactic (radiogalaxies); Energy equipartition

PHASM319 – Formation and Evolution of Stellar Systems (Term 1)

Prerequisites

PHAS3137 – Physical Cosmology or equivalent

Aims of the Course

This course aims to:
- give a detailed description of the structure, physical characteristics, dynamics and mechanisms that determine the kinematic structure, origin and evolution of clusters and galaxies
- discuss applications, including stellar clusters within the Galaxy, spiral and elliptical galaxies and clusters of galaxies, with emphasis given to the interpretation of observational data relating to the Milky Way

Objectives

After completing this course students should be able to:
- identify the dynamical processes that operate within star clusters, galaxies and clusters of galaxies
- explain the observed characteristics of stellar motions within the Milky Way
- use this information to elucidate the internal structure of the Galaxy
- be able to discuss the dynamical structure and observational appearance of clusters and external galaxies
- understand how these objects have formed and are evolving

Methodology and Assessment

30 lectures and 3 problem class/discussion periods.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

- *Stellar Dynamics* (I.R. King, W.H. Freeman, 1996)
- Galaxies: *Structure and Evolution* (R.J. Tayler, Cambridge Univ. Press, 1993)

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below)

The observational properties of galaxies and clusters [1 lecture]
Historical introduction; Galaxy and cluster classification; Observational overview; The theoretical problem

The mathematical foundations of stellar dynamics [3 lectures]
Stellar dynamics; The equations of motion; The Collisionless Boltzmann Equation (CBE); The solution of the CBE; Time-independent solution of the CBE; Jeans' theorem; Using the distribution function

The Milky Way I: Individual motions [3 lectures]

Galactic coordinates and the Local Standard of Rest; Galactic rotation in the solar neighbourhood; The determination of Oort's constants; Differential motion and epicyclic orbits; Motion perpendicular to the galactic plane

The Milky Way II: The Collisionless Boltzmann Equation [3 lectures]

The CBE in galactic coordinates; The third integral; Probing deeper into the Galaxy; The Oort substitution; The Jeans' equations; The density distribution from individual orbits

Evolution of dynamical systems [4 lectures]

Relaxing assumptions; Two-body encounters and collisions; The relaxation timescale; The relative importance of close and distant encounters; Comparison with crossing time and age; The Fokker-Planck equation; Dynamical friction; The Kolmogorov-Feller equation; The virial theorem; Applications of the virial theorem

Stellar clusters [4 lectures]

Introduction; Entropy; Evaporation of clusters; Models of globular clusters; Tidal forces in globular clusters; Dynamical evolution of clusters; Other long-term evolutionary effects; The importance of binaries

Galaxy formation [4 lectures]

Structure formation in an expanding background; The need for dark matter; Spherical collapse: Cooling and the sizes of galaxies; Hierarchical growth; Probing dark matter halos; Galaxy mergers; Galaxy formation and environment; The bimodality of the properties of galaxies

Chemical Evolution of Galaxies [2 lectures]

Overview of stellar evolution; Stellar yields; The stellar initial mass function; Basic equations of chemical enrichment

Spiral galaxies [3 lectures]

Instabilities and the Toomre criterion; The spiral arms; Galactic warps; Bars; The Tully-Fisher relation: photometric and baryonic

Elliptical galaxies [3 lectures]

Fits to smoothed intensity profiles; Evidence for triaxiallity in ellipticals; Schwarzschild modelling of ellipticals; Scaling relations: Fundamental plane and colour-magnitude relation

PHASM336 – Advanced Physical Cosmology (Term 2)

Prerequisites

This course requires PHAS3137 or similar and a knowledge of MATH3305 (Maths for GR).

Course aims

The aim of the course is to provide an advanced level exposition of modern theoretical and observational cosmology, building upon the foundations provided by the third year course PHAS3136. The emphasis will be on developing physical understanding rather than on mathematical principles.

Over the past two decades, cosmology has made dramatic advances. A flood of data has transformed our understanding of the basic parameters of the universe -- the expansion rate, the densities of various types of energy and the nature of the primordial density variations. The basic Big Bang picture, underpinned by General Relativity, continues to hold good, explaining the expansion of the universe, the cosmic microwave background radiation, the synthesis of light chemical elements and the formation of stars, galaxies and large-scale structures. However, there are important gaps in our understanding including the nature of the dark matter, the cause of the observed late-time acceleration of the universe and the classic puzzles of the initial singularity and what caused the Big Bang.

This course will develop the standard Big Bang cosmology and review its major successes and some of the challenges now faced at the cutting-edge of the field.

After the completion of this course, students will have an appreciation of the basic theoretical foundations of physical cosmology, as well as an advanced understanding of the physics of several observational results critical to our current picture of the Universe.

Objectives

Specifically, after this course the students should be able to:

- understand the concepts of the metric and the geodesic equation, and to apply the mathematical language of General Relativity to the flat Friedmann-Robertson-Walker (FRW) metric
- state the Einstein equation; derive the Einstein tensor in a flat FRW universe; describe physically the components of the energy-momentum tensor and write them down for dust and for a perfect fluid; derive the continuity and Euler equations from conservation of the energy momentum tensor; derive from the Einstein equation the Friedmann equations for a flat FRW universe
- understand how the cosmological principle leads to the general FRW metric; to derive and use the Friedmann equations in a general FRW metric
- understand and calculate the dynamics of the FRW universe when its equation of state is dominated by matter, radiation, curvature, and a cosmological constant; to understand the relationship between spatial curvature and the destiny of the universe, and how this relationship is modified in the presence of a cosmological constant
- understand and calculate time and distance measurements in the FRW background
- describe in GR language general particle motion in the FRW background, and to understand and use the derivation of the energy momentum tensor for a scalar field from the principle of least action (variational calculus will be reviewed)

- describe the standard Big Bang puzzles and their resolution via inflation; understand the implementation of inflation via a scalar field; describe qualitatively how measurements of the primordial power spectrum allows us to test the theory
- understand and use the basic statistical properties imposed on cosmological fields (such as the matter overdensity) by the assumption that they respect the symmetries of the FRW background (i.e. isotropy and homogeneity)
- understand and use cosmological perturbation theory, in particular to derive and describe the evolution of density perturbations during matter and radiation domination.
- understand and derive the morphology of the cosmic microwave background acoustic peak structure using the forced/damped simple harmonic oscillator equation.
- understand and use some key results from structure formation, including the linear power spectrum of matter fluctuations, two point correlation function, Limber's approximation, redshift space distortions in linear theory, spherical collapse, and the Press-Schecter formalism

Detailed Syllabus

Part I: The homogeneous universe [10]

The metric	[1]
The geodesic equation	[1]
The Einstein equation	[1]
The general Friedmann-Robertson-Walker metric in GR	[2]
Time and distance in GR	[1]
Particles and fields in cosmology	[2]
Inflation	[2]

Part II: The perturbed Universe [10]

Statistics of random fields	[2]
Perturbation theory	[2]
Comoving curvature perturbation	[2]
The cosmic microwave background	[4]

Part III: Structure formation [10]

The linear-theory matter power spectrum	[3]
Two-point correlation function and Limber’s approximation	[1]
Redshift space distortions in linear theory	[2]
Spherical collapse and the Press-Schechter formalism	[2]
Latest cosmological results/methods (non examinable)	[2]

The last (non-examinable) part of the course will review the latest measurements of cosmological parameters from current data.

Proposed Assessment Methodology

The course is based on 30 lectures plus 3 mandatory sessions which are used for reviewing homeworks and practicing solving new problems. There are 4 problem sheets, which include both essay work and calculation of numerical results for different cosmological models. The course is assessed by written examination (90% of total course marks) and by problem sheets (10%).

Recommended Texts

Modern Cosmology Dodelson
An Introduction to General Relativity, Space-time and Geometry Carroll
Cosmology Weinberg

PHASM421 – Atom and Photon Physics (Term 1)

Prerequisites

Knowledge of quantum physics and atomic physics to at least second year level, e.g. UCL courses PHAS2222 and PHAS2224.

Aims of the Course

This course aims to provide:

- a modern course on the interactions of atoms and photons with detailed discussion of high intensity field effects, such as multiphoton processes and extending to low field effects; cooling and trapping

Objectives

On completion of the course the student should be able to:

- describe the single photon interactions with atoms as in photo-ionization and excitation and the selection rules which govern them
- explain the role of A and B coefficients in emission and absorption and the relation with oscillator strengths
- describe the operation of YAG, Argon Ion and Dye Lasers and derive the formulae for light amplification
- explain the forms of line broadening and the nature of chaotic light and derive the first order correlation functions
- explain optical pumping, orientation and alignment
- describe the methods of saturation absorption spectroscopy and two photon spectroscopy
- derive the expression for 2-photon Doppler free absorption and explain the Lambshift in H
- describe multiphoton processes in atoms using real and virtual states
- explain ponder motive potential, ATI, stark shift and harmonic generations
- describe experiments of the Pump and Probe type, the two photon decay of H and electron and photon interactions
- derive formulae for Thompson and Compton scattering and the Kramers-Heisenberg formulae
- describe scattering processes; elastic, inelastic and super elastic
- derive the scattering amplitude for potential scattering in terms of partial waves
- explain the role of partial waves in the Ramsauer-Townsend effect and resonance structure
- derive the formulae for quantum beats and describe suitable experiments demonstrating the phenomena
- describe the interactions of a single atom with a cavity and the operation of a single atom maser
- describe the operation of a magneto-optical-trap and the recoil and Sisyphus cooling methods
- explain Bose condensation

Methodology and Assessment

The course consists of 30 lectures of course material which will also incorporate discussions of problems and question and answer sessions. Two hours of revision classes are offered prior to the exam. Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

Optoelectronics, Wilson and Hawkes (Chapman and Hall 1983)
Atomic and Laser Physics, Corney (Oxford 1977)
Quantum Theory of Light, Loudon (Oxford 1973)
Physics of Atoms and Molecules, Bransden and Joachain (Longman 1983)
Laser Spectroscopy, Demtröder (Springer 1998)

Where appropriate references will be given to some research papers and review articles. There is no one book which covers all the material in this course.

Syllabus
(The approximate allocation etc of lectures to topics is shown in brackets below)

Interaction of light with atoms (single photon) [4]
Processes - excitation, ionization, auto-ionization; A+B coefficients (semi classical treatment); Oscillator strengths and f-sum rule; Life times - experimental methods. (TOF and pulsed electron)

L.A.S.E.R. [3]
Line shapes g(□); Pressure, Doppler, Natural; Absorption and amplification of radiation; Population inversion; spontaneous and stimulated emission; YAG and Argon ion lasers; radiation - dye and solid; Mode structure

Chaotic light and coherence [2]
Line broadening; Intensity fluctuations of chaotic light; First order correlation functions; Hanbury Brown Twiss experiment

Laser spectroscopy [3]
Optical pumping - orientation and alignment; Saturation absorption spectroscopy; Lamp shift of H(1S) and H(2S); Doppler Free spectroscopy

Multiphoton processes [3]
Excitation, ionization, ATI; Laser field effects - pondermotive potential - Stark shifts - Harmonic Generation; Pump and probe spectroscopy; Multiphoton interactions via virtual and real states; Two photon decay of hydrogen (2S-1S); Simultaneous electron photon interactions

Light scattering by atoms [3]
Classical theory; Thompson and Compton scattering; Kramers-Heisenberg Formulae; (Rayleigh and Raman scattering)

Electron scattering by atoms [4]
Elastic, inelastic and superelastic; Potential scattering; Scattering amplitude - partial waves; Ramsauer-Townsend effect - cross sections; Resonance Structure

Coherence and cavity effects in atoms [4]
Quantum beats - beam foil spectroscopy; Wave packet evolution in Rydberg states; Atomic decay in cavity; Single atom Maser

Trapping and cooling [4]
Laser cooling of atoms; Trapping of atoms; Bose condensation; Physics of cold atoms - atomic interferometry

PHASM426 – Advanced Quantum Theory (Term 1)

Prerequisites

To have attended and passed the department's introductory quantum mechanics courses, PHAS2222: Quantum Physics and the intermediate course, PHAS3226: Quantum Mechanics, or equivalent courses.

The following topics will be assumed to have been covered:

- *Introductory material*: states, operators and time-independent Schrödinger equation, the Born probability rule, transmission and reflection coefficients, Dirac notation
- *Harmonic oscillator*: energy eigenvalues, ladder operators
- *Time-independent perturbation theory*: (non-degenerate case only) and some experience of its application in atomic physics

This is a theory course with a **strong mathematical component**, and students should feel confident in their ability to learn and apply new mathematical techniques.

Aims of the Course

This course aims to

- review the basics of quantum mechanics to establish a common body of knowledge for the students from the different Colleges on the Intercollegiate MSci. programme
- extend this, by discussing these basics in more formal mathematical terms
- explore the WKB approximation, as a method for studying tunnelling and quantum wells
- explore advanced topics in the dynamics of quantum systems; including time-dependent perturbation theory, and the dynamics of open quantum systems
- provide students with the techniques and terminology which they can apply in specialist courses and in their research projects

Objectives

After completing the module the student should be able to:

- have a familiarity with abstract vector space formalism, and be able to prove some of the important properties of vector spaces
- know how to express the postulates of quantum mechanics in terms of abstract vector spaces
- use the density matrix formalism to describe quantum experiments with statistical uncertainty, and to describe subsystems of entangled states
- be able to apply the WKB approximation to calculate tunnelling rates in 1-D problems, and the properties of bound states in 1-D quantum wells
- know how to describe light quantum mechanically and be able to use the Jaynes-Cummings model to describe atom-light interactions
- know the general properties of time evolution under the Schrödinger equation
- know the difference between the Schrödinger, Heisenberg and interaction pictures
- be able to derive and employ first- and higher- order time dependent perturbation theory, and apply this to constant and harmonic perturbations
- be familiar with the Lindblad form of master equations for the evolution of systems undergoing an incoherent process due to the interaction with an environment
- be able to identify quantum jump operators in a master equation and understand the evolution of master equations in terms of quantum trajectories

Methodology and Assessment

The module consists of 33 lectures.

These will be used to cover the syllabus material and to discuss problem sheets as the need arises. Assessment will be based on the results obtained in the final written examination (90%) and the best four marks out of five problem sheets (10%).

Textbooks

Those which are closest to the material and level of the course are (in alphabetical order)

- *Quantum Mechanics*, B.H. Bransden and C.J. Joachain, Prentice Hall
- *Quantum Mechanics volumes one and two*, C. Cohen-Tannoudji, B. Diu & F. Laloe, Wiley
- *Modern Quantum Mechanics*, J.J. Sakurai, Addison Wesley
- *Quantum Physics*, S.Gasiorowicz, Wiley
- *Quantum Mechanics*, F.Mandl, Wiley
- *Quantum Mechanics*, E.Merzbacher, (3rd Ed.) Wiley

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below)

Formal quantum mechanics [10.5 hours]
[Partly revision] Abstract vector spaces; norm, inner product, basis, linear functionals, operators, column vector and matrix representations of abstract vectors and operators, Dirac notation, Hermitian and unitary operators, projectors; Expectation values; Postulates of quantum mechanics; Representations of continuous variables, position and momentum; Compound systems, tensor product, entanglement; Statistical state preparation and mixed states, density operator formalism, density operators to describe sub-systems of entangled systems

Advanced wave mechanics - WKB approximation [4.5 hours]
WKB Ansatz and derivation of WKB approximation wave-functions; The failure of these wave-functions at classical turning points; The role of connection formulae; Application to quantum wells and quantum tunnelling in one-dimension

Atoms, light and their interaction [3 hours]
[Revision of] Quantum Harmonic oscillator, Wave equation and quantisation of light; Optical cavities and concept of a light mode; Two-level atom and dipole approximation; Rotating Wave Approximation and Jaynes-Cummings model

Advanced topics in time-dependence 1) - Unitary Evolution [3 hours]
Unitary evolution under the Schrödinger equation, Split operator method and Tsuzuki-Trotter decomposition; Heisenberg picture, Interaction picture; Example: Jaynes-Cummings model in the interaction picture

Advanced topics in time-dependence 2) - Time-dependent perturbation theory [6 hours]
Dirac's method as application of interaction picture; Time-dependent perturbation theory; First-order time-dependent perturbation theory; Higher-order time-dependent theory; Examples: constant perturbation and harmonic perturbation; Fermi's Golden Rule with examples of its application

Advanced topics in time-dependence 3) - Open quantum systems [6 hours]
Von Neumann equation for density matrices; Interaction with environment; Evolution of a sub-system; Markov approximation; Abstract approach to non-unitary evolution; Completely positive

maps; Kraus operators; Master equations; Lindblad form, derivation from Kraus operator Ansatz; Quantum trajectories and jump operators; Example: Damped quantum harmonic oscillator

PHASM427 – Quantum Computation and Communication (Term 1)

Aims

The course aims to
- provide a comprehensive introduction to the emerging area of quantum information science
- acquaint the student with the practical applications and importance of some basic notions of quantum physics such as quantum two state systems (qubits), entanglement and decoherence
- train physics students to think as information scientists, and train computer science/mathematics students to think as physicists
- arm a student with the basic concepts, mathematical tools and the knowledge of state of the art experiments in quantum computation & communication to enable him/her embark on a research degree in the area

Objectives

After learning the background the student should
- be able to apply the knowledge of quantum two state systems to any relevant phenomena (even when outside the premise of quantum information)
- be able to demonstrate the greater power of quantum computation through the simplest quantum algorithm (the Deutsch algorithm)
- know that the linearity of quantum mechanics prohibits certain machines such as an universal quantum cloner

After learning about quantum cryptography the student should
- be able to show how quantum mechanics can aid in physically secure key distribution
- be knowledgeable of the technology used in the long distance transmission of quantum states through optical fibers

After learning about quantum entanglement the student should
- be able to recognize an entangled pure state
- know how to quantitatively test for quantum non-locality
- be able to work through the mathematics underlying schemes such as dense coding, teleportation, entanglement swapping as well their simple variants
- know how polarization entangled photons can be generated
- be able to calculate the von Neumann entropy of arbitrary mixed states and the amount of entanglement of pure bi-partite state.

After learning about quantum computation the student should
- know the basic quantum logic gates
- be able to construct circuits for arbitrary multi-qubit unitary operations using universal quantum gates
- be able to describe the important quantum algorithms such as Shor’s algorithm & Grover’s algorithm

After learning about decoherence & quantum error correction the student should
- be able to describe simple models of errors on qubits due to their interaction with an environment
- be able to write down simple quantum error correction codes and demonstrate how they correct arbitrary errors

- be able to describe elementary schemes of entanglement concentration and distillation

After learning about physical realization of quantum computers the student should

- be able to describe quantum computation using ion traps, specific solid state systems and NMR
- be able to assess the merits of other systems as potential hardware for quantum computers and work out how to encode qubits and construct quantum gates in such systems

Methodology and Assessment

The course consists of 30 lectures of course material which will also incorporate discussions of problems and question and answer sessions. Two hours of revision classes are offered prior to the exam. Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Syllabus

Background [3]: The qubit and its physical realization; Single qubit operations and measurements; The Deutsch algorithm; Quantum no-cloning

Quantum Cryptography [3]: The BB84 quantum key distribution protocol; elementary discussion of security; physical implementations of kilometers

Quantum Entanglement [8]: State space of two qubits; Entangled states; Bell's inequality; Entanglement based cryptography; Quantum Dense Coding; Quantum Teleportation; Entanglement Swapping; Polarization entangled photons & implementations; von-Neumann entropy; Quantification of pure state entanglement

Quantum Computation [8]: Tensor product structure of the state space of many qubits; Discussion of the power of quantum computers; The Deutsch-Jozsa algorithm; Quantum simulations; Quantum logic gates and circuits; Universal quantum gates; Quantum Fourier Transform; Phase Estimation; Shor's algorithm; Grover's algorithm

Decoherence & Quantum Error Correction [4]: Decoherence; Errors in quantum computation & communication; Quantum error correcting codes; Elementary discussion of entanglement concentration & distillation

Physical Realization of Quantum Computers [4]: Ion trap quantum computers; Solid state implementations (Kane proposal as an example); NMR quantum computer

PHASM431 – Molecular Physics (Term 2)

Pre-requisites

An introductory course on quantum mechanics such as UCL courses PHAS2222 Quantum Physics. The course should include: Quantum mechanics of the hydrogen atom including treatment of angular momentum and the radial wave function; expectation values; the Pauli Principle. Useful but not essential is some introduction to atomic physics of many electron atoms, for instance: UCL courses PHAS2224 Atomic and Molecular Physics or PHAS3338 Astronomical Spectroscopy. Topics which are helpful background are the independent particle model, addition of angular momentum, spin states and spectroscopic notation.

Aims of the Course

This course aims to provide:

- an introduction to the physics of small molecules including their structure, spectra and behaviour in electron collisions

Objectives

On completion of the course the student should be able to:

- describe the components of the molecular Hamiltonian and their relative magnitude
- state the Born-Oppenheimer approximation
- describe covalent and ionic bonds in terms of simple wave functions
- state the Pauli Principle, how it leads to exchange and the role of exchange forces in molecular bonding
- describe potential energy curves for diatomic molecules and define the dissociation energy and united atom limits
- analyse the long range interactions between closed shell systems
- describe rotational and vibrational motion of small molecules and give simple models for the corresponding energy levels
- give examples of molecular spectra in the microwave, infrared and optical
- state selection rules for the spectra of diatomic molecules
- interpret simple vibrational and rotational spectra
- explain the influence of temperature on a molecular spectrum
- describe experiments to measure spectra
- describe Raman spectroscopy and other spectroscopic techniques
- describe the selection rules obeyed by rotational, vibrational and electronic transitions
- describe the effect of the Pauli Principle on molecular level populations and spectra
- describe possible decay routes for an electronically excited molecule
- describe the physical processes which occur in CO_2 and dye laser systems
- state the Franck-Condon principle and use it to interpret vibrational distributions in electronic spectra and electron molecule excitation processes
- describe the possible relaxation pathways for electronically excited polyatomic molecules in the condensed phase
- explain how solvent reorganization leads to time-dependent changes in emission spectra
- explain how dipole-dipole transfer leads to changes in emission lifetime anisotropy
- describe experiments used to measure the fluorescence lifetime and anisotropy of a molecular probe
- discuss the applications of fluorescent probes to the study of biomolecular systems

Methodology and Assessment

The course consists of 30 lectures of course material which will also incorporate discussions of problems and question and answer sessions. Two hours of revision classes are offered prior to the exam. Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

- *Physics of Atoms and Molecules*, B H Bransden and C J Joachain (Longman, 1983) (Covers all the course but is not detailed on molecular spectra)
- *Molecular Quantum Mechanics*, P W Atkins (Oxford University) (Good on molecular structure)
- *Fundamentals of Molecular Spectroscopy,* 4th Edition, C.W. Banwell and E. McGrath (McGraw-Hill, 1994) (Introductory molecular spectroscopy book)
- *Spectra of Atoms and Molecules*, P F Bernath (Oxford University, 1995) (A more advanced alternative to Banwell and McGrath)
- *Molecular Fluorescence (Principles and Applications)*, B. Valeur (Wiley-VCH, 2002) (Condensed phase photophysics and applications of fluorescence)

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below)

Molecular structure [16]
Brief recap of atomic physics: n,l,m,s; He atom, orbital approximation, exchange; The molecular Hamiltonian and the Born-Oppenheimer approximation; Electronic structure, ionic and covalent bonding, Bonding in H_2^+ and H_2. Muon catalysed fusion; Dissociation and united atom limits; Long range forces; Isomers and chirality; Vibrational structure: Harmonic motion and beyond, energy levels and wave functions; Rotational structure: Rigid rotor and energy levels Energy scales within a molecule: ionisation and dissociation; Nuclear spin effects; Labelling schemes for electronic, vibrational and rotational states

Molecular spectra [7]
Microwave, infrared and optical spectra of molecules; Selection rules, Franck-Condon principle; Experimental set-ups; Examples: the CO_2 laser, stimulated emission pumping experiment; Raman spectroscopy; Ortho-para states; Absorption spectra of simple diatomics (eg. O_2 and NO, N_2); Simple polyatomics (ozone, water)

Molecular probes [7]
Photophysics of small polyatomic molecules in condensed phases; solvation effects, resonance energy transfer, fluorescence lifetime and anisotropy measurements; Experimental techniques and applications to biomolecular systems

PHASM442 – Particle Physics (Term 1)

Prerequisites

Students should have taken the UCL courses: Quantum Mechanics PHAS3226 and Nuclear and Particle Physics PHAS3224 or the equivalent and additionally have familiarity with special relativity, (four-vectors), Maxwell's equations (in differential form) and matrices.

Aims of the Course

This course aims to:

- introduce the student to the basic concepts of particle physics, including the mathematical representation of the fundamental interactions and the role of symmetries
- emphasise how particle physics is actually carried out with reference to data from experiment which will be used to illustrate the underlying physics of the strong and electroweak interactions, gauge symmetries and spontaneous symmetry breaking

Objectives

On completion of this course, students should have a broad overview of the current state of knowledge of particle physics. Students should be able to:

- state the particle content and force carriers of the standard model
- manipulate relativistic kinematics (Scalar products of four-vectors)
- state the definition of cross section and luminosity
- be able to convert to and from natural units
- state the Dirac and Klein-Gordon equations
- state the propagator for the photon, the W and the Z and give simple implications for cross sections and scattering kinematics
- understand and draw Feynman diagrams for leading order processes, relating these to the Feynman rules and cross sections
- give an account of the basic principles underlying the design of modern particle physics detectors and describe how events are identified in them
- explain the relationship between structure function data, QCD and the quark parton model;
- manipulate Dirac spinors
- state the electromagnetic and weak currents and describe the sense in which they are ‘unified'
- give an account of the relationship between chirality and helicity and the role of the neutrino
- give an account of current open questions in particle physics

Methodology and Assessment

The course consists of 30 lectures of course material which will also incorporate discussions of problem sheets and question and answer sessions.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

- *Introduction to Elementary Particles:* D. Griffiths
- *Quarks and Leptons:* F. Halzen and A.D. Martin
- *Introduction to High Energy Physics (4th ed):* D.H. Perkins

Syllabus

Broken down into eleven 2.5 hr sessions.

1. Introduction, Basic Concepts
Particles and forces; Natural units; Four vectors and invariants; Cross sections & luminosity; Fermi's golden rule; Feynman diagrams and rules

2. Simple cross section Calculation from Feynman Rules
Phase space; Flux; Reaction rate calculation; CM frame; Mandelstam variables; Higher Orders; Renormalisation; Running coupling constants

3. Symmetries and Conservation Laws
Symmetries and Conservation Laws; Parity and C symmetry; Parity and C-Parity violation, CP violation

4. Relativistic Wave Equations without interactions
From Schrodinger to Klein Gordon to the Dirac Equation; Dirac Matrices; Spin and anti-particles; Continuity Equation; Dirac observables

5. Relativistic Maxwell's equations & Gauge Transformations
Maxwell's equations using 4 vectors; Gauge transformations; Dirac equation + EM, QED Lagrangians

6. QED & Angular Distributions
QED scattering Cross Section calculations; helicity and chirality; angular distributions; forward backward asymmetries

7. Quark properties, QCD & Deep Inelastic Scattering
QCD - running of strong coupling, confinement, asymptotic freedom; Elastic electron-proton scattering; Deep Inelastic scattering; Scaling and the quark parton model; Factorisation; Scaling violations and QCD; HERA and ZEUS; Measurement of proton structure at HERA; Neutral and Charged Currents at HERA; Running of strong coupling; Confinement; QCD Lagrangian

8. The Weak Interaction-1
Weak interactions; The two component neutrino; V-A Weak current; Parity Violation in weak interactions; Pion, Muon and Tau Decay

9. The Weak Interaction-2
Quark sector in electroweak theory; GIM mechanism, CKM matrix; detecting heavy quark decays

10. The Higgs and Beyond The Standard Model
Higgs mechanism; alternative mass generation mechanisms; SUSY; extra dimensions; dark matter; Neutrino oscillations and properties

11. Revision & Problem Sheets

PHASM445 – Quantum Field Theory

Prerequisites

PHASM426, Advanced Quantum Theory or equivalent is required. PHAS3424, Dynamical Systems and PHASM442 are recommended as is Math6202, Mathematics for Physics and Astronomy.

Aims of the Course

The course is aimed at students who want to understand and possibly in future pursue research in theoretical high energy physics. The approach is mathematical and complements other particle physics courses which give a more intuitive approach, more physics results and comparison of data and theory. Although presenting the topic from a particle physics based approach, much of the material will be of use to those interested in, or intending to do research in theoretical condensed matter physics as well. A reminder of various relevant aspects of quantum mechanics and classical field theory will be given. Then the necessary background will be built up to the path integral approach to calculating cross-sections, or Green's functions for a given process. The use of a significant number of mathematical methods to describe and make predictions for physical processes will be developed, which will be useful in a wide variety of potential future areas of research.

Objectives

On completion of the course, students should be able to:

- For a particular particle content, identify the form of the Lagrangian for the corresponding Quantum Field Theory
- Obtain, with justification, the Feynman rules for the Theory
- Construct operators for basic physical quantities for simple Field Theories, and obtain
  and interpret expectation values
- Calculate matrix elements and cross-sections at tree level, and in the most basic cases
  at one loop
- Isolate ultraviolet divergences, and explain the relevance of these in terms of running masses, couplings

Methodology and Assessment

The course consists of 30 lectures. Assessment is based on the final written examination (90%) and problem sheets (10%).

Textbooks

Gauge theories in particle physics: Vols. I and II, *I.J.R. Aitchison* & *A.J.G. Hey* (IoP publishing)
Quantum Field Theory, *F. Mandl & G. Shaw* (Wiley)
An Introduction to Quantum Field Theory (Frontiers in Physics), *M.E. Peskin & D.V Schroeder*, Addison-Wesley Publishing Company

Syllabus

The course is split into nine significant sections:

Reminder of Lagrangian and Hamiltonian Mechanics (3 hours)
Introduction of Lagrangian and Hamiltonian field theory; Importance of Poisson brackets

Quantisation of a free scalar field theory (3 hours)
Introduction of creation and annihilation operators and canonical quantisation

Introduction of point interactions (4 hours)
Calculation of scattering matrix elements and LSZ reduction formula; Wicks theorem and normal ordering; Generating functionals and origin of Feynman diagrams

Quantisation for fermionic fields (2 hours)
Recap of relativistic quantum mechanics and symmetries in fermionic systems

Creation and annihilation operators for fermions and anti-commutation relations (3 hours)

Quantisation of photon field and necessity for gauge fixing (2 hours)

Origin of Feynman rules in QED (3 hours)
Simple examples

Introduction to path integral techniques (5 hours)
Quantisation of non-Abelian gauge theories

Introduction to renormalisation (5 hours)
Ultraviolet divergences and their regularization; Counterterms and origin of running masses and couplings; Implications for physics

PHASM465 – Space Plasma and Magnetospheric Physics (Term 2)

Prerequisites

While the course is essentially self-contained, some knowledge of basic electromagnetism and mathematical methods is required. In particular it is assumed that the students are familiar with Maxwell's equations and related vector algebra.

Aims of the Course

This course aims:

- to learn about the solar wind and its interaction with various bodies in the solar system, in particular discussing the case of the Earth and the environment in which most spacecraft operate

Objectives

On completion of this course, students should be able to:

- explain what a plasma is
- discuss the motion of a single charged particle in various electric and/or magnetic field configurations, and also to discuss the adiabatic invariants
- discuss the behaviour of particles in the Earth's radiation belts, including source and loss processes
- be familiar with basic magnetohydrodynamics
- describe the solar wind, including its behaviour near the Sun, near Earth and at the boundary of the heliosphere
- describe the solar wind interaction with unmagnetised bodies, such as comets, the Moon and Venus
- describe the solar wind interaction with magnetised bodies, concentrating on the case of the Earth and its magnetosphere
- be familiar with the closed and open models of magnetospheres
- perform calculations in the above areas

Methodology and Assessment

The material is presented in 30 lectures which are reinforced by problem sheets. Reading from recommended texts may be useful, but is not essential. Some video material will accompany the conventional lectures. Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Syllabus

(The approximate allocation of lectures to topics is shown in brackets below)

Introduction [1]
Plasmas in the solar system, solar effects on Earth, historical context of the development of this rapidly developing field

Plasmas [3]

What is a plasma, and what is special about space plasmas; Debye shielding, introduction to different theoretical methods of describing plasmas

Single Particle Theory [7]
Particle motion in various electric and magnetic field configurations; magnetic mirrors; adiabatic invariants; particle energisation

Earth's Radiation Belts [4]
Observed particle populations; bounce motion, drift motion; South Atlantic Anomaly; drift shell splitting; source and acceleration of radiation belt particles; transport and loss of radiation belt particles

Introduction to Magnetohydrodynamics [3]
Limits of applicability; convective derivative; pressure tensor; continuity equation; charge conservation and field aligned currents; equation of motion; generalised Ohm's law; frozen-in flow; magnetic diffusion; equation of state; fluid drifts; magnetic pressure and tension

The Solar Wind [2]
Introduction, including concept of heliosphere; fluid model of the solar wind (Parker); interplanetary magnetic field and sector structure; fast and slow solar wind; solar wind at Earth; coronal mass ejections

Collisionless shocks [3]
Shock jump conditions, shock structure, Earth bow shock, solar wind shocks

The magnetosphere and its dynamicsMagnetised Bodies [6]
Magnetospheric convection, magnetospheric currents, the magnetopause, open magnetosphere formation, magnetosphere-ionosphere coupling, non-steady magnetosphere

The Solar Wind Interaction with Unmagnetised Bodies [1]
The Moon; Venus, Comets

Course website
http://www.mssl.ucl.ac.uk/~ajc/4465/4465_resources.htm

Recommended books and resources

- *Basic space plasma physics*. W. Baumjohann and R.A. Treumann, Imperial College Press, 1996
- *Introduction to Space Physics* - Edited by M.G.Kivelson and C.T.Russell, Cambridge University Press, 1995

Also:

- *Physics of Space Plasmas, an introduction*. G.K.Parks, Addison-Wesley, 1991.
- *Guide to the Sun*, K.J.H.Phillips, Cambridge University Press, 1992.
- *Sun, Earth and Sky*, K.R.Lang, Springer-Verlag, 1995.
- *Introduction to plasma physics*, F.F. Chen, Plenum, 2nd edition, 1984
- *Fundamentals of plasma physics*, J.A. Bittencourt, Pergamon, 1986

PHASM472 – Order and Excitations in Condensed Matter (Term 2)

Prerequisites

PHAS3225 – Solid State Physics, or an equivalent from another department.

Aims of the Course

The course aims to

- provide an appreciation of the great diversity of ordering phenomena (structural, magnetic, electronic, etc.) that occurs in condensed matter systems, and the importance that order and excitations play in determining the properties of solids
- introduce a unified description of phase transitions and critical phenomena
- describe the principles and practice of experiments to determine ordered structures and excitation spectra using modern x-ray and neutron scattering techniques, including a one-day visit to the Rutherford Appleton Laboratory

Objectives

After completion of the course students should be able to:

- appreciate the great diversity of ordering phenomena that occur in the solid state
- understand the basic crystal structures, including fcc, hcp, bcc, CsCl, diamond, and be able to represent them using unit cell plans
- recognise the intrinsic dependence of physical properties on structure
- understand the range of possible structural disorder in crystals, both positional and orientational
- understand the relationship between the descriptions of crystal structures in real and reciprocal spaces
- understand the properties of isolated magnetic moments
- understand the origin of Hund's rules and how they may be applied to calculate the magnetic moments of ions from different rows of the periodic table
- understand crystal fields and how they modify the magnetism of ions in the solid state
- understand the quantum mechanical origin of the exchange interaction, and the nature of direct, indirect and double exchange
- appreciate the great variety of magnetic structures found in materials, including ferromagnetism, antiferromagnetism, ferrimagnetism, helical order, spin-glass formation
- understand the Weiss models of ferromagnetism and antiferromagnetism
- understand concepts in the magnetism of metals including Pauli paramagnetism, Stoner criterion, spin-density waves, Kondo effect
- understand the physics of the scattering of x-rays by electrons
- understand the scattering of neutrons by nuclear and magnetic scattering processes, and the concepts of coherent and incoherent scattering
- understand that the scattering pattern from an assembly of scatterers is a Fourier transform of the scattering-factor weighted positions of the scattering centres, and hence how the scattering intensity carries information on the structure of the scattering system
- understand the Laue equations so as to be able to visualise scattering events in reciprocal space
- appreciate the range of diffraction techniques for solving the structure of materials
- understand the excitation spectrum of the one-dimensional, harmonic mono-atomic chain and how this facilitates the calculation of dispersion curves in three-dimensional materials, with examples of force constant calculations in face-centred-cubic and body-centred materials

- understand the excitation spectrum of the one dimensional diatomic chain, and how the concepts of acoustic and optic modes carry over into real three-dimensionsal systems
- understand the quantum mechanical description of elastic excitations (phonons)
- understand the consequences of anharmonic interactions on the physical properties of materials
- understand the concept of spin waves as applied to ferromagnets and antiferromagnets and the semi-classical calculation of the dispersion relation in each case
- understand the how the quantum mechanical approach leads to quantization of the spin waves as magnons
- appreciate how the semi-classical approach breaks down as the number of dimensions is reduced and the spin quantum number approaches the quantum limit S=1/2
- understand the mechanism behind the production of neutrons, and the principles of the instrumentation required perform elastic and inelastic scattering experiments
- understand the production of x-rays from a synchrotron source, and how the properties of synchrotron radiation has revolutionised x-ray science
- appreciate the variety of information obtainable with modern spectroscopic techniques
- understand structural and magnetic order as examples of broken symmetries
- understand the order parameter concept, and how the general features of phase transitions can be understood to a first approximation by Landau theory
- appreciate the behaviour of various model systems (Ising, Heisenberg, etc)
- understand how the structures of liquids, including solutions, are determined experimentally using x-ray and neutron scattering, and how the liquid structure factor relates to the radial distribution function
- understand the underlying structural nature of glasses, describe their generic similarities with and differences from liquids, and understand the physics behind their formation as well as being able to describe different possible formation methods
- relate the physical properties of glasses to their structures, understand their deformation mechanisms, the physical reasons underlying their intrinsic strength, low corrosion, homogeneity, electronic (amorphous semiconductors) and magnetic properties

Methodology and Assessment

This will mainly be through teaching by the lecturer, but will also include assigned pre-class reading and tutorial discussions. In addition to studying standard texts, the students will also be given selected research papers to read and discuss. A full day visit to Rutherford Appleton Laboratory will be included in the course, where the students will have a tour of state-of-the-art facilities for neutron and x-ray scattering, as well as lectures on the principles of their operation. The class contact time will be the equivalent of 11 three-hour sessions.

Assessment is based on the results obtained in the final written examination (90%) and three problem sheets (10%).

Textbooks

Main texts:
Structure and Dynamics: An Atomic View of Materials, Martin T. Dove (OUP)
Magnetism in Condensed Matter, Stephen Blundell (OUP)

Additional texts:
Elements of Modern X-ray Physics, Jens Als-Nielsen and Des McMorrow (Wiley)
Introduction to the Theory of Thermal Neutron Scattering, G.L. Squires (Dover)

Syllabus

The allocation of topics to sessions is shown below. Each session is approximately three lectures.

Atomic Scale Structure of Material (session 1): The rich spectrum of condensed matter; Energy and time scales in condensed matter systems; Crystalline materials: crystal structure as the convolution of lattice and basis; Formal introduction to reciprocal space.

Magnetism: Moments, Environments and Interactions (session 2) Magnetic moments and angular momentum; diamagnetism and paramagnetism; Hund's rule; Crystal fields; Exchange interactions

Order and Magnetic Structure (session 3) Weiss model of ferromagnetism and antiferromagnetism; Ferrimagnetism; Helical order; Spin Glasses; Magnetism in Metals; Spin-density waves; Kondo effect

Scattering Theory (sessions 4 and 5) X-ray scattering from a free electron (Thomson scattering); Atomic form factors; Scattering from a crystal lattice, Laue Condition and unit cell struture factors; Ewald construction; Dispersion corrections; QM derivation of cross-section; Neutron scattering lengths; Coherent and incoherent scattering

Excitations of Crystalline Materials (session 6) Dispersion curves of 1D monoatomic chain (revision); Understanding of dispersion curves in 3D materials; Examples of force constants in FCC and BCC lattices; Dispersion of 1D diatomic chain; Acoustic and Optic modes in real 3D systems; Phonons and second quantization; Anharmonic interactions

Magnetic Excitations (session 7) Excitations in ferromagnets and antiferromagnets; Magnons; Bloch T^3/2 law; Excitations in 1, 2 and 3 dimension; Quantum phase transitions

Sources of X-rays and Neutrons (session 8) Full day visit to RAL; Neutron Sources and Instrumentation; Synchrotron Radiation; Applications of Synchrotron Radiation

Modern Spectroscopic Techniques (session 9)
Neutron scattering: triple-axis spectrometer, time-of-flight, polarized neutrons; X-ray scattering: X-ray magnetic circular dichroism, resonant magnetic scattering, reflectivity

Phase transitions and Critical Phenomena (session 10) Broken symmetry and order parameters in condensed matter; Landau theory and its application to structural phase transitions, ferromagnetism; Ising and Heisenberg models; Critical exponents; Universality and scaling

Local Order in Liquids and Amorphous Solids (session 11) Structure of simple liquids; Radial distribution function; Dynamics: viscosity, diffusion; Modelling; Glass formation; Simple and complex glasses; Quasi-crystals

PHASM474 – Plastic and Molecular (opto)electronics (Term 2)

Prerequisites

The course is intended for graduate students with backgrounds in the physical and chemical sciences and engineering, and only requires previous knowledge of the fundamentals of mathematics and physics as taught in first and second year courses. Specific concepts and methods of solid-state physics will be introduced in the lectures where needed.

Aim of the course

Organic and printable electronics and photonics are enabling technologies set to revolutionise the world of consumer ITC, with their obvious and rapidly expanding application to displays and ITC in general, and, in perspective, to low-cost photovoltaics and biomedical applications. The course will provide a fundamental introduction to the physics and photophysics of carbon-based semiconductors and to the fundamental processes taking place in the devices that incorporate them. The course will enable students to understand recent and future development in the broad area of plastic, printable and "stretchable" electronics, which is set to drive the next paradigm shift in ITC, which arguably has already started with the introduction of AMOLEDs.

Objectives

After completing this course, students should be able to:

- Understand the difference between metals, insulators and semiconductor (including the concept of work function and Fermi energy, also in relation to Fermi-Dirac statistics)
- Understand and describe the nature of the π-π bonds and of π-electron systems
- Describe the major differences between organic and inorganic semiconductors
- Describe the primary photoexcitations in organic semiconductors (excitons, excimers, exciplexes, polarons, charge-transfer excitons, Frenkel, Wannier), in terms of size, energetics, spin multiplicity, lifetimes
- Explain the role of electron-phonon interactions in the photophysics of organic semiconductors
- Explain the role of intersystem crossing in the photophysics of organic semiconductors
- Explain the role of disorder in the photophysics of organic semiconductors, and be familiar with methods to describe such disorder (e.g. with the help of Gaussian density of states)
- Explain the nature of "site-selective spectroscopy" and its usefulness for organic semiconductors
- Describe the fundamental processes taking place in OLEDs
- Sketch and interpret band diagrams and use them to determine built-in voltages in devices with a "sandwich" structures
- Calculate the electroluminescence efficiency of OLEDs as a function of photoluminescence efficiency, singlet/triplet ratio, outcoupling efficiency, and carriers balance
- Be familiar with photometric and radiometric units
- Explain how the energy-level line-up at organic semiconductors/electrodes interfaces can be investigated via electroabsorption experiments
- Be familiar with techniques for the measurement of the electrodes work function such as "Kelvin probe" and ultraviolet photoelectron spectroscopy
- Describe the fundamental processes taking place in organic PVDs
- Understand the dependence of the photon to current conversion efficiency on the

fundamental processes taking place in PVDs

- Describe the meaning of "Fill factor"' "open-circuit voltage", "short-circuit current", and how these quantity are related to the power conversion efficiency of solar cells
- Explain the concept of type II heterojunction, and why this is needed for achieving high efficiency in excitonic solar cells.
- Describe the fundamental processes taking place in organic FETs, in particular channel formation upon application of a gate-voltage to a MIS capacitor
- Describe the difference between unipolar and complementary FETs
- Sketch the scheme for the basic gates, and for simple logic circuits incorporating organic FETs (e.g. ring-oscillators, or circuits to drive an AMOLED pixel)
- Draw the band diagram of an OFET in the various regions of operation
- Extract the mobility of the semiconductor from output/transfer characteristics of OFETs
- Describe non-covalent interactions and the meaning of "supramolecular electronics"
- Explain what is meant for threaded molecular wires (TMWs), dendrimers, dendrons
- Give a few examples of molecular photoswitches and of their applications
- Describe discotic systems and their potential impact on organic electronics

Methodology & Assessment

The course consists of 30 lectures of course material. Two hours of revision classes are offered prior to the exam. Assessment is based on the results obtained in the final written examination (90%) and four problem sheets (10%).

Textbooks

Handouts will be provided by the lecturer during the course of the term. Suggested complementary books for consultation:

- *Electronic Processes in Organic Crystals and Polymers*, M Pope, C. Swenberg, Oxford University Press, 2nd ed., Oxford, 1999
- *Organic Photovoltaics,* C Brabec, V Dyakonov, J Parisi, NS Sarifictci, eds., Springer, Berlin, 2004
- *Physics of Solar Cells,* P Wurfel, Wiley-VCH, Weinheim, 2005
- *Organic Light-Emitting Devices*, K Müllen and U. Scherf eds. Wiley-VCH, Weinheim, 2006
- *Organic Electronics,* H Klauk, ed. Wiley-VCH, Weinheim, 2006
- *Organic Field-Effect Transistors,* Z Bao and J Locklin, eds., CRC Press/Taylor and Francis, Boca Raton, 2007
- *Organic Thin Film Transistor Integration: A Hybrid Approach* F Li, A Nathan, Y Wu eds. Wiley-VCH, Weinheim, 2011

Detailed Syllabus [Lectures in hours in brackets]

1) Introduction [6]

(a) Inorganic semiconductors

(b)Organic semiconducting (macro)molecules: (i) π-orbitals and conjugation, (ii) Excitations: excitons and polarons, (iii) Exciton spin: singlets and triplets, (iv) Synopsis electronic and optical processes, (v) Optical properties: a few examples (Energy gap vs. molecular weight, Electron-phonon coupling: vibrational structure and thermochromism, Förster transfer, site-selective spectroscopy, (vi) Summary of optical properties

2) Polymer-based light-emitting diodes (LEDs) [8]

(a) Structure
(b) Fundamental processes: (i) Charge injection, (ii) Charge transport, (iii) Exciton formation (Mutual capture and exciton characteristics: binding energy, spin-multiplicity, capture cross-section); (iv) Exciton decay: Radiative and non-radiative decay, Exciton lifetime, Efficiency
(c) Characterisation of PLEDs: (i) Relevant performance parameters, (ii) Characterising metal-semiconductor contacts: electroabsorption as a non-invasive tool for the study of the energy level line-up in finished devices
(d) Practical implementations: (i) Anodes, (ii) Cathodes, (iii) Active materials **(**Singlet emitters, triplet emitters – enhanced spin-orbit coupling via doping with rare-earth ligands**,** Blends: trying to achieve the best of all worlds**,** prototypical materials for red, green and blue emission (singlet emitters), (iv) Fabrication technology: the advantage of solution processabilit (spin-coating, ink-jet printing (IJP), screen-printing and other examples)
(e) State of the art devices and future prospects

3) Polymer-based photovoltaic diodes (PVDs) [6]:
(a) Fundamental processes (exciton absorption, dissociation, charge collection
(b) Characterisation of PVDs (Relevant performance parameters)
(c) Examples of polymer- PVDs (Polymer-polymer heterojunctions; Enhanced dissociation at type II heterojunctions; Preparation methods: polymer blends and spontaneous phase separation; C60-polymer structures; heterojunctions with nanocrystals, nanorods, etc.)
(d) State of the art devices and future prospects

4) Polymer-based field-effect transistors, FET [6]s:
(a) Structure and fundamental processes (channel formation, charge transport)
(b) Characterisation (Relevant performance parameters)
(c) Examples of successful strategies; (d) State of the art devices and future prospect

5) Molecular switches and motors [2]
(a) Photoswitches: from solution to surfaces
(b) Examples: Azobenzene, spiropyranes, di-arylethenes
(c) Photochromic (e.g. thermochromic switches)
(d) Potential applications

6) Supramolecular structures and dendrimers [2]:
(a) Introduction to secondary (non covalent) interactions and their role in organic solids
(b) Insulated molecular wires, IMWs and threaded molecular wires (TMWs)
(c) Discotic and stacking systems (e.g. hexabenzocoronenes (HBC), porphyrine and phthalocyanine, rylenes – perylenes terrylenes and quaterrylenes), nanographenes
(d) Dendrimers and dendronised materials for supramolecular architectures
(e) Potential applications

PHASM800 – Molecular Biophysics (Term 2)

Prerequisites

It is recommended but not mandatory that students have taken PHAS1228 (Thermal Physics). PHAS2228 (Statistical Thermodynamics) would be useful but is not essential. The required concepts in statistical mechanics will be (re-)introduced during the course.

Aims of the Course

The course will provide the students with insights in the physical concepts of some of the most fascinating processes that have been discovered in the last decades: those underpinning the molecular machinery of the biological cell. These concepts will be introduced and illustrated by a wide range of phenomena and processes in the cell, including bio-molecular structure, DNA packing in the genome, molecular motors and neural signaling.
The aim of the course is therefore to provide students with:

- Knowledge and understanding of physical concepts which are relevant for understanding biology at the micro- to nano-scale
- Knowledge and understanding of how these concepts are applied to describe various processes in the biological cell

Objectives

After completing this half-unit course, students should be able to:

- Give a general description of the biological cell and its contents
- Explain the concepts of free energy and Boltzmann distribution and discuss osmotic pressure, protein structure, ligand-receptor binding and ATP hydrolysis in terms of these concepts
- Explain the statistical-mechanical two-state model, describe ligand-receptor binding and phosphorylation as two-state systems and give examples of “cooperative” binding
- Describe how polymer structure can be viewed as the result of random walk, using the concept of persistence length, and discuss DNA and single-molecular mechanics in terms of this model
- Explain the worm-like chain model and describe the energetics of DNA bending and packing; explain how such models are relevant for the rigidity of cells
- Explain the low Reynolds-number limit of the Navier-Stoke's equation and discuss its consequences for dynamics in biological systems
- Explain simple solutions of the diffusion equation in biological systems and their consequences for diffusion and transport in cells
- Explain the concept of rate equations and apply it to step-wise molecular reactions
- Give an overview of the physical concepts involved in molecular motors and apply them to obtain a quantitative description of motor driven motion and force generation
- Describe neural signaling in terms of propagating (Nernst) action potentials and ion channel kinetics
- Link the material in the course to at least one specific example of research in the recent scientific literature

Methodology and Assessment

This is a half-unit course, with 30 lectures and 3 discussion/problems classes. Basic problem-solving skills will be stimulated by the setting of a weekly problem question. The answers will be collected weekly and more extensively discussed during the discussion/problem classes. The marks on these problem questions account for 10% of the overall course assessment. The remaining 90% is determined via an unseen written examination.

Textbooks

The course will make extensive use of the following book, parts of which will be obligatory reading material:

- *Physical Biology of the Cell*, 1st Edition, R. Phillips, J. Kondev, and J. Theriot, Garland Science 2009

Other books which may be useful include the following. They cover more material than is in the syllabus.

- *Biological Physics*, 1st Edition, Philip Nelson, W.H. Freeman, 2004
- *Mechanics of Motor Proteins and the Cytoskeleton*, 1st Edition, J. Howard, Sinauer Associates, 2001
- *Protein Physics*, 1st Edition, A.V. Finkelstein and O.B. Ptitsyn, Academic Press, 2002
- *Molecular Driving Forces*, 1st Edition, K.A. Dill and S. Bromberg, Garland Science, 2003

The following books may be useful for biological reference.

- *Molecular Biology of the Cell*, 4th Edition, B. Alberts et al., Garland Science, 2002
- *Cell Biology*, 2nd Edition, T.D. Pollard, W.C. Earnshaw and J. Lippincott-Schwartz, Elsevier, 2007

Syllabus
(The approximate allocation of lectures to topics is given in brackets below)

Biological cells [3]
Introduction to the biology of the cell – cell types – cell components – DNA, RNA, proteins, lipids, polysaccharides – overview of functional processes in cells

Statistical mechanics in the cell [4]
Deterministic versus thermal forces – free-energy minimisation and entropy, Boltzmann distribution – free energy of dilute solutions, osmotic pressure/forces – consequences for protein structure and hydrophobicity – equilibrium constants for ligand-receptor binding and ATP hydrolysis

Two-state systems [3]
Biomolecules with multiple states – Gibbs distribution – ligand-receptor binding, phosphorylation – “cooperative” binding

Structure of macromolecules [3]
Random walk models of polymers – entropy, elastic properties and persistence length of polymers – DNA looping, condensation and melting – single-molecule mechanics

Elastic-rod theory for (biological) macromolecules [3]
Beam deformation and persistence length – worm-like chain model – beam theory applied to DNA – cytoskeleton

Motion in biological environment [4]

Navier-Stokes equation – viscosity and Reynold's number in cells – diffusion equation and its solutions – transport and signaling in cells – diffusion limited reactions

Rate equations and dynamics in the cell [3]
Chemical concentrations determine reaction rates – rate equations for step-wise molecular reactions – Michaelis-Menten kinetics

Molecular motors [4]
Molecular motors in the cell – rectified Brownian motion – diffusion equation for a molecular motor – energy states and two-state model for molecular motors – force generation by polymerization

Action potentials in nerve cells [3]
Nerst potentials for ions – two-state model for ion channels – propagation of action potentials – channel conductance

Fourth Year Intercollegiate MSci Courses

For full details and module content, please refer to the MSci Handbook on the web:
http://www.rhul.ac.uk/physics/informationforcurrentstudents/msci4thyear/msci4thyear.aspx

The list in the above booklet indicates the taught courses of the fourth year of the Intercollegiate MSci degree programmes. It includes some UCL courses. Each module listed on page 4 of the MSci Handbook has a code number which is different at each College. All modules are a half course unit. The list also shows the course title, lecturer and the term in which it is taught. Also indicated is the College supplying the course.

For UCL students wishing to enter one of these external courses in PORTICO, the KCL (code 10), QMUL (code13) and RHUL (code47) modules codes as used at UCL can be found in the following table. All course listed are registered at UCL as Masters Level.

[MSc students - please note that the codes listed here are for MSci students only. For MSc codes please consult the MSc Programme Tutor.]

Term	Title, College and local College code	UCL code in Portico (0.5cu)
1	Math Methods for Theoretical Physics , KCL , 7CCP4201	10PIM201
1	Lie Groups and Lie Algebras € , KCL+ , 7CCMMS01	10MAMS01
1	Advanced Quantum Theory , UCL , PHASM426	PHASM426
1	Relativistic Waves & Quantum Fields , QMUL, SPA7018U	13PIM242
1	Electromagnetic Theory , QMUL, SPA7007U	13PIM261
1	Formation and Evolution of Stellar Clusters , UCL , PHASM319	PHASM319
1	Atom and Photon Physics , UCL , PHASM421	PHASM421
1	Particle Physics , UCL , PHASM442	PHASM442
1	Particle Accelerator Physics , RHUL§ , PH4450	47PIM450
1	Physics at the Nanoscale , RHUL , PH4475	47PIM475
1	Superfluids Condensates and Superconductors , RHUL , PH4478	47PIM478
1	Statistical Data Analysis , RHUL , PH4515	47PIM515
1	Stellar Structure and Evolution # , QMUL ‡ , SPA7023U	***not allowed to UCL UGs***
1	Solar System # , QMUL ‡ , SPA7022U	***not allowed to UCL UGs***
1	Environmental Remote Sensing , KCL++ , 7SSG5029	10GGM029
1	Theory of Complex Networks # , KCL+ , 7CCMCS02	***not allowed to UCL UGs***
1	Equilibrium Analysis of Complex Systems , KCL+ , 7CCMCS03	10MAMS03
1	Phase Transitions, QMUL, SPA7013U	13PIM017
2	Statistical Mechanics , RHUL , PH4211	47PIM211
2	Electronic Structure Methods, QMUL, SPA7008U	13PIM016
2	Advanced Quantum Field Theory , QMUL, SPA7001U	13PIM416
2	Advanced Photonics , KCL , 7CCP4126	10PIM126
2	Quantum Computation and Communication , UCL , PHASM427	PHASM427
2	Molecular Physics , UCL , PHASM431	PHASM431
2	Order and Excitations in Condensed Matter , UCL , PHASM472	PHASM472
2	Theoretical Treatments of Nano-systems , KCL , 7CCP4473	10PIM473
2	Standard Model Physics and Beyond , KCL , 7CCP4501	10PIM501

2	Nuclear Magnetic Resonance , RHUL* , PH4512	47PIM512
2	String Theory and Branes € , KCL+ , 7CMMS34	10MAMS34
2	Supersymmetry €€ , KCL+ , 7CMMS40	10MAMS40
2	Relativity and Gravitation # , QMUL ‡ , SPA7019U	***not allowed***
2	General Relativity and Cosmology , KCL , 7CCP4630	10PIM630
2	Astroparticle Cosmology , KCL , 7CCP4600	10PIM600
2	Planetary Atmospheres , UCL , PHASM312	PHASM312
2	Solar Physics , UCL , PHASM314	PHASM314
2	The Galaxy , QMUL ‡ , SPA7010U	13PIM660
2	Space Plasma and Magnetospheric Physics , UCL , PHASM465	PHASM465
2	Molecular Biophysics , UCL , PHASM800	PHASM800
2	Dynamical Analysis of Complex Systems , KCL+ , 7CCMCS04	10MAMS04
2	Mathematical Biology , KCL+ , 7CCMCS05	10MAMS05
2	Elements of Statistical Learning # , KCL+ , 7CCMCS06	***not allowed***
1$	Cosmology , QMUL ‡ , SPA7005U	13PIM601
2$	Astrophysical Plasmas , QMUL ‡ , SPA7004U	13MAM708
2$	Extrasolar Planets & Astrophysical Discs , QMUL ‡ , SPA7009U	13MAM735
2	Functional Methods in Quantum Field Theory , QMUL , SPA7007U	13PIM024
2	Advanced Physical Cosmology , UCL , PHASM336	PHASM336
2$	Electromagnetic Radiation in Astrophysics , QMUL , SPA7006U	13PIM006

Note: greyed-out courses will not run this session

§ Course taught over VideoCon network – sites at UCL, QMUL & RHUL
‡ Course taught by the Mathematics department of QMUL. Check the course start dates with the lecturer.

$ Course taught at QMUL in the evening this session.

* Course taught at RHUL in Egham (also available over VideoCon at QMUL)

Course unavailable to UCL students for syllabus reasons
+ Course taught by the Mathematics department of KCL. Check the course start dates with the lecturer.
In the interest of balance students will ordinarily take no more than three KCL maths courses.
++ Course taught by the Geography department at KCL. Check the course start dates with the lecturer.

€ Course content is mathematically demanding