DEPARTMENT OF PHYSICS AND ASTRONOMY

3rd Year
Course Descriptions

2014/15

INTRODUCTION

This handbook contains details about all the constituent courses for 3rd year full-time 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. 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 part of the Departmental website. The latter handbook gives information on how these courses fit into particular degree structures. 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 courses, please contact Departmental Programme 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/.

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PHAS3135 – The Physics of Stars (Term 1)

This course covers a wide range of basic stellar-astrophysics material at an intermediate to advanced level. In particular it addresses topics in stellar atmospheres, stellar structure and stellar evolution in greater depth than PHAS2112, building directly on that course.

Pre-requisite

PHAS2112 (Astrophysical Processes)

Aims

This course aims to:

- Provide a quantitative introduction to the physical nature of stellar atmospheres
- Develop the basic theory of stellar structure through analytical models
- Provide an intermediate-level description of how stars evolve

Objectives

On successful completion of this course, a student should be able to:

- Understand the basic concepts of opacity and emissivity in the context of stellar atmospheres and interiors
- Describe the basic physical atomic processes that contribute to the opacity, and the main frequency and temperature dependences
- Understand the interaction of radiation and matter, through the equation of radiative
- Radiation transfer in plane-parallel, static geometry (atmospheres) and diffusive transport (interiors)
- Derive the formal solution of the equation of radiative transfer, and have an appreciation of the grey-atmosphere solution
- Understand the basics of the construction of LTE model atmospheres, and their limitations
- Understand the basic processes leading to the calculation of model lines and continua in model atmospheres
- Describe the process of energy transport by convection in stellar interiors and atmospheres
- Construct simple stellar models based on polytropes, and understand their relationships to real stars
- Describe the major stages of stellar evolution
- Understand the effects of initial mass on evolution

Course structure & assessment

30 lectures, plus four problem-solving classes. Assessment based on final examination (90%) and three problem sheets (10%).

Core recommended texts

The Observation and Analysis of Stellar Photospheres, D. F. Gray (CUP, 2008)
An Introduction to the Theory of Stellar Structure and Evolution, D. Prialnik (CUP, 2009)

A longer reading list will be provided to students, including selected articles in the on-line Encyclopedia of Astronomy & Astrophysics, together with detailed lecture notes (after lectures).

Syllabus
[The approximate allocation of lectures to topics is shown in brackets below]

Introduction: overview [2]
Motivation: the spectroscopic determination of stellar properties, and their interpretation through stellar structure & evolution; Review of basic equations: Mass continuity, hydrostatic equilibrium, radiation field & opacity; equation of radiative transfer along a ray

Introduction: opacity sources [2]
Bound-bound, bound-free, free-free opacities; electron & Rayleigh scattering; Rosseland mean opacity; Kramer's opacity law

Stellar atmospheres: structures & continua [6]
Equation of radiative transfer in stellar atmospheres: formal solution; Grey atmosphere; Eddington, Milne-Eddington approximations; Eddington-Barbier relation, limb darkening; `Real-world' construction of LTE model atmospheres (Lambda, Unsold-Lucy iteration)

Stellar atmospheres: spectral-line formation [6]
Transfer equation and source function for lines; Calculation of line profiles in LTE; Break-down of LTE; P-Cygni profiles

Stellar structure: radiative and convective energy transport in interiors [3]
Gas, electron, and radiation pressures; Equations of state for an ideal gas and a polytrope; Diffusive radiative transfer; Schwarzschild criterion, mixing-length formalism

Stellar structure: simple models [4]
Polytropic models: Lane-Emden equation; Application to stars; Mass-radius relationship; Eddington standard model; Chandrasekhar mass

Stellar Evolution: pre-main-sequence [2]
Jeans mass; Pre-main-sequence phase; Hayashi (fully convective) tracks

Stellar Evolution: main sequence [3]
Homologous stellar models; Evolution on the main sequence

Stellar Evolution: post-main-sequence [2]
Evolution of the main sequence, to the red-giant branch; End-points of stellar evolution: dependence on initial mass

PHAS3137 – Physical Cosmology (Term 2)

Outline and Prerequisites

This course is designed to provide both an introduction to basic cosmological principles and a summary of selected topics in extragalactic astronomy.

The only pre-requisites are basic mathematical skills (i.e., elementary calculus) and basic physics (E=hf, dE=-pdV, etc...) which will be reviewed. Knowledge of astronomical nomenclature and jargon is not required in this course. Students will not normally have encountered General Relativity at the time they take this course and the development of the material as necessary, is therefore essentially non-GR, although GR results are introduced.

Aims of the Course

This course aims to:

- Summarise the essential physics describing the evolution of the Universe
- Summarise the thermal history of our Universe and their consequences
- Explain the formation of structure in our Universe

Objectives

After completion of this course students should be able to:

- Describe the gross characteristics of evolution of matter and radiation in the Universe, including the formation of the microwave background and of the light elements
- Discuss the role of inflation in resolving several problems with the traditional Big Bang model
- Describe how theory and observation lead to the inference of baryonic and non-baryonic dark matter on a variety of scales
- Explain the creation of cosmological perturbations which created structures in our Universe and how they grow with time
- Explain the thermal history of the Universe, the implications for freezeout, nucleosynthesis, the CMB formation and inflation
- Describe a variety of techniques for estimating masses, and mass:light ratios, in clusters of galaxies
- Explain the nature of the luminosity functions, their cosmological uses, how they evolve with time, and how selection effects can bias the results
- Explain the nature of the fluctuations in the CMB spectrum

Syllabus

Part I: The unperturbed universe [12]

- Revision of physics needed for the course: statistics, thermo [1]
- Introduction; brief history of the Universe from $t=10^{-43}$ sec to the present; observational basis of our current cosmological model [2]
- Metrics; Friedman equations; the evolution of the scale factor; the acceleration and fluid equations [3]
- Derivation of cosmological parameters; specific models (Milne, EdS); Distances and Time in cosmology [3]

- Galaxy counts; Luminosity functions and cosmological evolution of counts; Cosmological volume; log N - log S test and V/V_max tests [2]
- Galaxy k-corrections and effects on the luminosity functions; Photometric redshifts [1]

Part II: The thermal history of the universe [8]

- Relic abundances and freezeout [2]
- Baryogenesis and nucleosynthesis [2]
- The CMB spectrum, recombination and the Saha equation [2]
- The problems with the hot big bang model; Inflation and dynamics [2]

Part III: Structure formation [10]

- Dark matter evidence; 21cm; Clusters of galaxies and mass estimates from: weak and strong lensing, X-rays, virial theorem [3]
- Jeans theory in a Newtonian formalism; implications for the power spectrum; Free streaming and relativistic neutrinos [3]
- Peculiar velocities and redshift space distortions [1]
- The Lyman alpha forest and the Gunn-Peterson test. Reionization [1]
- Physics of the CMB anisotropies [2]
- Topics in Galaxy formation and Modern cosmology [2]

Methodology and Assessment

30 lectures, with 3- 4 problem-solving tutorial classes/discussion periods. Assessment is based on an unseen written examination (90%) and continuous assessment (10%) based on 4 problem sheets.

Recommended Texts

An introduction to Modern Cosmology, Liddle (Introductory reading)
Galaxy Formation, Longair (Main text)
An Introduction to Galaxies and Cosmology Jones & Lambourne (Secondary text)

PHAS3201 – Electromagnetic Theory (Term 1)

Prerequisites

Students taking this course should have taken PHAS2201: Electricity and Magnetism, or equivalent. The mathematical prerequisites are PHAS1245 – Maths 1 and PHAS1246 - Maths 2 in the first year and PHAS2246 Maths 3 in the second year, or equivalent mathematics courses.

Aims of the Course

This course aims to:

- Discuss the magnetic properties of materials
- Build on the contents of the second year course; Electricity and Magnetism PHAS2201, to establish Maxwell's equations of electromagnetism, and use them to derive electromagnetic wave equations
- Understand the propagation of electromagnetic waves in vacuo, in dielectrics and in conductors
- Explain energy flow (Poynting's theorem), momentum and radiation pressure, the optical phenomena of reflection, refraction and polarization, discussing applications in fibre optics and radio communications
- Use the retarded vector potential to understand the radiation from an oscillating dipole
- Understand how electric and magnetic fields behave under relativistic transformations

Objectives

After completing the course the student should be able to:

- understand the relationship between the **E, D** and **P** fields, between the **B, H** and **M** fields
- be able to derive the continuity conditions for **B** and **H** at boundaries between media; distinguish between diamagnetic, paramagnetic and ferromagnetic behaviour
- use the vector potential **A** in the Coulomb gauge to calculate the field due to a magnetic dipole
- calculate approximate values for the **B** and **H** fields in simple electromagnets
- understand the need for displacement currents
- explain the physical meaning of Maxwell's equations, in both integral and differential form, and use them to; (i) derive the wave equation in vacuum and the transverse nature of electromagnetic waves; (ii) account for the propagation of energy, momentum and for radiation pressure; (iii) determine the reflection, refraction and polarization amplitudes at boundaries between dielectric media, and derive Snell's law and Brewster's angle; (iv) establish the relationship between relative permittivity and refractive index; (v) explain total internal reflection, its use in fibre optics and its frustration as an example of tunnelling; (vi) derive conditions for the propagation of electromagnetic waves in, and reflection from, metals; (vii) derive the dispersion relation for the propagation of waves in a plasma, and discuss its relevance to radio communication
- understand how an oscillating dipole emits radiation and use the vector potential in the Lorentz gauge to calculate fields and energy fluxes in the far-field
- be able to transform electric and magnetic fields between inertial frames

Lectures and Assessment

27 lectures plus 6 discussion periods. Assessment is based on the results obtained in the final examination (90%) and from the best 3 sets out of 5 sets of 3 homework problems (10%).

Textbook

Introduction to Electrodynamics, David J. Griffiths – Third Edition, Prentice Hall

Syllabus

Introduction [1]
Mathematical tools; Brief summary of results from Maths I, II and III, as needed in this course, including differential form of Gauss' law and electrostatic potential V

Dielectric media [2]
Brief revision of capacitor and dielectric constant; E-field pattern of electric dipole from V; Polarisation P as electric dipole moment per unit volume, free and polarisation charge densities - volume and surface; Displacement D as field whose divergence is free charge density: relative permittivity and electrical susceptibility; Energy density in electric field, via capacitor

Magnetic fields [3]
Brief revision of Faraday, Ampere and Biot-Savart laws; Introduce magnetic vector potential A; B as curl A, lack of uniqueness (c.f. V), Coulomb gauge; A from current distribution; Field pattern of current loop (i.e. magnetic dipole), c.f. electric dipole in far field

Linear magnetic media [3]
Magnetisation M as dipole moment per unit volume, elementary current loops, free and magnetisation current densities - surface and volume; J_m as curl of M; Magnetic intensity H as field whose curl is J_f; Relative permeability and magnetic susceptibility; Diamagnetic and paramagnetic materials: brief microscopic explanations, current loops or intrinsic moments; Boundary conditions on B and D from pillbox integral; Continuity of lines of force; Boundary conditions on H and E from loop integral

Ferromagnetism [3]
Intrinsic magnetic moments at atomic level; Qualitative description of short and long range forces, ordering below transition temperature, mention of ferrimagnetic and antiferromagnetic; Ferromagnetic domains, B vs H plot, hysteresis, major and minor loops, normal magnetisation curve, saturation, scale of ferromagnetic amplification of B, remanence, coercivity; B and H in infinite solenoid compared to uniformly magnetised bar: winding on infinite bar, winding on toroid; Fluxmeter for B and H in toroid to show hysteresis loop; Energy density in magnetic field, via inductor

Maxwell equations and e.m. waves [4]
Displacement current from continuity equation; generalised Ampere law; Maxwell's equations in differential and integral form; Wave equations for E, D, B and H; Relation between field vectors and propagation vector; Description of types of polarisation; linear, elliptical, circular, unpolarised, mixed

Reflection and refraction at a plane dielectric surface [3]

Refractive index; Snell's law and law of reflection, reflection and transmission coefficients, Fresnel relations, Brewster angle, critical angle, total internal reflection, mention of evanescent wave

Energy flow and the Poynting vector [1.5]
Static energy density in electric and magnetic fields; Poynting's theorem and the Poynting vector; Pressure due to e.m. waves

Waves in conducting media [2.5]
Poor and good conductors: skin depth, dispersion relation, reflection at metal surface; Plasma frequency, simple plasma dispersion relation, superluminal phase velocity

Emission of radiation [2]
Hertzian dipole; retarded time; Lorentz condition, retarded potentials, far field pattern of E and B, radiated power

Relativistic transformations of electromagnetic fields [2]
Revision of 4-vectors (r,t) and (p, E); Invariance of 4-vector dot product; Continuity equation as 4-div of (J, □); Lorentz condition as 4-div of (A,V); Transformation of E and B fields

PHAS3224 – Nuclear and Particle Physics (Term 2)

Prerequisites

An introductory course in atomic physics (such as PHAS2224) and an introductory course in quantum physics (such as PHAS2222), or their equivalents in other departments.

Aim of the Course

The aim of the course is to provide an introduction to the physical concepts of nuclear and particle physics and the experimental techniques which they use

Objectives

After completing the course, students should:

- understand the basic ideas and techniques of the subject, including the description of reactions in terms of amplitudes and their relation to simple measurable quantities.

In nuclear physics, students should:

- know the basic phenomena of nuclear physics, including the properties of the nuclear force, the behaviour of binding energies as a function of mass number, and nuclei shapes and sizes and how these are determined
- understand the interpretation of binding energies in terms of the semi-empirical mass formula of the liquid drop model
- know the systematics of nuclear stability and the phenomenology of α, β and γ decays and spontaneous fission
- understand how a wide range of nuclear data, including spins, parities and magnetic moments, are interpreted in the Fermi gas model, the shell model and the collective model
- understand the theory of nuclear β-decay
- understand the physics of induced fission, how fission chain reactions occur and how these may be harnessed to provide sources of power, both controlled and explosive
- understand the physics of nuclear fusion and its role in stellar evolution, and the difficulties of achieving fusion both in principle and in practice

In particle physics, students should:

- appreciate the need for antiparticles
- understand the relationship between exchange of particles and the range of forces
- know how to interpret interactions in terms of Feynman diagrams
- know the roles and properties of each of the three families of particles (quarks, leptons and gauge bosons) of the standard model of particle physics
- understand in elementary terms the physics of neutrino and Kaon oscillations
- know the properties of hadrons and understand their importance as evidence for the quark model
- understand the principles of the interpretation of the fundamental strong interaction via quantum chromodynamics (QCD), including the roles of the colour quantum number, confinement and asymptotic freedom

- understand the evidence for QCD from experiments on jets and nucleon structure
- understand the spin and symmetry structures of the weak interactions and tests of these from the decays of the μ, π and K^0 mesons
- understand how unification of the electromagnetic and weak interactions comes about and the interpretation of the resulting electroweak interaction in the standard model
- understand in elementary terms the Higgs mechanism and appreciate the significance of the discovery of the Higgs boson

In experimental methods, students should:

- know the principles of a range of particle accelerators used in nuclear and particle physics
- know the physics of energy losses of particles with mass interacting with matter, including losses by ionisation, radiation and short range interactions with nuclei, and the losses incurred by photons
- know the principles of a range of detectors for time resolution, measurements of position, momentum, energy and particle identification, and how these are combined in modern experiments

Methodology and Assessment

The course consists of 30 lectures supplemented by 3 lecture periods for coursework problems and other matters as they arise. Assessment is based on an unseen written examination (90%) and the best 4 of 5 coursework problem papers (10%).

Textbooks

Core texts:
Nuclear and Particle Physics – An introduction, B.R. Martin (Wiley)
Particles and Nuclei (2nd Ed), B Povh, K Rith, C Scholz and F Zetsche (Springer)
Particle Physics (2nd Ed), B R Martin and G Shaw (Wiley)

Other useful texts:
An Introduction to Nuclear Physics, W N Cottingham and D A Greenwood (Cambridge)
Nuclear and Particle Physics, W S C Williams (Oxford)
Introduction to Nuclear and Particle Physics, A Das and T Ferbel (Wiley)
Introduction to High Energy Physics (4th Ed), D H Perkins (Cambridge)

Syllabus
(The *approximate* assignment of lectures to each is shown in brackets)

The course is divided into eight sections:

1. Basic Ideas (3)
History; the standard model; relativity and antiparticles; particle reactions; Feynman diagrams; particle exchange – range of forces; Yukawa potential; the scattering amplitude; cross-sections; unstable particles; units: length, mass and energy

2. Nuclear Phenomenology (4)

Notation; mass and binding energies; nuclear forces; shapes and sizes; liquid drop model: semi-empirical mass formula; nuclear stability; □–decay: phenomenology; □–decay; fission; □-decay

3. *Leptons, Quarks and Hadrons (4)*

Lepton multiplets; lepton numbers; neutrinos; neutrino mixing and oscillations; universal lepton interactions; numbers of neutrinos; evidence for quarks; properties of quarks; quark numbers; hadrons; flavour independence and hadron multiplets

4. *Experimental Methods (5)*

Overview; accelerators; beams; particle interactions with matter (short-range interactions with nuclei, ionisation energy losses, radiation energy losses, interactions of photons in matter); particle detectors (time resolution: scintillation counters, measurement of position, measurement of momentum, particle identification, energy measurements: calorimeters, layered detectors)

5. *Quark Interactions: QCD and Colour (3)*

Colour; quantum chromodynamics (QCD); the strong coupling constant; asymptotic freedom; jets and gluons; colour counting; deep inelastic scattering: nucleon structure

6. *Electroweak Interactions (5)*

Charged and neutral currents; symmetries of the weak interaction; spin structure of the weak interactions; neutral kaons; □ mixing and CP violation; strangeness oscillations; □ bosons; weak interactions of hadrons; neutral currents and the unified theory; The Higgs boson

7. *Structure of Nuclei (4)*

Fermi gas model; the shell model: basic ideas; spins, parities and magnetic moments in the shell model; excited states in the shell model; collective model; □-Decay; Fermi theory; electron momentum distribution; Kurie plots and the neutrino mass

8. *Fission and Fusion (2)*

Induced fission – fissile materials; fission chain reactions; power from nuclear fission: nuclear reactors; nuclear fusion: Coulomb barrier; stellar fusion; fusion reactors

PHAS3225 - Solid State Physics (Term 2)

Prerequisites

PHAS2228 Statistical Physics of Matter or an equivalent course in other Departments

Aims of the Course

The aim of the course is to:

- Show how the diverse properties (mechanical, electronic, and optical) of solid materials can be related to interactions at the atomistic level, using theoretical models
- Provide a sound foundation for the advanced condensed matter options in the third and fourth years
- Show how the study of condensed matter plays a vital part both in other areas of physics and, more generally in science, technology and industry

Objectives

After completing this course, student will be able to:

- describe simple structures in terms of a lattice and unit cell, calculate the cohesive energy of these structures and understand (in outline) how they are determined experimentally
- understand the basic features of the coupled modes of oscillation of atoms in a crystal lattice using the one-dimensional chain as a model and relate crystal properties (specific heat, thermal conductivity) to the behaviour of these oscillations
- explain the basic features of the stress/strain curve for a simple metal using ideas of dislocation production and motion
- derive the free electron model and show how this can provide an explanation for many features of metallic behaviour
- appreciate the strengths and weaknesses of the free electron model and explain the effect of the lattice on the behaviour of electrons in solids both from the point of view of the nearly-free electron model and the tight-binding model
- explain the basic features of semiconductors and relate this to simple semiconductor devices

Syllabus

Part 0: Introduction to condensed matter
An introductory lecture in which the aims and content of the course will be discussed

Part 1: Structural properties of solids

1.1 Interatomic bonding and material structure (5 lectures)
Crystal structures will be described in terms of the Bravais lattice and basis. The hcp, bcc, fcc and diamond structures will be discussed, together with the related ZnS and CsCl structures. We shall introduce the idea of a primitive unit cell and contrast it with a conventional cell. We shall discuss the use of Miller indices to designate lattices, planes and directions in crystals.

The distinction between directional (covalent) and non-directional (van der Waals, ionic and metallic) bonding will be related to the kinds of structures seen.
We shall calculate cohesive energies of various structures for van der Waals and ionic bonded materials to determine which is most stable. We shall discuss the structures of ionic materials using models of packed spheres.

1.2 Diffraction methods and structural determination (2 lectures)
We shall discuss diffraction methods for determining crystal structure. The main techniques (diffractometers, powder photographs and Laue photographs) will be described. We shall briefly discuss the advantages and disadvantages of using neutrons, electrons and X-rays to determine structures. We shall introduce the idea of atoms as individual scattering centres and argue that this can be used to understand the intensities of the diffraction pattern.

1.3 Lattice dynamics and phonons (4 lectures)
We shall consider the coupled modes of oscillation of atoms in a crystal lattice, using a one-dimensional chain of identical atoms. The harmonic approximation will be introduced. We shall discuss the effect of the boundary conditions on the solution and introduce the idea of a Brillouin zone. The dispersion relation and the density of states of oscillatory modes will be derived and discussed. The connection between the normal modes and the idea of a phonon will be made. We shall use the one-dimensional chain with different masses to illustrate the ideas of acoustic and optic modes and hence the idea of a band gap in the density of states. The extension of the lattice dynamics calculation to three dimensions will be discussed at a qualitative level. We shall discuss the experimental determination of phonon densities of states.

1.4 Thermal properties of solids (3 lectures)
We shall review the Debye and Einstein models for the specific heat of solids. We shall illustrate these models using the one-dimensional chain of identical atoms. We shall compare these models with more exact calculations.

We shall discuss thermal conductivity by phonon transport using a kinetic theory analogous to the kinetic theory of gases. The idea of a phonon mean free path will be discussed and a qualitative account of phonon scattering mechanisms given. In particular, we shall discuss the Umklapp mechanism for phonon-phonon scattering and how it can contribute to thermal resistance.

1.5 Mechanical properties of solids (3 lectures)
We shall demonstrate that the theoretical yield stress is far greater than the observed yield stress for any material. We shall introduce the idea of a dislocation and show how it can lower the yield stress using the 'carpet ruck' analogy. We shall discuss the two pure types of dislocation (edge and screw) and introduce the concept of a Burgers vector.

PHAS3225 part 2: Electrons in solids

2.1. Electronic and optical properties of solids (1 lecture)
The variety of electronic and optical properties of solids will be discussed briefly using simple ideas of valence and conduction band structure for the electronic energy spectrum in materials, with examples. We shall take as examples materials ranging from electrical insulators to semiconductors and conductors. Transparency and opacity of solids will be considered, together with field emission and contact potentials We shall draw analogies between electron and phonon spectra, particularly with regard to band gaps.

2.2. Models of electrons in solids (7 lectures)

Models will be used to show how electronic structure emerges from the fundamental interactions of electrons in materials, as described by quantum mechanics. We shall review the free electron model and show how electrons bind atoms together in metals and covalent solids. We shall calculate the electronic specific heat and, using the idea of a relaxation time, calculate the thermal conductivity due to free electrons, and discuss electrical current, resistivity and the Wiedemann-Franz law. Using perturbation theory and Bloch's theorem, the nearly-free electron model will be introduced to show how band gaps in the electron energy spectrum arise. The tight binding model will be introduced and used to demonstrate, from a different point of view, how band gaps emerge. We shall discuss the drift of electrons in bands, introducing the idea of the effective mass.

2.3. Semiconductors (6 lectures)
We shall discuss the electronic structure of intrinsic and n- and p-type doped semiconductors. Donor and acceptor states and the electronic structure of each type of semiconductor will be described. Holes and electrons will be discussed. We shall consider processes taking place at pn junctions, including carrier generation, and recombination. We shall discuss the operation of field effect transistors, light emitting diodes, semiconductor lasers and solar panels.

Assessment
Students will be set five problems sheets, and the marks given for the best four will account for 10% of the course assessment. The remaining 90% will be awarded on the basis of the end-of-session exam.

Reading list

There are many books available on solid state physics. The following book is recommended:

- *Introduction to Solid State Physics*, 8th edition, C. Kittel

Some aspects of the course are treated well by:

- *Solid State Physics*, J.R. Hook and H.E. Hall
- *Understanding the Properties of Matter*, M. DePodesta
- *Three Phases of Matter*, 2nd edition, A.J. Walton

Advanced texts for continued studies are:

- *Solid State Physics*, 2nd edition, J.S. Blakemore
- *Solid State Physics*, N.W. Ashcroft and N.D. Mermin

PHAS3226 – Quantum Mechanics (Term 1)

Prerequisites

To have completed the Department's introductory Quantum Physics course, PHAS2222 or equivalent. PHAS2224, the Atomic and Molecular Physics course is desirable. Frequent reference is made to the material in PHAS2222.

The following topics should have been covered previously:

The time-independent Schrödinger wave equation and its solution for: (1) quantum wells and quantum barriers/steps (2) The harmonic oscillator (classical and quantum) (3) The hydrogen atom including the radial equation as well as the angular equation and its solution with spherical harmonics. An understanding of atomic spectroscopic notation (n,l,m quantum numbers) and their physical basis is assumed. The expansion postulate; the Born interpretation of the wave function; simple calculations of probabilities and expectation values. For a time-independent Hamiltonian, an understanding of the separability of the full Schrodinger equation into a time-independent wave equation in position space and a time-dependent component is assumed. Familiarity with applications to eigenstates and or superpositions thereof is assumed. A basic understanding of the postulates of quantum theory is assumed.

Mathematical content

Studying quantum mechanics at this level requires some specific mathematical tools. Physics and Astronomy students will cover this material in PHAS1245, PHAS1246 and PHAS2246. Students from other departments who have not taken PHAS2246 are **strongly recommended** to have learnt this material via an equivalent course or self-study.

Aims of the Course

This course aims to:

- Introduce the basic concepts of Heisenberg's matrix mechanics. The second year course (PHAS2222) dealt primarily with the Schrodinger's matter wave dynamics. In PHAS3226, matrix mechanics is introduced as an alternative approach to quantum dynamics. It is also shown to provide a complementary approach, enabling the treatment of systems (such as spin systems) where solutions of the non-relativistic Schrodinger wave equation in position coordinates is not possible
- Apply matrix mechanics and operator algebra to the Quantum Harmonic Oscillator and its relation to the 2nd year wave dynamics solutions using Hermite polynomials
- Apply matrix mechanics and operator algebra to quantum angular momentum
- Demonstrate that matrix mechanics predicts and permits solution of spin-1/2 systems using Pauli matrices
- Develop understanding of fundamental concepts using these new methods. The Heisenberg uncertainty principle is shown to be just one among a family of generalized uncertainty relations, which arise from the basic mathematical structure of quantum theory, complementing arguments (eg Heisenberg microscope) introduced in the second year
- Explore some concepts of two-particle systems. The addition of two-spins is analysed including fundamental implications, exemplified by the Einstein-Podolsky-Rosen paradox and Bell inequalities
- Introduce approximate methods (time-independent perturbation theory, variational principle) to extend the PHAS2222 analytical solution of the hydrogen atom to

encompass atoms in weak external electric and magnetic fields and two-electron systems like helium atoms

- Introduce symmetry requirements and the Pauli Principle

Objectives

After completing the module the student should be able to:

- Formulate most quantum expressions using abstract Dirac notation and understand that it is not simply shorthand notation for second-year expressions
- Understand how to formulate and solve simple quantum problems expressing quantum states as vectors and quantum operators as matrices
- Use commutator algebra and creation/annihilation operators to solve for the Quantum Harmonic Oscillator
- Derive generalized uncertainty relations; calculate variances and uncertainties for arbitrary observables. In this context, have a clear understanding of the relation and difference between operators and observables
- Use commutator algebra and raising/lowering operators to calculate angular momentum observables
- Calculate the states and observables of spin-1/2 systems using Pauli matrices
- Understand and estimate corrections to the energy and properties of low-lying states of helium atoms using approximate methods and symmetry
- Understand time-independent perturbation theory
- Understand the variational principle
- Understand the Pauli Principle and symmetrisation requirements on quantum states including for combinations of space/spin states

Methodology and Assessment

The module consists of 30-33 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 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)

1) Formal quantum mechanics [7 hours]
Revision of year 2 concepts using Dirac bracket notation:
Introduction to Dirac notation and application to PHAS2222 material including orthonormality of quantum states, scalar products, expansion postulate, Linear Hermitian Operators and derivations of their their properties; simple eigenvalue equations for energy, linear and angular momentum; Representations of general operators as matrices and states as vectors using a basis of orthonormal states; Basis set transformations: proof that

eigenvalue spectrum is representation independent; Similarity transformations and applications to calculations of observables such as eigenvalues and expectation values

2) The Quantum Harmonic Oscillator; Generalised Uncertainty Relations [7]
Introduction of creation and annihilation operators: main commutator relations, the number operator; Solution of the QHO eigenstates and spectrum using this method; Relation to wave dynamics and Hermite polynomial solutions obtained previously; The zero-point energy as a consequence of both commutator algebra as well as wave solutions; Uncertainty relations for general operators derived from Schwarz inequalities; Solutions of simple examples including Heisenberg Uncertainty Principle

3) Generalised Angular Momentum [4 hours]
Commutator algebra and raising/lowering operators; Obtaining angular momentum eigenvalue and eigenstates using raising and lowering operators; Matrix representation and solution of simple problems

4) Spin-1/2 systems [8 hours]
Introduction to spin-1/2 systems; Matrix representations of spin using eigenstates of z-component of spin: spinors and Pauli matrices; Matrix representations of eigentates of spin operators along arbitrary directions; Basis set and similarity transformations between different basis sets; Addition of two spins; The EPR paradox and derivation of Bell inequalities

5) Approximate methods and many-body systems [7 hours]
Derivation of time independent Perturbation theory; First and second order theory and examples: helium and atoms in external fields; The variational principle; example with helium; Symmetry, fermions, bosons and the Pauli principle; Two-particle space-spin symmetry; Slater determinants for many body systems; Exchange corrections in helium spectrum

PHAS3330 – Observational Astronomy 1: Techniques (Term 1)

Prerequisites

Students are normally expected to have passed one of the first year courses in observational astronomy at ULO.

Aims of the Course

The aims of this course are to:

- apply contemporary research methods used by astronomers in investigating the Universe by observation at the telescope
- become confident in the use of a medium-sized telescope
- use a selection of computer software packages used in the reduction and analysis of astronomical data
- acquire sufficient expertise to be able to observe confidently and productively at any research grade observatory in the world

Objectives

On successful completion of this course the student should:

- be able to plan a coherent and scientifically useful programme of astronomical observations
- be able to observe with the Allen or Radcliffe telescope at ULO under the supervision of a member of staff
- be able to use instrumentation, such as a spectrograph or CCD camera, on the above-mentioned telescopes
- be able to use the computer system and Starlink software at ULO to reduce and analyse astronomical observations
- have an improved understanding of statistical techniques used in the analysis of scientific observations
- have developed further the art of writing a scientific report

Methodology and Assessment

Assessment is continuous. Credit is awarded for written reports submitted by the student.

Students are trained in the use of the telescopes and computers at ULO, and they learn how to plan a schedule of observations. This material is consolidated by the completion of three compulsory experiments in the early part of the course. The expertise so gained is then applied to two longer experiments chosen by the student from a list of approximately nine. Each experiment is described in a written script which is available to the student for perusal before he or she commences it. Experiments are completed under the guidance and supervision of members of staff and student demonstrators.

The organiser of the course provides tutorial presentations to assist the students in preparing for and completing their experiments. Areas related to observational astronomy such as positional astronomy, coordinate systems and statistics are covered.

Students receive written feedback on the quality of their written reports.

Three compulsory experiments on astronomical techniques make up 3/8 of the credit awarded for the course. These are:

- Observing Programmes for the Allen and Radcliffe Telescopes
- Training and Observing with the Allen and Radcliffe Telescopes
- Computing Facilities for Observational Astronomy

The balancing 5/8 of credit is obtained by completing two experiments chosen from the list given in the syllabus (the subject matter of each experiment is indicated in parentheses).

Textbooks

The script for each experiment includes a relevant bibliography. The following text is an excellent general reference for the course:

- *Observational Astronomy*, D. Scott Birney, ISBN 0 521 38199 1 (Cambridge University Press, 1991)

Syllabus

Coordinates of a Celestial Object (CCD imaging at the telescope, measurement of coordinates, transformation between coordinate systems, positional astronomy, apparent stellar motions)

Measurement of Lunar Libration (CCD imaging, phases of the Moon, topology of the Moon, measurement of coordinates, transformation between coordinate systems, relationship between geocentric and topocentric lunar librations)

Spectroscopy of Unusual Stars (CCD spectroscopy, radiation from a star absorption and/or emission lines in the spectrum of a star, variable stars, unusual stars)

The Determination of the Mass Loss Rate of a Luminous OB Star from its H-alpha Emission (CCD spectroscopy, radiation from a star, stellar emission lines, hot stars, mass loss in stellar winds, physical conditions at the surface of a star)

Measurement of Stellar Radial Velocity (photographic spectroscopy, use of a measuring engine, wavelength calibration of a spectrum, the F-test, the Doppler relation, geocentric and heliocentric velocity corrections)

Spectrophotometry of Seyfert Galaxies (emission lines in nebulae, line ratios, the Doppler shift of a galaxy, radiation from active galaxies, physical conditions in active galaxies, the distance and luminosity of an active galaxy)

Interstellar Extinction from IUE Spectra of O Stars (the interstellar medium, hot stars, ultraviolet spectroscopy, stellar winds, P-Cygni profile)

Reduction of All Sky UBV Photometric Observations (extinction of starlight by the Earth's atmosphere, calibration of photometric observations)

The Orbit of the Planet of 51 Pegasi (astronomical computer programming, optimisation of a model, orbital parameters from radial velocity curves, mass function of a binary system)

A detailed Course Guide and set of Experiment Scripts is provided for each student enrolled in the course.

PHAS3331 – Observational Astronomy II: Applications (Term 2)

PHAS3331 is a half-unit course in observational astronomy held at the University of London Observatory (ULO), Mill Hill. It is available to students in the final year of the BSc, or the third year of the MSci degree programmes in Astronomy, Astrophysics and related subjects taken within the Department of Physics and Astronomy at UCL. Students taking PHAS3331 make further use of instrumentation on the two largest telescopes at ULO in applying the techniques acquired during course PHAS3330 to more extended observational projects.

Prerequisites

Students are normally expected to have passed course PHAS3330.

Aims of the Course

This course aims to:

- learn and apply further contemporary research methods used by astronomers in investigating the Universe by observation at the telescope
- to make further use of one or both of the larger telescopes at ULO
- to apply the computing techniques learned during course PHAS3330 to the reduction and analysis of more extensive sets of astronomical data

Objectives

After completion of this course it is intended that the students will become considerably more self-sufficient in obtaining, reducing and analysing astronomical data.

Methodology and Assessment

Assessment is continuous. Credit is awarded for written reports submitted by the student. Two projects are chosen by the student from a list of approximately six. Each project is described in a written script which is available to the student for perusal before he or she commences it. Projects are completed under the guidance and supervision of members of staff and student demonstrators.

The organiser of the course is available to provide tutorial presentations to assist the preparation and completion of project reports.

Textbooks

The script for each project includes a relevant bibliography. The following text is an excellent general reference for the course:

- *Observational Astronomy*, D. Scott Birney, ISBN 0 521 38199 1 (Cambridge University Press, 1991)

Syllabus

Course credit is obtained by completing two projects chosen from the following list (the subject matter of each experiment is indicated in parenthesis):

1. Measurement of the Proper Motion of a Star (CCD imaging at the telescope, use of a data archive, measurement of coordinates, transformation between coordinate systems, positional astronomy, apparent stellar motions, stellar proper motions)
2. Determination of the Elements of the Orbit of a Solar System Object (astronomical computer programming, orbital elements)
3. Classification of Stellar Spectra (CCD spectroscopy at the telescope, stellar spectra, stellar classification systems)
4. Spectroscopy of Unusual Stars (CCD spectroscopy, radiation from a star, absorption and/or emission lines in the spectrum of a star, variable stars, unusual stars. This is a more extended version of the experiment available under course PHAS3330).
5. Spectroscopy of Gaseous Nebulae (CCD spectroscopy, emission lines in nebulae, photometric calibration of spectra, line ratios, radiation from nebulae, physical conditions within nebulae)
6. Measurement of Stellar Radial Velocity by the Cross-correlation of Digital Spectra (CCD spectroscopy, stellar absorption lines, cross-correlation, stellar radial velocities, radial velocity standards, geocentric and helioocentric corrections to radial velocities)

PHAS3332 – Observational Astronomy III: Field Trip (Term 2)

PHAS3332 is a half-unit course in observational astronomy consisting of field work carried out at an observatory outside the UK supplemented by orientation and data reduction sessions carried out at the University of London Observatory (ULO), Mill Hill. During recent academic years, field work has been conducted during February/March at the Observatoire de Haute-Province, France.

Prerequisites

Students are normally expected to have passed course PHAS3330. The capacity of course PHAS3332 is limited and, if demand exceeds the number of available places, participants are selected on the basis of their performance in course PHAS3330.

Aims of the Course

The aims of this course are to:

- apply the observational techniques learned during earlier courses at UCL to complete successfully observing programmes on large telescopes at a foreign observatory;
- complete spectroscopic and photometric investigations of a specific class of celestial object
- apply the computing techniques learned during course PHAS3330 to the reduction and analysis of extensive sets of astronomical data
- gain experience of working in an environment where the native language is not English
- develop interpersonal and liaison skills by working in collaboration on large projects during a short period of time

Objectives

After completing the course the student should:

- understand and work to an observing brief prepared by the organiser of the course
- improve research skills, including use of some sources not in English
- be able to plan an observing programme in consultation with other student participants in the Field Trip
- gain experience of high resolution astronomical spectroscopy
- obtain experience in CCD imaging photometry
- improve his or her understanding of the subject areas studied during the Field Trip, which in the past have included the photometry of cataclysmic variables, spectroscopy of active galaxies and high-resolution spectroscopy of chemically peculiar stars and spectroscopic binaries

Methodology and Assessment

Assessment is continuous. Credit is awarded for written reports submitted by the student. during the first week of the third term.

After being briefed by the course organiser, and after researching the host observatory and the subject matter of the Field Trip, each student prepares an ‘orientation report’ assessed at 1/5 of the total credit for the course.

Observing in the field is carried out by groups of three students under the supervision of a member of an accompanying member of staff from UCL. Students liaise and cooperate to optimise the time they spend jointly observing with the telescopes. Data reduction is commenced at the host observatory, and a literature search carried out. On return to England the students complete data reduction and analysis at ULO under the guidance of the course organiser. Two long projects are completed and submitted soon after the Easter holiday. The report for each comprises 2/5 of the credit for the course.

The organiser of the course (or other members of staff) may provide lectures and tutorial presentations to assist with the preparation and completion of project reports.

Textbooks

The observing proposal for each project submitted to the host observatory includes a relevant bibliography. The following text is an excellent general reference for the course:

- *Observational Astronomy*, D. Scott Birney, ISBN 0 521 38199 1 (Cambridge University Press, 1991)

The following web site describes the telescopes and instrumentation at the Observatoire de Haute-Provence: http://www.obs-hp.fr/.

Syllabus

Orientation sessions covering the scientific content of the observing programmes and the telescopes and instrumentation to be used at the host observatory are held during January and February. The students submit a report on their orientation which comprises 1/5 of the credit for the course.

Field work occurs during February/early March and is reported in two project reports each of which comprise 2/5 of the credit for the course. The subject matter of the projects varies from year to year in order to ensure topicality and competitiveness of the request for observing time. Past field trips conducted at the Observatoire de Haute-Provence (OHP) have involved work in the following subject areas:

- ***CCD Imaging Photometry of Cataclysmic Variable Stars*** (using the 0.80-m reflector at OHP)
- ***Spectroscopy of Active Galactic Nuclei*** (using the 1.52-m telescope at OHP)
- ***High-resolution Spectroscopy of Chemically Peculiar Stars and Spectroscopic Binaries*** (using the 1.52-m telescope at OHP)

If poor weather prevents the gathering of sufficient data at the telescope, observations from Field Trips conducted in previous years has been archived and will be made available.

PHAS3334 – Interstellar Physics (Term 2)

Prerequisites

None

Aims of the Course

The aims of this course are to:

- teach the basic physics of the interstellar gas in its diffuse, ionised and molecular phases, together with the properties of interstellar dust
- develop a qualitative and quantitative understanding of the microscopic processes that are occurring within and controlling the macroscopic processes of the interstellar medium
- apply this to describe quantitatively the physical processes involved in the process of star formation and in the impact of stars on their environments

Objectives

- heating and cooling processes in diffuse media, formation and destruction of molecules in diffuse media
- the roles of dust in the interstellar medium
- ionised regions around hot stars and their evolution
- gas dynamics and astrophysical shocks
- stellar winds and supernova explosions and their effects on their environments
- structure in the interstellar medium
- large scale processes in star forming regions

Methodology and Assessment

The course consists of 30 lectures. There are 4 problem sheets associated with the course, of which the best 3 will be used for the continuous assessment mark. Overall assessment is based on the results obtained for the final examination (90%) and for the problem sheets (10%).

Textbook

- *The Physics of the Interstellar Medium* (J.E. Dyson and D.A. Williams, Manchester University Press. 2nd Edition)

Syllabus

[The approximate allocation of lectures to topic is shown in brackets below]

Introduction [2]

History; Components of the ISM; Interstellar magnetic fields

Gas Dynamics [5]

Heating and cooling: hydrodynamics, sound waves; Shocks: cooling processes in shocked gases/isothermal shocks

HII Regions, Stellar Winds and Supernovae [8]
Ionised nebulae/HII regions & photoionised gas; The evolution of ionised regions; Stellar winds, supernovae, and their effects on the ISM

Star Formation [5]
Hydrostatic equilibrium, free-fall & induced star formation; Observational signatures of star formation; Gas flows from star-forming regions; Circumstellar and protoplanetary disks: the interstellar magnetic field

Dust [5]
Review of interstellar extinction & reddening; Cosmic dust & depletions; Formation & destruction of dust; Overview of grain components in the ISM: gas ratios, grain temperatures & size distribution; Scattering, absorption & grain charge

Molecules [5]
Brief revision of molecular spectra; Molecule formation (dark clouds); The chemistry of H_2: chemistry in diffuse clouds; Molecular gas in the intergalactic medium

PHAS3338 – Astronomical Spectroscopy (Term 1)

Prerequisites

This course is intended for students in the third year of Astronomy, Astrophysics or Mathematics and Astronomy degrees but might be taken by others with a suitable background. It is essential to have taken a second-year quantum course, such as PHAS2222 Quantum Physics. Students should normally also have taken PHAS2112 Astrophysical Processes. This course may not be taken in combination with PHAS2224 Atomic and Molecular Physics.

Aims of the Course

This course aims to:

- discuss the nature of spectral lines formed in astronomical objects
- extend the knowledge of atomic physics and to a lesser extent of quantum physics acquired in PHAS2222 and PHAS2112
- introduce basic ideas of molecular structure
- discuss the emission and absorption of radiation by atoms and molecules, concentrating on line radiation
- discuss the formation of emission and absorption lines in astronomical objects at all wavelengths from X-rays to radio, including excitation mechanisms
- provide the background required to understand astronomical applications of spectroscopy in other 3rd year and 4th year courses including observational astronomy practicals and lecture courses in astrophysics

Objectives

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

- identify astronomical spectral lines and interpret how they are formed
- outline the principles of the structure of atoms, including: electronic and nuclear angular momenta, the exclusion principle and electron shells; fine and hyperfine structure
- discuss the processes of emission and absorption of radiation by atoms, defining the oscillator strength and the Einstein coefficients, and including: recombination and ionisation; selection rules; forbidden transitions; fine and hyperfine structure transitions; autoionisation; inner shell transitions
- describe properties of atoms in magnetic fields and the resulting effects on their spectra
- explain the electronic, vibrational and rotational structure and spectra of diatomic molecules, including an outline of angular momentum coupling schemes
- outline types of polyatomic molecules and their spectra
- discuss astronomical applications of atomic and molecular spectroscopy, at all wavelengths from X-rays to the radio and in all types of object, indicating the types of result that can be obtained and including consideration of excitation mechanisms

Methodology and Assessment

The course consists of 30 lectures and 3 problem classes. The assessment is based on an unseen written examination (90%) and 4 problem sheets (10%).

Textbooks

- *Introduction to the Structure of Matter,* J.J. Brehm and W.J. Mullin *“”* (Wiley, 1989)
- *Astronomical Spectroscopy,* J Tennyson, (ICP, 2005)
- *Modern Spectroscopy,* J.M. Hollas (Wiley, 3rd Edition 1996)
- *Interpreting Astronomical Spectra,* D. Emerson (Wiley, 1996)

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

Hydrogen lines in nebular spectra; Energy levels for the hydrogen atom; The Balmer formula and spectral lines; Hydrogen in stellar atmospheres and envelopes; Photoionisation and recombination in nebulae; Recombination as an excitation mechanism; Recombination lines, optical and radio including nuclear mass effects [4]

Qualitative description of absorption and emission of radiation by atoms; Einstein coefficients, oscillator strength; Laser and maser processes [2]

Angular momentum; Addition of angular momenta; Electron spin; Helium atom; singlet and triplet splitting; Energy-level diagram; Helium spectrum in nebulae and stars: helium abundance [3]

Angular momentum in complex atoms; LS coupling; Spectroscopic notation; Configurations, terms, levels and states; Pauli exclusion principle; Shells and the periodic table; Selection rules; Forbidden transitions: intercombination lines [4]

Many-electron atoms; Screening and quantum defect; Alkali spectra; the sodium D lines; Isoelectronic sequences; Equivalent width and column density [2]

Spin-orbit interaction and fine structure; Excitation mechanisms and atomic fine-structure transitions; O^{2+} as an example of a complex ion, showing term and level structure and spectrum (IR fine structure, forbidden lines, Bowen optical allowed lines); Spectra of nebulae [2]

Molecules in stars, planets and the interstellar medium; Introduction to the structure of diatomic molecules; Rotational, vibrational and electronic spectra; Reduced mass and isotopic effects [5]

Outline of structure of polyatomic molecules; Rotational and vibrational spectra; Interstellar spectra of polyatomic molecules [3]

Spectra of atoms with two valence electrons; Autoionisation and dielectronic recombination [1]

Atoms in magnetic fields: weak and strong field cases; Astronomical applications; Nuclear interactions and hyperfine structure: optical spectra and 21cm radiation; Hyperfine effects in molecular spectra [3]

AGN and solar high-temperature spectra; X-ray spectra; Inner shell excitation; Auger ionisation; Highly-ionised atoms [1]

PHAS3400 - Physics Project BSc (Term 1 & 2)

Prerequisites

Normally PHAS2440 and PHAS2441 Practical Physics 2A and 2B, or PHAS2130 Practical Astrophysics 2A, or PHAS2442 Practical Physics 2C. Theoretical Physics students need to have done Mathematica courses instead of labs. High (60% or more) aggregated marks for years 1 and 2 are normally required.

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. Taken in their final year of study by some students following Physics-related BSc degrees, course PHAS3400 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 and periodically reporting on progress
- have further developed the reporting skills practised 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 usually 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 summarising progress.

Project Report: At the end of the project, each student must present a 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%

PHAS3424 – Theory of Dynamical Systems (Term 1)

Prerequisites

Good passes in PHAS2246 and preferably MATH6202 and PHAS2423 courses or equivalent. In particular students should have shown competence in linear algebra, differentiation, integration and solution of linear first and second order (constant-coefficient) differential equations.

Aims of the Course

This optional course aims to:

- Stretch mathematically-inclined students by presenting advanced material on the dynamics of classical systems. The second year modules MATH6202 and PHAS2423 would be an advantage but not a prerequisite
- develop Lagrangian and Hamiltonian mechanics for single particles and for fields
- understand the role of non-linearity in discrete and continuous equations of motion, particularly through the development of phase space portraits, local stability analysis and bifurcation diagrams
- show how non-linear classical mechanics can give rise to chaotic motion, and to describe the character of chaos
- develop ideas of scale-invariance and fractal geometry

Objectives

This course is primarily about classical dynamics, and is designed to stretch and inspire students who are interested in Mathematical Physics.

For Continuous Dynamical Systems, students should be able to:

- derive the Lagrangian and Hamiltonian using generalised coordinates and momenta for simple mechanical systems;
- derive the equations of energy, momentum and angular momentum conservation from symmetries of the Hamiltonian;
- derive and manipulate Hamiltonians and Lagrangians for classical field theories, including electromagnetism;
- derive and give a physical interpretation of Liouville's theorem in n dimensions;
- determine the local and global stability of the equilibrium of a linear system;
- find the equilibria and determine their local stability for one- and two-dimensional nonlinear systems;
- give a qualitative analysis of the global phase portrait for simple one- and two-dimensional systems;
- give examples of the saddle-node, transcritical, pitchfork and Hopf bifurcations;
- determine the type of bifurcation in one-dimensional real and complex systems;

For Discrete Dynamical Systems, students should be able to:

- find equilibria and cycles for simple systems, and determine their stability;
- describe period-doubling bifurcations for a general discrete system;
- calculate the Lyapunov exponent of a given trajectory and interpret the result for attracting and repelling trajectories;
- give a qualitative description of the origin of chaotic behaviour in discrete systems;
- understand the concept and define various properties of fractals

Methodology and Assessment

The course consists of 30 lectures and 3 examples classes. There are 4 problem sheets associated with the course, of which all contribute to the coursework credit. Assessment is based on the results obtained in the final examination (90%) and in homework problems (10%).

Syllabus

Continuous Dynamical Systems [18]
Hamiltonian dynamical systems; Symmetry and conservation in Hamiltonian systems; Liouville's Theorem; Local stability analysis; Bifurcation analysis for one and two-dimensional systems, including Hopf bifurcation; Examples

Discrete Dynamical Systems [12]
Iterated maps as dynamical systems in discrete time; The logistic map as main example; Equilibria, cycles and their stability; Period doubling, bifurcations; Simple random properties of chaotic trajectories; Lyapunov exponents*;* Fractal geometry

PHAS3427 - Climate & Energy (Term 2)

Prerequisites

An introductory course in thermodynamics, such as PHAS2228, or its equivalent.

Aim of the Course

The aim of the course is to provide an introduction to the science of climate change, the physics of energy generation and distribution by various means, and the possibility of intervening in the Earth's climate.

Course Objectives

Upon completing the course, students will have an appreciation of the basic science of climate change. Students will have a detailed and quantitative understanding of energy generation and distribution by various means. Finally they will have a familiarity with the potential impact and feasibility of various proposals for making interventions in the Earth's climate system.

In climate change, students should:

- understand the basic energy balance of the Earth's atmosphere
- understand the basic elements of the global carbon cycle and appreciate the relative sizes of natural and anthropogenic contributions
- have an understanding of some the most important means by which the Earth's climate history has been reconstructed
- be able to understand and weigh the evidence for anthropogenic climate change
- have some appreciation for other factors that can affect climate variability

In energy, students should:

- know the current level of green house gas emissions globally and by region/country in CO_2 equivalent tons per year per person. They should be able to distinguish between current rates of emission and historic (or integrated) rates of emission
- understand the science underlying power generation by thermal sources, hydro, tidal and wave power, wind power, solar energy, biomass, nuclear fission and fusion, and the operation of a power grid
- understand for each source the environmental impact, the economics and prospects. The costs and the CO_2 emissions should be known for each installed and generated megawatt of power
- appreciate how this knowledge can be used to determine an energy strategy for the UK and further afield

In climate intervention, students should:

- become acquainted with the science of carbon capture and sequestration
- understand the leading proposals for intervening in the Earth's climate through carbon dioxide removal
- understand the leading proposals for intervening in the Earth's climate through solar radiation management

- appreciate the difficulties inherent in any climate intervention: the technological challenges, the timescales and costs involved and the possible undesirable side-effects of any intervention

Methodology and Assessment

The course consists of 33 lectures. Assessment is based on an unseen written examination (90%) and 4 coursework problem papers (10%).

Textbooks

Global Warming – A Very Short Introduction, M. Maslin (Oxford 2009)
Energy Science – principles, technologies and impacts, J. Andrews & N. Jelley (Oxford 2007)
Sustainable Energy – without the hot air, D. MacKay (UIT 2009 – also freely available online)
Renewable Energy in Power Systems, L. Freris & D. Infield (Wiley 2008)
Geoengineering the climate, report of the Royal Society 2009 (freely available online)

Syllabus

The course is divided into eight sections. The *approximate* assignment of lectures to each is shown in brackets.

1. Climate Change (4)
The energy balance of the Earth's atmosphere; the global carbon cycle; the climate record; the evidence for anthropogenic climate change; the basic physics of the greenhouse effect; climate modelling and uncertainties on future predictions

2. Energy Science (3)
Brief history of energy technology; green house emissions globally and by region in tons of CO_2 equivalent per person per year; historically integrated emissions; energy & power units; energy requirements from transport, domestic heating & cooling, food production and industry

3. Energy Production (3)
Heat, temperature and the First Law of Thermodynamics; the Carnot cycle and its efficiency; gas turbines and the Brayton cycle and its efficiency; the Stirling cycle and its efficiency; the thermal properties of steam and water; the Rankine cycle and modern steam turbines; fossil fuels, their energy content and CO_2 emissions per megawatt; EEP - Environmental Impact, Economics and Prospects for existing generation capacity and prospective energy sources

4. Renewable Energy Sources (8)
Hydroelectric power; essential fluid mechanics to calculate yields from tidal and wave power; power output from a dam; water turbines - the Pelton wheel and the Fourneyron turbine; tidal power and tidal resonance; wave energy and wave power devices; wind power and modern wind turbines; principles of operation of horizontal wind turbines; wind turbine blade design; on-shore and off-shore wind farms; solar energy; the solar spectrum and intensity; photovoltaics; solar thermal power plants; biomass; photosynthesis and crop yields

5. Nuclear Power (4)

Energy from fission; fissile nuclei and delayed neutrons; energy released per fission, the four factor formula and reactor control; gas and water cooled reactors currently operating in the UK; proposed fission reactor designs : the EDF AREVA and the Toshiba-Westinghouse design; reactor safety; global uranium resources; accelerator or neutron source initiated fission reactors; energy from fusion; the D-T reaction; magnetic vs. inertial confinement

6. Electricity Generation, Transmission and Storage (2)

Modern AC generators; AC and DC transmission; the power grid; transformers, rectifiers and inverters; batteries; fuel cells

7. Energy: The Future (3)

Prospects for more efficient transport and heating schemes; energy strategies for the UK; energy plans for Europe, America and the World

8. Climate Intervention (6)

Carbon capture and storage at source; carbon dioxide removal; removing CO_2 from the air; ocean fertilisation; biomass fixing; solar radiation management; increasing cloud albedo; stratospheric aerosols; feasibility, effectiveness, costs & risks of each approach

PHAS3440 - Experimental Physics (Term 1)

Prerequisites

Normally PHAS2440 – Practical Physics 2A; PHAS2130 – Practical Astrophysics 2A; or PHAS2442 – Practical Physics 2C

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. Course PHAS3440 is intended for students following Physics degree programmes, and aims to build on and extend the skills acquired in First and Second Year Laboratory courses via the following objectives:

Objectives

At the end of the course you should:

- Have improved your skills and your confidence in the acquisition and analysis of experimental data through the performance of one lengthy extended experiment with more complex instrumentation
- Have built further on the skills you have acquired in first and second years to record your work concisely and precisely in your laboratory notebook, ***as you perform it***
- Have further improved the skills acquired in first and second years to condense the information contained in the record that you have made in your laboratory notebooks into a concise, but precise and complete formal report of the experiment in word-processed form
- Have further practised skills acquired in the first two years in the identification and propagation of experimental uncertainties and been introduced to confidence intervals, hypothesis testing based on   analysis and maximum likelihood analysis
- Be acquainted with some of the principles underlying the design of electronic systems from simple single function blocks, and have some experience of the practical aspects of their construction using integrated circuits

Course Contents

Long experiment: A single long physics laboratory experiment lasting for five weeks. This takes place in the third year laboratory. Each experiment is supported by a folder containing a description, guidance and references.

Short course in electronics: A series of tasks divided into two experiments is performed, to introduce the student to the use of stabilized power supplies and integrated circuits to build complex systems. In the first experiment the stabilized power supply needed for the system is also developed. In the second a digital thermometer is constructed using a range of electronics needed to convert the analogue signal from the transducer (thermistor) to a digital display of temperature.

Formal report: A formal report written on the subject of the long experiment.
Treatment of experimental data: Students work through a set of instruction notes independently at their own pace. Two problem papers are set.

Methodology and Assessment

Assessment is continuous. In the laboratory sessions, students work for about 10 sessions on one long experiment and for 10 sessions on the electronics short course. Unlike experiments in the First and Second year Labs, students working on their long experiments are not given prescriptive scripts to work from, but rather dossiers of information which fall short complete prescriptions. Information is prescriptive where necessary, for instance where safety or the correct operation of equipment is involved, but in other respects good progress depends on the student seeking out additional information, either by discussion with demonstrators, expert technical advice in the Department, or from the literature. Demonstrators exercise looser supervision than in First and Second Year labs but are on hand to help students understand experiments, overcome difficulties as they arise and check that lab books are being properly kept (with one demonstrator per 10 to 12 students). At the end of the long experiment students prepare a formal report based on the record kept in the laboratory notebook. The advice given to students on good practice in the keeping of the lab notebook and the preparation of the formal report is the same as that given in the earlier year laboratories, but their application is in the more demanding context of the long experiment.

For the Treatment of Experimental Data component, students work independently outside formal class, through an instruction text designed to introduce the new techniques. The Lab Course Supervisor holds tutorials for any students who request individual help. Assessment is by two problem sheets set during the course.

All assessed work is both first and second marked. The different course components contribute the total assessment with the following weights.

- Long experiment; 35%
- Formal report; 15%
- Electronics; 40%
- Treatment of experimental data problem sheets; 10%

Textbooks

There are no textbooks which the students are expected to buy. The following are provided for reference in the laboratory and the students are expected to consult them to find relevant information required in experiments.

- *Table of Physical Constants, Kaye and Laby*.
- *Handbook of Chemistry and Physics*, CRC Press
- *Measurements and their Uncertainties: A practical guide to modern error analysis*, Hughes and Hase, OUP

PHAS3441 – Physics Group Project (Term 2)

Prerequisites

Normally (not Theoretical Physicists) PHAS2440 Practical Physics 2A and PHAS2441 Practical Physics 2B, or PHAS2430 – Practical Astrophysics 2A, or PHAS2442 – Practical Physics 2C.

Aims of the Course

The course aims to teach students to function effectively as a member of a project team in a group situation simulating the kind of working environment they will encounter in the course of their professional careers, whether as physicists or in other fields.

Objectives

Through (a) an initial 1.5-day training session, and (b) working within a group of generally 5 - 7 peers for a period of eleven weeks, the students accomplish a significant and challenging technical task. Specific skills to be developed and practised include:

- understanding group roles and how groups work
- project management skills
- working successfully within constrained resources
- communicating effectively both orally and in writing
- setting and meeting deadlines
- working effectively as a team
- running, and participating effectively in, meetings
- generating and critically assessing ideas
- problem solving
- planning and setting priorities
- decision making
- negotiating skills
- risk identification and assessment
- presentational skills
- report writing

Course Contents

Project: Each group will have an assigned team project, produced by the organisation that has commissioned the group to undertake the task, and which will form the basis of the scientific work on the project.

Initial Meeting: Each team should arrange as soon as possible in the last week of term before Christmas a meeting with the Board Member who is the agent appointed by the group that has commissioned the project. At the first meeting with the Board Member, students should familiarise themselves with the nature of the project, the background to it, the kind of work that they will need to do to successfully complete it, intermediate milestones that may be set by the agent, the resources available to their group, source material, and other information that they feel they need to begin their work.

Organisation of the work: This is up to the team to decide. Students may find it sensible to identify sub-tasks that individual members might tackle and report back on to the group (the Board Member may have suggestions, but it is students' responsibility as a team to decide on any sub-tasks). However students break down the work, they will need mechanisms to ensure effective communication, both within the group and with their Board Member. Students will also need to set up, and observe, appropriate deadlines.

Meetings with Board Members: The course requires groups to hold meetings with their Board Member approximately fortnightly. Groups will be penalised if they hold fewer than 5 such meetings, including the initial one. At these project meetings, groups will be required to report on progress, raise any problems, and set up actions and milestones for the following work period. Each team will be responsible for preparing and circulating appropriate documents in advance of the meeting, including agendas, and for making and keeping an adequate record of the meetings, including any action lists. Although your Board Member will act as Chairman for the initial meeting, students should decide on a chairman and secretary for the second meeting. Copies of all documentation of these meetings must be submitted as an appendix to the final written report. All team members are expected to attend all of these project meetings. Attendance must be recorded and any unavoidable absences covered by apologies in advance with reasons, and actions taken to ensure that the absence of a team member does not adversely affect the conduct of any meeting.

Mid-term Review: One of the aims of the course is to help students to operate effectively in a variety of ways as a member of a team undertaking a significant task. As part of this process, half way through the term, each team will be commissioned to review the operation of one of the other groups. This review will take place in week 6 and a one (A4) page report on group findings must be with the Board Member of the team being reviewed, and the Course Coordinator one week later.

Final written report: All members of the team must contribute to this report, with authorship identified in the various sections. More details on the kind of report expected will be explained at the start of the course.

Final oral presentation: The final oral presentations of all teams will take at the end of the Spring Term in the Massey Theatre. Again, all members of each team must contribute to preparing, and take part in, this presentation. More details on the kind of presentation expected will be given.

Assessment: Students will be assessed both on the performance of their team in achieving its task, and on their individual performance as a member of the team. Methods of assessment to be used include continuous assessment during the term, the final written report, and the final oral presentation. Each team will also be asked to produce a critical assessment of its own performance, which should be no more than one A4 sheet, and be given to the Course Co-ordinator. This document should include the group's assessment of the contribution of each individual team member.

Prize for Best Presentation: A prize will be awarded on the day for the best presentation by any of the teams. This is awarded after the presentations following a vote of all the Board members.

PHAS3443 – Lasers and Modern Optics (Term 2)

Pre-requisites

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

Aims of the course

The aim of the course is to:

- provide a useful and exciting course on lasers and modern optics with insight into non-linear processes and modern applications of lasers.

Objectives

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

- derive the matrices for translation, reflection and refraction
- explain the paraxial approximation and ray tracing in thick optics
- do optical calculations on model and real optical systems
- explain the role of A and B coefficients in laser action
- derive the equations for a 4-level laser and solve to obtain the population invasions
- describe the principles of Q-switching and mode locking
- describe the processes of obtaining a population in version in He-Ne, Ruby, and NH3 lasers
- explain the nature of coherence in ordinary light and laser light and derive the formula of the first order correlation
- explain the principles of Gaussian optics
- derive the stability condition for optical resonators
- calculate laser beam focussing properties in real systems
- describe the physical principles of non-linear optical behaviour and harmonic generation
- describe the physical processes of electro-optic, magneto-optic and acousto-optic effects
- derive the formulae for polarisation rotation in crystal material
- describe the use of electro-optic derives in laser systems
- describe and apply Fresnel's equations to refraction
- derive the formulae giving the mode propagation in a semi-infinite slab of dioelectric
- describe the propagation of light in a fibre optic and the effects of aperture and dispersion

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. The assessment is based on an unseen written examination (90%) and continuous assessment (10%). The continuous assessment mark is determined using the four problem sheets.

Textbooks

- *Introduction to Electro-optics,* Hawkes & Wilson (Prentice-Hall 1993)
- *Introduction to Optics,* Pedrotti and Pedrotti (Prentice-Hall 1984)

The students are advised to purchase a copy of Hawkes & Wilson, as this is a major source of material for the course.

Syllabus

Matrix optics [5]
Application of matrix methods in paraxial optics; translation and refraction matrices; ray transfer matrix for an optical system; derivation of the properties of a system from its matrix; extension of ray transfer method to reflecting systems

Laser principles [7]
Stimulated emission, Einstein coefficients, amplification coefficients; Threshold condition; Saturation behaviour, homogenous and inhomogeneously broadened transitions; Rate equations, 4-level laser, dynamic behaviour; Q-switching, laser resonator modes; Mode locking; Description of specific lasers; ruby, dye He-Ne, CO_2, NH_3 semiconductors; Coherence concepts

Gaussian beams [3]
Illustrative examples, including stability criteria for optical resonators and beam matching systems; Ray matrix analysis

Electro-optics[5]
Review of crystal optics; The electro-optic effect - amplitude and phase modulation via the electro-optic effect; Magneto-optic and acousto-optic effects; Applications to switching

Nonlinear optics [5]
Examples of nonlinear optical behaviour - optical harmonic generation, optical parametric oscillation; Analytical treatment of nonlinear optical phenomena

Guided wave optics [5]
Optical fibre waveguides; Waveguide modes; Mode losses, dispersion; Single-mode and multi-mode guides; Optical fibres; monomode and multimode, step-index and grades; loss mechanisms and bandwidth limitations

PHAS3444 – Practical for Natural Science (Term 1)

Prerequisites

PHAS2444

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. Course PHAS3444 is intended for Natural Science students following the Physics stream, and aims to build on and extend the skills acquired in First and Second Year Laboratory & Computing courses via the objectives shown below.

Objectives

At the end of the course you should:

- Have improved your skills and your confidence in the acquisition and analysis of experimental data through the performance of one lengthy extended experiment with more complex instrumentation
- Have built further on the skills you have acquired in first and second years to record your work concisely and precisely in your laboratory notebook, ***as you perform it***
- Have further improved the skills acquired in first and second years to condense the information contained in the record that you have made in your laboratory notebooks into a concise, but precise and complete formal report of the experiment in word-processed form
- Have further practised skills acquired in the first two years in the identification and propagation of experimental uncertainties and been introduced to confidence intervals, hypothesis testing based on analysis and maximum likelihood analysis
- Grasped basic principles of computer programming and be able to apply the Mathematica algebraic language and the Matlab programming language to a range of physical problems and data analysis tasks

Course Contents

Long experiment: A single long physics laboratory experiment lasting for five weeks. This takes place in the third year laboratory. The experiment is supported by a folder containing a description, guidance and references.

Formal report: A formal report written on the subject of the long experiment.

Treatment of experimental data: Students work through a set of instruction notes independently at their own pace. A problem paper on data analysis forms part of the assessment for the course.

Mathematica/Matlab: Students work under supervision through a series of exercises which introduce them to the capabilities of Computer Algebra Systems and mathematical packages with programmable capabilities. Topics covered include; algebraic capabilities, differential and integral calculus, numerical procedures, matrix manipulations, simultaneous equations and eigensystems, differential equations and boundary conditions, numerical solutions of algebraic, transcendental and differential equations, functions, modules and procedures, programming styles (procedural and functional), implicit and explicit loops, recursion, and graphical procedures. Examples are drawn from a range of physical problems.

Methodology and Assessment

In the laboratory sessions, students work for about 10 sessions on one long experiment and for 10 sessions on the computing component. Unlike experiments in the First and Second year Labs, students working on their long experiments are not given prescriptive scripts to work from, but rather dossiers of information which fall short complete prescriptions. Information is prescriptive where necessary, for instance where safety or the correct operation of equipment is involved, but in other respects good progress depends on the student seeking out additional information, either by discussion with demonstrators, expert technical advice in the Department, or from the literature. Demonstrators exercise looser supervision than in First and Second Year labs but are on hand to help students understand experiments, overcome difficulties as they arise and check that lab books are being properly kept (with one demonstrator per 10 to 12 students). At the end of the long experiment students prepare a formal report based on the record kept in the laboratory notebook on which they are assessed. The advice given to students on good practice in the keeping of the lab notebook and the preparation of the formal report is the same as that given in the earlier year laboratories, but their application is in the more demanding context of the long experiment.

For the Treatment of Experimental Data component, students work independently outside formal class, through an instruction text designed to introduce the new techniques. There is an introductory lecture given before the first session and this is followed by informal group meetings during the first experimental session. Assessment is a problem sheet on data analysis.

In the Mathematica/Matlab component students work singly at a computer terminal and are assessed on the basis of problem sheets.

The different course components contribute the total assessment with the following weights.

- Formal report; 40%
- Data Analysis coursework; 10%
- Computing component; 50%

Textbooks

There are no textbooks which the students are expected to buy. The following are provided for reference in the laboratory and the students are expected to consult them to find relevant information required in experiments.

- *Table of Physical Constants*, Kaye and Laby
- *Handbook of Chemistry and Physics*, CRC Press
- *Measurements and their Uncertainties: A practical guide to modern error analysis*, Hughes and Hase, OUP

PHAS3447- Materials and Nanomaterials (Term 2)

Prerequisites

It is recommended, but not mandatory, that students should have taken PHAS1228 – Thermal Physics and PHAS2228 – Statistical Thermodynamics.

Aims of the Course

The aim of the course is to provide students with:

- Knowledge and understanding of the mechanical, electrical, magnetic and optical properties of a variety of materials, including metals, ceramics, polymers, composites, nanostructured materials and nanocomposites
- Knowledge and understanding of the relationship between material properties and the microstructure

Objectives

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

- Understand the relationship between interatomic potentials and the properties of metals, ceramics and polymers
- Describe point, line and surface defects in crystals and discuss their role in controlling the mechanical, electrical and magnetic properties of materials
- Explain the role of dislocations in plastic deformation and strengthening mechanisms used to counter it
- Explain the atomistic mechanisms involved in fracture, fatigue and creep and use fracture mechanics to calculate the critical stress
- Explain how the exceptional mechanical properties of nanostructured materials relate to microstructure
- Sketch and interpret phase diagrams and use them to determine phase compositions and equilibrium microstructures
- Sketch and interpret isothermal transformation diagrams and understand the shape in relation to nucleation and growth mechanisms
- Sketch and describe the microstructures of eutectoid steels and the relationship with the mechanical properties
- Describe the mechanical properties of superalloys and nanostructured alloys and explain the properties in terms of the atomistic mechanisms
- Explain the properties of ceramic materials in terms of crystal structures and bonding
- Explain the relationship between the exceptional properties of carbon nanotubes and the atomic structure, and discuss potential applications
- Describe and explain the structure and properties of amorphous and semicrystalline polymers
- Define elastic, plastic and elastomeric polymers, sketch the stress-strain curves and explain in terms of the atomistic mechanisms
- Describe and calculate the properties of composite materials
- Explain the exceptional properties nanocomposite materials
- Define and discuss the stability of colloids
- Explain the electrical properties of conductors, semiconductors and insulators

- Describe the magnetic properties of hard and soft magnetic materials and the relationship to the microstructure
- Describe the properties of magnetic memory materials and give examples
- Describe and explain the optical properties of metals and non-metals, including the refraction, colour, opacity, translucency and luminescence

Methodology and Assessment

This is a half-unit course, with 30 lectures and 3 discussion/problems classes. Progress during the course is monitored through three problems sheets handed out at the beginning of weeks 3, 6 and 9, and collected at the end of weeks 4, 7 and 10. The marks on these problem sheets account for 10% of the overall course assessment. The remaining 90% is determined via an unseen written examination.

Textbooks

Most of the course material is covered in:

- *Material Science and Engineering: An introduction*, 7th Edition, W.D. Callister Jr., Wiley 2007

Other books which may be useful include the following. In most cases they cover more material than is in the syllabus.

- *Engineering Materials 1: An introduction to their properties and applications,* 2nd Edition, M.F. Ashby and D.R.H. Jones, Butterworth and Heinemann, 1996
- *Engineering Materials 2: An introduction to Microstructures, Processing and Design,* 2nd Edition, M.F. Ashby and D.R.H. Jones, Butterworth and Heinemann, 1998
- *Introduction to Dislocations*, D. Hull and D.J. Bacon, Butterworth and Heinemann
- *Introduction to magnetism and magnetic materials*, D C Jiles, Chapman and Hall (1991)
- *Introduction to the electronic properties of materials*, D C Jiles, Chapman and Hall (1994)
- *Introduction to polymers*, 2nd ed., R J Young, Chapman and Hall (1991)
- *An introduction to composite materials*, D Hull, Cambridge University Press (1981)

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

Background [5]
Introduction to material science and nanomaterials: structure and bonding, defects, diffusion

Microstructure and mechanical properties of metal alloys [10]
Mechanical properties: elastic and plastic deformation, strengthening mechanisms Failure, fracture, fatigue and creep; Mechanical properties of nanostructured materials; Phase diagrams: binary isomorphous and eutectic systems, iron-carbon phase diagram: Microstructure in steels; Phase transformations; Alloys: light alloys, superalloys, nanostructured alloys

Non-metallic materials [9]
Ceramics: structure, properties, processing, glasses, carbon nanotubes; Polymers, structure, properties, processing, thermoplasts, thermosets and elastomers, viscoelasticity;

Composites, particle reinforced and fibre reinforced composites, nanocomposites Colloids, examples, stability, gels

Functional properties of materials [6]
Electrical properties: conductors/semiconductors/insulators, ferroelectrics, piezoelectrics; Magnetic properties: hysteresis, hard/soft magnetic materials, magnetic memory; Optical properties: opacity and translucency, luminescence, fibre optics, photonics

PHAS3459 – Scientific Programming using Object Orientated Languages (Term 1)

Prerequisites

Students are not expected to be familiar with a programming language, although prior exposure is beneficial. The initial modules will cover the basics. Students are expected to be adept at using a PC environment (logging on, use of windows, e-mail, WWW etc.). Course information and notes will be provided via the Web and work will be submitted entirely electronically.

Aims of the Course

The course aims to:

- give the student an introduction to the use of object-oriented (OO) programming in the context of physics data handling and analysis situations;
- give the student sufficient programming expertise to be able to design and implement simple analysis programs such as would arise in 3rd year laboratories and 3rd and 4th year project work.

The programming exercises will use the Java language.

Objectives

The objectives of the course have three broad categories:

1) Basic program control & OO concepts/design
The student will become familiar with the following OO programming concepts, which are used widely in all OO languages:

- in-built data types and their manipulation
- algorithm steering elements
- user-defined data types: classes and objects
- manipulation of objects using methods
- constructors and destructors
- polymorphism / method overloading
- inheritance, abstract methods and interfaces

2) Implementing the most widely used Java programming tools
The student will become familiar, using the Java language, with the code and concepts, required to:

- input and output data (to screen and files)
- organise lists and other collections of objects using Java collections
- handle program exceptions
- create a multi-threaded application
- create a simple graphical interface

3) Program Design and Applications
The student will become familiar with:

- how Java runs programs: JVM
- Java packages, jar files
- constructing a multi-faceted program
- applying programming concepts to physics analysis and modelling situations

Finally the student will have a working knowledge of the principal differences between OO programming using Java and using the C++ language.

Methodology and Assessment

The course is taught in two three-hour sessions per week for 11 weeks. The majority of the time in the course will be devoted to hands-on practice on the computers. The course will be assessed as follows: (i) 25% - the completion of exercises to be performed during the sessions and in the student's own time; (ii) 25% - a test (taken approximately 2/3 the way through the course) comprising multiple-choice questions and a programming exercise; (iii) 50% - a test in the final week of term, which will involve a more extended programming exercise. All of these tests are practical 'on-line' computing tasks that will be taken during the time-tabled lecture times. There is no 'off-line' written examination in term 3.

Textbooks

There is no single recommended textbook for this course. A list of suggested books is available on the course web site. However, in making a choice one should bear in mind that computing books are often expensive and in the case of Java books fall into three categories: ones for the absolute beginner (only covering the material in the first four weeks of the course); ones for the already expert programmer (covering applications e.g. network, database, XML) and ones which concentrate purely on the Java graphical interfaces at the expense of covering the key OO concepts. The entire material for the course is generally covered in more than a single book. There are also many useful (and less useful) sources of information on the Web.

Syllabus

The course is divided into modules, as follows:

Module 1: Introduction & Getting Started [Week 1/2]

- Course introduction: aims and objectives; course format; course assesment; exam format; course personnel
- Editing, compiling and running programs: using the Eclipse IDE.
- What is OO programming?
- Basic coding concepts/structures
    - built-in types: int, float etc
    - functions
- Algorithm control:
    - branching: if, else…
    - loops: for, while…

Module 2: User defined data types: classes, encapsulation, polymorphism [Week 2/3]

- Defining a user class: concepts, syntax and methods
- Encapsulation; public and private methods and variables
- Static methods
- Contructors
- Method overloading: polymorphism
- Data types as objects: Integer, Float, String etc
- Converting types: casting
-

Module 3: Input/Output of data (to screen/file) [Week 3]

- Reading input from user: System.in
- Getting data into and from files: FileReader/Writer; BufferedReader/Writer
- Manipulating data using tokens: StringTokenizer

Module 4: Handling Exceptions [Week 3/4]

- What are exceptions?
- Rules/syntax for using exceptions: throw(s), try, catch, finally
- Strategy for dealing with multiple exceptions

Module 5: Manipulating Objects: Storing (Collections), Copying, Checking for Equality [Week 5/6]

- Storing multiple items
- Arrays: int[], float[]
- Parameter passing to functions:
    - primitive types vs objects ("pass-by-value")
    - changing the contents of an object via a function call
- Mutable/Immutable Objects
- Java collection classes: lists, set, maps
- Vector class
- Looping over collections: Enumeration, Iterator
- Hashtable class
- The null object
- Copying Objects: clone()
- Testing for equality of two Objects: ==; equals()

Module 6: Inheritance, Abstract Methods,Interfaces [Week 7/8]

- Inheritance: extends
- Abstract methods and classes
- Interfaces: implements

Module 7: Building Larger Programs [Week 9]

- How Java runs programs: JVM
- Splitting code into packages: package; import
- The core Java utility classes.
- Design rules for building a multi-faceted program
- Using pre-defined patterns e.g. singleton
- Applying this to real-case physics examples

Module 8: Useful Java classes for application programming: Threads, Graphics (Applets) [Week 10]

- Executing separate pieces of code as separate entities: Thread class
- Thread lifecycle
- Defining/running a thread
- Synchronising and Prioritising multiple threads: synchronized,
- Introduction to applets
- Building a simple graphical interface using the java.awt classes
- Physics applets

Module 9: Differences between Java and C++ [Week 10]

- Key differences between Java & C++
- Quick overview of C++ syntax
- Pros/Cons of C++ vs Java

PHAS3661 – Physics of the Earth (Term 1)

Prerequisites

Students taking the course will require a background in mathematics to first year standard. The course will require an understanding of partial differentiation, vector calculus and spherical harmonic representation of potential fields.

Aims of the Course

This course aims to introduce Physics undergraduates to the subject of Global Geophysics with the emphasis on the application of mathematical and physical principles to understand the large scale structured evolution of the Earth's surface, its deep interior and its climate.

Objectives

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

- understand how simple measurements may be used to determine the mass and density of the Earth
- calculate how the strength of and direction of Earth gravity's varies with latitude due to its rotation and shape
- understand how to represent the Earth's gravity field using spherical harmonic expansion and how subtle changes in gravity can provide insights into the Earth's near surface and subsurface structure
- using the principle of isostacy derive expressions for thickness of the lithosphere beneath mountain ranges and ocean basins
- show how Earth's magnetism may be used to determine rates of continental drift and how past plate motions relate to tectonic structures on the ocean floor
- understand the mechanisms of Earthquake generation and show how the seismic waves they produce can provide quantitative information about the structure of the Earth's interior
- show how the early evolution of the solar system may be used to gain insight into the composition of the Earth
- show, by deriving an expression for the planetary equilibrium temperature, that a natural greenhouse effect exists and that the emission of various man made gases may enhance this effect
- understand what drives the climate system and the basic interactions between its different elements
- understand how satellites can contribute both to studies of solid Earth geophysics and to monitoring the climate system

Methodology and Assessment

This is a half-unit course, with 27 lectures and 3 discussion classes. There will be 3 hours of Problem-Solving Tutorials and 3 continuous assessment papers, with 3 questions in each. Lecture notes are provided on Moodle. The marks from the Problem Classes/homeworks will account for 10% of the marks for the course, with the remaining 90% coming from the unseen written examination.

Textbooks

- *The Inaccessible Earth*, Brown and Husset, Chapman & Hall, 1995
- *The Solid Earth*, Fowler, Cambridge University Press, 1993

Syllabus

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

Earth mass and density [3]

Gravitational Potential, Gravitational potential of a sphere, Mass and density of the Earth, Experiments of Nevil Maskelyne, Experiments of Von Jolly, Satellite determination, Precession and Nutation

Earth Gravity [9]

Figure of the Earth/Earth rotation/Deflection of the vertical, Gravitational potential/Laplace's equation, Spherical harmonic representation/Moments of inertia. Geopotential/Clairault's theorem, International gravity formula, Measurements of gravity, Etovos/Free air/Bouguer corrections, Isostatic compensation/Postglacial rebound, Gravity anomalies, Satellite measurement of J2, Satellite altimetric geoid

Earth magnetism and plate tectonics [3]

Earth's magnetic field/Secular variation, Magnetic reversals, Remnant magnetism; Paleomagnetic pole drift, Ocean floor magnetisation/age/spreading, Continental drift, Mid-ocean spreading ridges/subduction/fracture zones, Measurement of plate motions, Driving forces for plate motion

Earthquakes [1]

Types of wave; Nomenclature of body waves, Earthquake mechanisms, Location of deep and shallow earthquakes, Earthquake magnitudes; Comparison with underground nuclear tests

Seismology [6]

Waves and vibrations in solids, Seismographs and arrays, Travel time curves, Seismic ray parameter, Effects of layering, Major subdivisions of Earth, Velocity depth derivation

Origin of the Solar system [2]

Models for the formation of the solar system, Origin of the elements Meteorite types and compositions, Chemical fractionation, Accretion and chemical layering of planets, Age determination by radioactive decay processes

Earth's Climate [3]

Planetary Equilibrium Temperature, Greenhouse Effect, Earth's Climate System, Oceans, Cryosphere

Applications of radar altimetry to geophysics and climate [3]

Mission instrument design, Operating frequency & mode, Radar equation, Pulse compression, Extraction of ocean parameters, Orbit pattern, Oceanographic applications Solid Earth applications, Non-Ocean applications.

03MA0075 – Mathematical Education for Physical & Mathematical Sciences (Term 1)

Course description and objectives

The objective of this course is to introduce students - typically maths or physics undergraduates – to central ideas of mathematical education. These ideas include:

- theories of learning mathematics
- the nature of mathematics in various curricula
    - in particular the relationship between mathematics, physics and 'science' in school curricula in England and, by comparison, other countries
- schooling and schools
- pedagogy of mathematics teaching
    - issues in physics teaching: moving from 'science' GCSE to 'physics' A level
- research in mathematical/science education

A further objective is to offer insights into teaching as a career and to facilitate opportunities for students to have some school experience. To this end, students intending on enrolling on this course are encouraged to apply to participate concurrently in the 'Students' Associates Scheme' (SAS) at "level 2" organised through Institute of Education. School-based work required by the SAS forms a natural basis for the coursework component of the assessment for this course. Students not participating in the SAS shall have different coursework options.

Recommended texts

- Bramall, S. & White, J. (2000) *Why Learn Maths?* London: Institute of Education
- Goulding,M.(2004) *Learning to teach Mathematics in the Secondary School* 2nd ed. London: David
- Haggarty, L. (2002) *Aspects of Mathematics Education* London: Routledge & Falmer

Detailed syllabus (provisional)

Learning about learning mathematics

- Starting from here: learning undergraduate mathematics. Concepts, processes, fluency, symbolism, working memory, affect
- Case study: Stokes's theorem – conceptualisation through physical concepts and/or through mathematical structural thinking
- Experience: reflection on own thinking while doing a mathematical task

What is mathematics as represented in various curricula?

- History of mathematics curricula in England and another example (perhaps Hungary, Scotland or China)
- Relations between mathematics and science in school curricula in England: what is 'advanced physics' without calculus?
- National Curriculum Mathematics in England today

Mathematics, tools, teaching and learning

- Brief history of interface of mathematical development and tool development
- Computers for thinking, teaching and learning
- Experience: a technological environment and mathematical/science tasks

Teaching mathematics and physics

- Teaching methods; teachers' beliefs; Similarities and differences between physics (science) and mathematics teachers
- Pedagogical knowledge for mathematics teaching
- Assessment, assessment, assessment

Learning mathematics

- Theories of learning and their evolution
- The brain and mathematics
- Misconceptions and particular special needs (what can go wrong)

Sociology and mathematics or science education

- Who *does* do mathematics/physics? Issues of race, class and gender
- The concept of inclusion in present government policy
- Socio-cultural theories of thinking about mathematical education

Teaching Mathematics or physics in schools

- What it feels like to teach maths to kids every day: communication, learning from them
- Accountability: Ofsted, governors, parents
- Experience: extra-curricular mathematics

Language and culture within mathematics education

- Context and learning mathematics; language issues
- Theories of situated learning and meaning
- On the nature of abstraction - as in mathematics or physics - and learning

Research in mathematics education

- Comparing a pair of research reports in mathematics or science education: learning to read and critique
- What is true? Different conceptions of the nature of truth
- What do you want to know about mathematical/physics education? Questions to/for research

Review

- Coursework preparation
- Examination preparation
- Other issues

Examination

There will be a two-hour examination in May.

Coursework

Coursework for this module is a 2000 word paper due in May. The aim is that you produce a thoughtful and self-revised piece of written work that engages you in reflective interrogation of an educational issue, relevant to mathematics or physics/science. The paper should present a clear argument for a proposition and show an understanding of differing opinion by a synthesis of evidence, literature and your own views.

Website http://mathsed.mst-online.org/