DEPARTMENT OF PHYSICS AND ASTRONOMY

2nd Year
Course Descriptions

2015/16

INTRODUCTION

This handbook contains details about all the constituent courses for 2nd year full-time undergraduate programmes which are planned to be offered by the Department of Physics and Astronomy in 2015/16. 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 2015/16.* 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 course(s), please contact Departmental Programme Tutor, Dr S Zochowski.

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

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PHAS2112 – Astrophysical Processes: Nebulae to Stars (Term 2)

Prerequisites

In order to take PHAS2112 Astrophysical Processes: Nebulae to Stars, the student should normally attend PHAS2222 Quantum Physics and PHAS2228 (Statistical Thermodynamics)

Aims of the Course

This course aims to:

- Provide an introduction to a range of important physical processses that operate in astrophysical environments, including the photoionization and recombination of atoms; heating and cooling mechanisms in nebulae and the interstellar medium; the formation of absorption lines; radiative transfer and energy transport, the equations of stellar structure and the Virial theorem; and fusion and other nuclear processes that operate in stars

Objectives

After completion of this course students should be:

- Equipped with knowledge of the basic physical processes and astrophysical concepts that underline subsequent courses on the interstellar medium, stellar atmospheres and stellar structure and evolution.

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

Textbooks

- *The Physics of the Interstellar Medium* (2nd Edition, J.E. Dyson & D.A. Williams, Institute of Physics Publishing, 1997)
- *Astrophysics I. Stars; II. Interstellar Matter & Galaxies* (R. Bowers & T. Deeming, Jones & Bartlett, 1984)
- *The Stars: their structure and Evolution* (R.J. Tayler, Cambridge Univ. Press, 1994)

Syllabus

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

Radiation and Matter [6 lectures]

Basic description of fluxes and intensities: relationship to magnitudes; Moments of the radiation field; Atomic transitions: opacity and optical depth; Absorption & emission coefficients; source function; equation of transfer along a ray; Summary of distributions (black-body, Boltzmann, etc)

Interstellar Medium [6 lectures]

Basic composition (gas and dust); Line broadening in the interstellar context (natural, thermal, turbulent); Curve of growth; abundances

Ionized Nebulae [4 lectures]

Physical conditions; Diagnostics of temperature and density (excitation of optically thin emission lines); Ionization equilibrium; basic derivation of 'Stromgren Sphere'; Free-free radio continuum

Stellar Physics [5 lectures]
Local Thermodynamic Equilibrium; Equations of state; Hydrostatic equilibrium; Radiation pressure, Eddington limit; Virial theorem, stellar timescales

Nuclear Processes [6 lectures]
PP chains; CNO cycles; 3-α processes, and late stages of burning; Neutron capture (*r* and *s* processes); Supernovae

PHAS2117 – Physics of the Solar System (Term 1)

Course information

Prerequisites

PHAS1245 – Maths I; PHAS1246 – Maths II; PHAS1247 – Classical Mechanics and PHAS1102 – Physics of the Universe

Aims

The course will use basic physics and Mathematics to compare and contrast the different bodies of the solar system and try to understand their composition and physical environment.

Objectives

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

- Demonstrate a basic knowledge of the theories of origin of the solar system
- Describe the distribution of matter in the solar system
- Describe the factors which control the thermal environment throughout the solar system
- Classify the bodies of the solar system in terms of broad types and describe their characteristics
- Demonstrate an understanding of the different interactions between the bodies of the solar system
- Read research literature with a critical eye, and appreciate the ingenuity as well as the limitation of current research.

Textbook

- *Planetary Sciences* (de Pater & Lissaur, Cambridge University Press)

Useful subsidiary texts:

- *The New Solar System* (Beatty, Petersen, Chaikin, Cambridge University Press)
- *Physics and Chemistry of the Solar System* (Lewis, Academic Press)
- *Introduction to Space Physics* (Kivelson & Russell, Cambridge University Press)
- Review journals e.g. Space Science Review, Annual Review of Astronomy and Astrophysics, Reviews of Geophysics and Space Physics, Annual Review of Earth and Planetary Science (see DMS Watson Library)

The websites that exist for all the satellites and instruments

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

Syllabus

[The approximate number of lectures allocated to a topic is given in brackets]

- Origin of the Solar System, dynamics and composition [1]
- Basic structure of the Sun in terms of the physics of energy transport from the core; Source of Solar magnetic field, solar activity and sunspots [4]
- The solar wind and the interplanetary magnetic field; The interaction of the solar wind with solar system bodies [3]
- Planetary magnetospheres, radiation belts, charged particle motions in a planetary magnetic field [5]
- Internal structure of the Terrestrial Planets; Interior and surface evolution; Observational methods, in particular seismic studies on Earth [5]
- Gravitational potential and tidal forces; Roche limit; Instability limit; Relevance to why rings surround the Gas Giants [3]
- Thermal structure and atmospheres of planets [3]
- The Gas Giants; Physics of hydrogen under great pressure [3]
- Asteroids and meteorites, Comets, the Oort Cloud and the Kuiper belt [3]

PHAS2130 – Practical Astrophysics and Computing (Term 2)

The course will run at UCL before reading week and at the Observatory thereafter. Note that Observatory hours (provisionally 15:00—21:00) may not be correctly listed in the timetable

Prerequisites

Normally PHAS1240 – Practical Physics and Computing

Aim of the Course

All Lab-based courses within the Department contribute to the continuing development of students' practical skills, extending throughout the four/three years of the MSci/BSc degrees. Collectively the courses have the overall aim of equipping the student with those practical skills which employers expect to find in graduates in physics whether they are employed in scientific research or development, or in a wider context. Intended mainly for students following the Astrophysics degree programme, PHAS2130 aims to build on and extend the skills acquired in the first-year lab course, with the following objectives:

Objectives

By the end of the course the students should have:

- Improved skill and confidence in the acquisition and analysis of experimental data through the performance of experiments and exercises beyond the introductory level encountered in the first-year lab course.
- Improved ability to record their work concisely and precisely, through repeated practice guided by frequent feedback from teachers
- Improved appreciation of the validity of the data obtained and consequent results; the ability to be able to identify the major sources of uncertainties; and to propagate measurement uncertainties through to estimated uncertainty on final results
- Improved ability to record measurements, analysis, and results in concise, but complete, accurate reports
- Gained greater insight into some of the phenomena treated in lecture courses in years 1 and 2 by performing related experiments and exercises
- Grasped basic principles of computer programming in a relevant language to a range of physical problems and data-analysis tasks

Course Contents

Treatment of Experimental Data: A course of about 6 lectures on the evaluation of experimental data. This course reinforces and extends the course given in the First Year and examines some more practical aspects of good data-taking techniques to make students aware that bad practice in taking data can affect the precision of results. One problem sheet is set.

Computing: For the session 2015/16, students will take a general computing-for-physicists course following on from the PHAS1240 Python course. Details of this course are as listed under the computing component of PHAS2441.

Observatory practicals: A set of experiments and exercises intended to develop some basic techniques of laboratory astrophysics, implementing some practical aspects of lecture courses. Use of the robotic-telescope system, practical computational exercises, and the Michelson interferometer.

Methodology and Assessment

Assessment is continuous. In the computing component students work singly at a computer terminal and are assessed on the basis of problem sheets. In the laboratory sessions students work in pairs following prescriptive scripts. Great emphasis is placed on the formation of good habits in the keeping of a laboratory notebook for which students are given detailed advice. Lab sessions are supervised at the rate of about one demonstrator per 10 to 12 students. Demonstrators not only help students understand experiments and overcome difficulties as they arise, but also inspect student notebooks to provide instant correctives to any bad practice arising.

Observatory work is assessed on the basis of written reports, which should be completed largely in 'real time'. Scripts provide detailed guidance on the expected levels of detail, experiment by experiment, and on relative weighting assigned to each element.

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

- Experimental-data problem paper: 9%
- Computing component: 45%
- Observatory practicals: 46%

Textbooks

There is no necessity for students to acquire specific textbooks. Relevant literature will be available at the Observatory.

PHAS2201 – Electricity and Magnetism (Term 1)

Prerequisites

PHAS1245 – Maths I; PHAS1246 – Maths II or equivalent

Aims

The course aims to provide an account of basic electric, magnetic and electromagnetic phenomena, and show how these are described by vector calculus, culminating in a description of Maxwell's equations.

Objectives

A student should be able to understand the basic laws of electrostatics, magnetostatics and time-varying electric and magnetic fields. They should be able to express them in mathematical form and solve simple problems, including an analysis of DC and AC circuits.

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

Textbooks

Electromagnetism, 2nd edition by I.S. Grant and W.R. Phillips (Wiley)
Physics for Scientists and Engineers, 6th edition by Serway and Jewett

Syllabus

Electrostatics [~6 lectures]

Coulomb's law; electric field; Gauss' law for electric fields; superposition principle; electric field for a continuous charge distributions and electrostatics in simple geometries (spherical, cylindrical and planar distribution of charges). Gauss' law in differential form. Electric potential; electric field as gradient of the potential; electric potential for a point charge; electric potential for a discrete and continuous charge distributions; electric dipole. Electrostatic energy; energy for a collection of discrete charges, and for a continuous charge distribution.

Conductors [~3 lectures]

Electric field and electric potential in outside charged conductors; method of images. Vacuum capacitors: definition of capacitance; parallel plates, capacitors in series and parallel; energy stored in a capacitor.

Electrostatics in non-conductors [~2 lectures]

Dielectrics: definition and examples. Polarisation. Definition of the ***D*** and ***P*** vector fields, boundary conditions and behaviour of these fields between two different materials Dielectrics in capacitors: induced charge, forces on dielectrics in non-uniform fields.

DC circuits [~3 lectures]
Current and resistance; Ohm's law; electrical energy and power; DC circuits: emf, Kirchoff's rules.

Magnetostatics [~4 lectures]

Gauss' Law for magnetic fields; electric currents; Magnetic field, motion of a charged particle in a magnetic field and Lorentz force. Hall effect. Parallel between the treatment of the magnetic field and electric dipoles. Ampere's law and Biot-Savart law. Magnetic field due to a straight wire, a solenoid, a toroid. Magnetic force between current carrying wires. Energy of a magnetic dipole in a uniform field. The vector potential ***A***.

Magnetism in matter [~2 lectures]

Diamagnetic materials, and their explanation in the semi-classical atomic model. Diamagnetic and ferromagnetic materials. Magnetisation. The vector ***H***, and behaviour of various fields between materials.

Electromagnetic induction [~4 lectures]

Magnetic flux and induction Faraday's law of electromagnetic induction. Examples of emf generated by translating and rotating bars. Lenz's law of electromagnetic induction; electric generators; self inductance and mutual inductance; self inductance of a solenoid; back emf; Faraday's law in differential form. Energy in the magnetic field. Transients in RLC circuits.

AC circuits [~3 lectures]

AC generators and transformers; circuit elements (R,C,L); impedance, complex exponential method for LCR circuits: the RC circuit, the RL circuit and the RLC circuit. Resonances, energy and power in the RLC circuit. Kirchhoff laws.

Maxwell's equations [~1 lecture]

Maxwell's equations in vacuo. Plane wave solution. Speed of light.

Mathematical techniques (throughout the course)

Vectors in space and operations between them. Differential operations on vectors. The operator Nabla, also called the del operator. Combinations of differential operations. Gauss-Green theorem. Stokes' theorem.

PHAS2222 – Quantum Physics (Term 1)

Prerequisites

PHAS1245 – Maths I; PHAS1246 – Maths II; PHAS1202 – Atoms, Stars and the Universe or PHAS1423 – Modern Physics, Astronomy and Cosmology; or equivalent courses in other departments.

Mathematical content

Studying quantum physics at this level requires some specific mathematical tools. Physics and Astronomy students will cover this material in PHAS1245, PHAS1246 and PHAS2246 (taught in parallel with PHAS2222). Students from other departments who do not take PHAS2246 are **strongly recommended** to learn this material via an equivalent course or self-study.

Aims

To provide an introduction to the basic ideas of non-relativistic quantum mechanics and to introduce the methods used in the solutions of simple quantum mechanical problems. This course prepares students for further study of atomic physics, quantum physics, and spectroscopy. It is a prerequisite for PHAS2224, Atomic and Molecular Physics, PHAS3226, Quantum Mechanics, PHAS2112, Astrophysical Processes and PHAS3338, Astronomical Spectroscopy.

Objectives
The numbers in brackets refer to sections in the Course Summary and in the lecture notes.

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

- Describe the photoelectric effect and relate observed behaviour to the predictions of the wave and photon theories of light (1.1)
- Describe Compton's X-ray scattering experiment and give the expression for the wavelength shift (1.2)
- Relate the energy and momentum of a photon to its frequency (1.3)
- State the de Broglie relation and apply it to the electron diffraction experiment of Davisson and Germer (1.3)
- Describe the two-slit interference experiment and discuss the interpretation in both the wave and particle pictures (1.3)
- Describe the Bohr microscope and relate it to the uncertainty relation for position and momentum and know the uncertainty relation for energy and time (1.4)
- State the time-dependent one-dimensional Schrödinger equation for a free particle and for a particle in a potential $V(x)$ (2.2)
- Explain the relationship between the wave-function of a particle and measurement of its position (2.3)
- State and understand the normalisation condition for the wave-function (2.3)
- State and explain the boundary conditions that must be satisfied by the wave-function (2.3)
- Show how the one-dimensional Schrödinger equation can be separated in time and space coordinates (2.4)
- Solve the time-independent Schrödinger equation (TISE) for an infinite square well potential to obtain the wave functions and allowed energies (3.2)

- Understand the solutions of the 1D TISE in the presence of a constant potential, including the use of complex exponentials (3.3)
- Explain the relationship between the solutions of the TISE for free particles and the flux of particles (3.4)
- Solve the TISE for a potential barrier or step (3.5)
- Discuss barrier penetration and give examples from physics and astronomy (3.6)
- Give a wave mechanical analysis of a simple harmonic oscillator including being able to recognise and manipulate the Schrödinger equation for the energy eigenvalues and the eigenfunctions (3.7)
- Describe and explain the classical and QM probability distributions for the simple harmonic oscillator (3.7)
- Understand the use of operators in QM, the meaning of eigenfunctions and eigenvalues and be able to write an eigenvalue equation and, in particular, to relate those of the operator $\hat{p}_x$ to the direction of motion of particles (4.2)
- Understand and define what is meant by orthonormality of eigenfunctions (4.3)
- Know the operators representing position, momentum and kinetic energy in one dimension and what is meant by the Hamiltonian operator (4.3)
- Understand and define the expectation value of an operator and be able to calculate expectation values of operators with simple wave functions (4.4)
- Define a commutator bracket and to understand the consequences of commutation in terms of measurement (4.4, 4.5)
- Understand what is meant by a stationary state and a conserved quantity (4.5)
- Define mathematically an Hermitian operator and explain the expansion postulate (4)
- Define the angular momentum $\hat{\underline{L}}$ in terms of Cartesian coordinates and be able to derive a commutation relation between two components of this operator (5.1)
- Derive commutation relations between the Cartesian components of $\hat{\underline{L}}$ and $\hat{\underline{L}}^2$ (5.2)
- Write down an eigenvalue equation for $\hat{L}_z$ and solve it to obtain eigenvalues and eigenfunctions (5.3)
- State the eigenvalues of $\hat{\underline{L}}^2$ and how they relate to those for $\hat{L}_z$ (5.4)
- Describe the eigenvalues of $\hat{\underline{L}}^2$ and $\hat{L}_z$ in terms of the vector model (5.5)
- Understand the method of separation of variables for solving the 3D TISE (6.1, 6.3)
- Sketch and explain the features of the effective potential for the motion of an electron in a hydrogen atom (6.4)
- Define and use atomic units (6.4)
- Solve the radial Schrödinger equation for an electron in a hydrogen atom at small and large distances (6.4, 6.5)
- Sketch and explain the hydrogen energy levels in terms of the appropriate quantum numbers and be able to use the spectroscopic notation for angular momentum quantum numbers (6.5)
- Recognise the treatment of a hydrogenic ion with nuclear charge Z (6.5)
- Describe and explain the Stern-Gerlach experiment (7.2)
- Give, and explain the significance of the quantum numbers that describe the states of the hydrogen atom (7.3)
- Know the rule for adding the orbital angular momentum and spin quantum numbers for the hydrogen atom to obtain the total angular momentum (7.4)
- Understand the idea of adding orbital and spin quantum numbers for more than one electron to obtain total orbital, spin and overall angular momentum quantum number (7.4)

Textbooks
Introduction to the Structure of Matter, J J Brehm and WJ Mullin, Wiley
Quantum Mechanics, AIM Rae, Adam Hilger (closest text to the lecture notes)

Quantum Mechanics, F Mandl, Wiley

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

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

The failure of classical mechanics **[3]**
Revision of key concepts and seminal experiments: photoelectric effect, Einstein's equation, Compton scattering, electron diffraction and de Broglie relation

Steps towards wave mechanics *[3]*
Wave-particle duality, Uncertainty principle (Bohr microscope); Time-dependent and time-independent Schrödinger equations; The wave function and its interpretation

One-dimensional time-independent problems *[6]*
Infinite square well potential; Finite square well; Probability flux and the potential barrier and step; Reflection and transmission; Tunnelling and examples in physics and astronomy; Wavepackets; The simple harmonic oscillator

The formal basis of quantum mechanics *[5]*
The postulates of quantum mechanics – operators, observables, eigenvalues and eigenfunctions; Hermitian operators and the Expansion Postulate

Angular momentum in quantum mechanics *[2]*
Operators, eigenvalues and eigenfunctions of $\hat{L}_z$ and $\hat{L}^2$

Three dimensional problems and the hydrogen atom *[4]*
Separation of variables for a three-dimensional rectangular well; Separation of space and time parts of the 3D Schrödinger equation for a central field; The radial Schrödinger equation, and casting it in a form suitable for solution by series method; Degeneracy and spectroscopic notation

Periodic potentials and crystals *[3]*
Kronig Penney model; Free electron model; Band structure

Electron spin and total angular momentum [3]
Magnetic moment of electron due to orbital motion; The Stern-Gerlach experiment; Electron spin and complete set of quantum numbers for the hydrogen atom; Rules for addition of angular momentum quantum numbers; Total spin and orbital angular momentum quantum numbers S, L, J; Construct J from S and L

PHAS2224 – Atomic and Molecular Physics (Term 2)

Prerequisites

PHAS2201 – Electricity and Magnetism, PHAS2222 – Quantum Physics (or equivalent courses, including the quantum mechanical treatment of the hydrogen atom), or equivalent courses in other departments

Mathematical content

Studying atomic and molecular physics 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 do not take PHAS2246 are **strongly recommended** to learn this material via an equivalent course or self-study.

Aims of the Course

- To provide an introduction to the structure and spectra of simple atoms and molecules
- To revise and go beyond the one-electron hydrogen atom introduced in the course PHAS2222, Quantum Physics
- To prepare students for more advanced courses in atomic and molecular spectroscopy such as PHAS4431 - Molecular Physics and PHAS4421 Atom and Photon Physics

Objectives

On successful completion of the course PHAS2224, the student should be able:

- To understand total and differential collisional cross sections in terms of a beam of incoming classical particles scattered by the target
- To relate the differential to the total cross section and to solve simple problems
- To understand the basics of quantum elastic scattering theory, in terms of an incoming plane wave giving rise to a scattered outgoing spherical wave
- To relate the quantum scattering amplitude to the differential cross section and hence the total cross section
- To understand the quantum mechanics of the hydrogen atom
- To derive and understand the idea of reduced mass and to adapt the H atom expressions for quantum energy and Bohr radius obtained for infinite nuclear mass to a more realistic calculations with finite nuclear mass
- To know and apply atomic and spectroscopic units to a range of problems in atomic physics
- To give the Hamiltonian for an atom with an arbitrary number of electrons
- To explain and apply the independent particle model and the central field approximation
- To know about one-electron orbitals characterised by quantum numbers n and l
- To explain the physical basis for Quantum Defect Theory and calculate alkali atom spectra using Quantum defects
- To understand the concept of indistinguishable particles and to state the Pauli Principle
- To explain implications for the Periodic Table of elements
- To understand and to be able to write down configurations of electron orbitals for a few key atomic elements

- To give a simple ansatz for the Helium symmetric and anti-symmetric two-electron wavefunctions
- To employ these to calculate the expectation value of the electron-electron and hence to derive the character of the exchange force for lowest lying singlet and triplet states of Helium
- To understand how the inclusion of the full, non-central electron-electron interaction leads to a breakdown of the one-electron orbital picture
- To understand and obtain terms from atomic configurations
- To state and apply Hund's coupling rules for ordering terms
- To derive a simple classical model for the spin-orbit interaction A L.S
- To calculate and apply the Lande interval rule E(j)-E(j-1) = A j
- To solve simple problems involving atomic terms and atomic levels
- To provide a summary and overview of the hierarchy of forces responsible for the spectra of the isolated many-electron atoms: Coulomb force, Hartree potential, exchange, correlation and spin-orbit coupling
- To explain, using a simple model for a dipole interacting with an electromagnetic field, the difference between dipole allowed and dipole forbidden transitions
- To state atomic selection rules
- To define metastable levels in terms of the behaviour of the Einstein coefficients for spontaneous emission
- To outline the technique of laser cooling of atoms
- To outline the main principles of laser light, including the role of metastable levels and population inversion
- To describe the main properties of X-ray spectra including continuous and characteristic emission
- To analyse the spectra of atoms in weak static fields; the magnetic moment associated with the electronic orbital and spin angular momenta; the competion between the spin orbit term and the interaction with the external field: the normal and anomalous Zeeman effects
- To describe the Stern-Gerlach experiment and its use in fundamental tests of quantum behaviour
- To understand the response of atoms to static electric fields: the linear, and the quadratic Stark effect
- To understand and derive the Born-Oppenheimer approximation
- To understand the character of low-lying electronic states of the simplest one-electron molecule (H_2^+) and the simplest two-electron molecule (H_2)
- To give the form of the electronic wavefunctions of these two species taking into account symmetry with respect to exchange of nuclei and for the two-electron case, with respect to exchange of the electrons
- To apply trial wavefunctions to calculate expectation values of the electronic energies and hence to deduce the stability of the lowest lying electronic states
- To understand the difference between a bonding and an anti-bonding state
- To analyse molecular spectra associated with rotation and vibration of the nuclei
- To derive a formula valid for ideal diatomic molecules assuming rigid rotation and harmonic vibrations
- To calculate the reduced mass of a diatom and to estimate the dependence of rotation and vibrational spectral frequencies on the reduced mass
- To understand the origin of deviations from the ideal case: anharmonic corrections, centrifugal distortion and the dependence of the rotational constant on vibrational quantum number
- To know molecular selection rules for rotational and vibrational transitions of diatomics and Polyatomics
- To explain the Franck-Condon rule for transitions between electronic states

Textbooks

- *Introduction to the Structure of Matter* (Wiley) by J.J.Brehm and W.J. Mullin mainly chapters 3, 6, 7, 8, 9, 10
- *Quantum Physics of Atoms, Molecules Solids, Nuclei and Particles* (Wiley) by R Eisberg and R Resnick
- *Physics of Atoms and Molecules* (Longman) by BH Bransden and CJ Joachain

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

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

Review of one electron atoms. [2]
One electron atoms; Correspondence Principle; Reduced mass; Atomic units and wavenumbers; Review of quantum angular momentum and spherical harmonics; Review of hydrogen atoms and spectra; Lyman, Balmer and Paschen series; Electron spin and antiparticles

Many electron atoms [10]
Independent particle and central field approximations; Alkali atoms and quantum defect theory; Indistinguishable particles, Pauli Principle; Helium atom and exchange. Configurations and terms; Spin-Orbit interaction; Levels and Spectroscopic notation; Overview of forces on isolated atom; Atoms in radiation: dipole allowed and forbidden transitions; Einstein coefficients; Metastable levels; Laser operation; Laser cooling; X rays and inner shell transitions

Molecular Structure and spectra [9]
The Born-Oppenheimer approximation; Electronic spectra: H_2^+ and H_2; Effects of symmetry and exchange; Bonding and anti-bonding orbitals; Nuclear motion: rotation and vibrational spectra for ideal molecules (rigid rotation, harmonic vibrations); Covalent and ionic bonds; Selection rules

Atoms and Electromagnetic Fields [4]
Atoms in static external fields: atoms in magnetic fields; Normal and anomalous Zeeman effect; Hyperfine splitting; The Stern-Gerlach experiment; NMR and ESR; Atoms in electric fields: Linear and Quadratic Stark effect

***Brief introduction to scattering* [2]**
Total cross section; Differential cross section; Examples of electron-, positron- and positronium- total cross-sections: dominant interactions; Quantum scattering

PHAS2228 – Statistical Physics of Matter (Term 2)

Prerequisites

PHAS1245- Maths I; PHAS1246 – Maths II; PHAS1228 – Thermal Physics

Aims and Objectives

The main aim of this course is to provide a statistical mechanical foundation to the classical laws of thermodynamics, with an emphasis on their application to understand the thermodynamic properties of matter. The specific objectives are as set out in the course outline. Most of the objectives involve establishing the properties of gases of various types, and then using this to study electromagnetic radiation, electrons in metals, superconductors, white dwarfs, neutron stars, as well as the more prosaic gases and condensable vapours.

Resources

There is more to the subject than can possibly be copied off a whiteboard in ~33 lectures. To study the subject seriously you will need to consult the recommended books and additional recommended websites. This Moodle page for this course will provide a set of notes covering lectures plus additional material. You will also be able to access problem sheets and past papers.

Aims

- To review concepts in classical thermodynamics, and to present the basic ideas and methods appropriate for the description of systems containing very many identical particles
- To compare and contrast the statistical mechanics of ideal gases comprised of bosons, fermions, and classical particles
- To develop the statistical mechanics of systems of harmonic oscillators
- To apply the statistical framework to form an appreciation of the thermal and electrical properties of solids

Objectives

On successful completion of PHAS2228 a student will be able to:
- state and understand the four laws of thermodynamics
- understand that the state of a system in thermodynamic equilibrium can be described by functions of state, and distinguish between isothermal/adiabatic and reversible/irreversible processes
- understand and manipulate the equation of state
- explain the difference between a thermodynamic macrostate of the system and an atomistic microstate of a system
- enumerate the microstates for simple systems of indistinguishable quantum particles
- express the mean value of a thermodynamic function in terms of the probability distribution of microstates
- postulate that the a priori probabilities of a system being in anyone of its accessible microstates are equal for an isolated system

- argue that the entropy is the logarithm of the statistical weight of a system, and give Boltzmann's definition of entropy
- state the condition for equilibrium in an isolated system
- obtain definitions of temperature, pressure and chemical potential in terms of entropy
- derive the Boltzmann distribution for a system in equilibrium with a heat bath
- relate the average energy and the Helmholtz free energy of the system to the partition function
- state the definition for equilibrium in a system in contact with a heat bath
- understand the significance of the Gibbs free energy in multi-component systems
- derive the Clausius-Clapeyron equation and understand its application to phase transitions
- derive the partition function for a quantum oscillator
- derive the density of momentum and energy states of a single free particle
- state the definition of a boson and a fermion in terms of the spin of the particles, and the occupation of single particle states
- derive the Bose-Einstein (BE), Fermi-Dirac (FD), and Maxwell Boltzmann (MB) distribution functions
- explain the role played by the chemical potential in these derivations, and be familiar with the partition function
- apply BE statistics to the case of a photon gas, and obtain Planck's Law of the energy density of black-body radiation, and sketch the temperature dependence of this energy spectrum
- understand the physics and behaviours of BE condensation and superfluids
- apply FD statistics to a free electron gas, and white dwarf and neutron stars
- express the criterion for validity of the classical regime in terms of occupation numbers of single particle energy levels
- determine the average kinetic energy of an ideal gas molecule, and obtain the equation of state of an ideal gas by differentiating the Helmholtz free energy with respect to volume
- determine the heat capacity of phonons in a solid
- determine the electrical conductivity of conductor and semi-conductors

Textbooks

The course will largely follow the treatment presented in

- Statistical Physics: an entropic approach, I.J. Ford, Wiley 2013.

and

- Solid State Physics, J. R. Hook & H. E. Hall, Wiley 1991.

A very fascinating introduction to the subject of statistical physics may be found in the very first section of

- Statistical Physics, Part I (Course of Theoretical Physics, Volume 5), L. D. Landau and E. L. Lifshitz, Butterworth-Heinemann, 1980.

I would not, however, recommend this volume as a textbook as, while incredibly deep, it may prove very difficult to approach.

All the following are useful too.

• Concepts in Thermal Physics, S.J. Blundell and K.M. Blundell, OUP
• Fundamentals of Statistical and Thermal Physics, F. Reif, McGraw-Hill
• Statistical Physics, F. Mandl, Wiley
• Molecular driving forces: Statistical thermodynamics in biology, chemistry, physics and nanoscience, K. Dill and S. Bromberg, Garland Science
• Introduction to the Structure of Matter, J. Brehm and W. Mullin, Wiley.

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

Syllabus

Part I. Thermodynamics

1. Review of Classical Thermodynamics

- The four laws of thermodynamics;
- Equations of state and functions of state; intensive and extensive quantities;
- Work, heat, energy and the First Law; the classical monoatomic ideal gas;
- Entropy and the Second Law; quasi-static and adiabatic transformations; the Carnot circle;
  Clausius's and Kelvin's statements of the Second Law;
- Temperature, pressure and chemical potential as derivatives of entropy;
- Thermodynamic potentials and Legendre transformations;
- Entropy and chemical potential of the ideal gas;
- Phase transitions and phase diagrams; Clausius-Clapeyron equation.

2. Statistical Thermodynamics

- The nature of probability; microstates and macrostates; Principle of equal a priori probabilities; microcanonical ensemble; statistical definition of entropy (Boltzmann's principle) and the second law;
- Statistical thermodynamics of harmonic oscillators; microcanonical and canonical ensembles of harmonic oscillators; the thermodynamic limit; the canonical partition function;
- Applications of the canonical partition function; Maxwell-Boltzmann distribution; equipartition theorem; heat capacities of solids (Einstein model) and diatomic gases; two-level systems (paramagnetism);
- Grand canonical ensemble and partition function; vacancies in crystals;
- Boltzmann, Gibbs and Shannon entropies;
- Statistical thermodynamics of the ideal gas; particle in a box; partition function of an N-particle gas.

Part II. Quantum Gases and Solids

3. Quantum gases

- Distinguishable and indistinguishable particles; indistinguishability and exchange symmetry of quantum particles; the Pauli exclusion principle;
- Grand canonical partition function of a single particle state; Bose-Einstein and Fermi-Dirac statistics
- The classical limit; Maxwell-Boltzmann statistics; partition function of an N-particle classical gas
- Density of states of non-relativistic particles; entropy of the classical gas; thermal de Broglie wavelength; conditions for quantum behaviour;
- General thermal properties of quantum gases;
- Bose-Einstein condensation;
- Degenerate Fermi gases; stability of white dwarfs and neutron stars, the Chandrasekhar limit.

4. Photons and phonons

- Electromagnetic waves in a box; field quantisation; partition function of the quantised field;

- Black-body spectrum; photon energy density, flux, pressure and entropy; Wien's law; Stefan's law; simplified model of the greenhouse effect;
- Debye model of heat capacities; phonons in solids.

5. Conductors, semi-conductors and superconductors

- The free electron model of metals; heat capacity, thermal conductivity and electrical conductivity; Wiedemann-Franz Law and range of validity;
- Semi-conductors; statistical thermodynamics of electrons and holes in the presence of impurities; intrinsic and extrinsic behaviour;
- Superconductivity; Cooper pairs; example of a BCS ground state

PHAS2246 – Mathematical Methods 3 (Term 1)

Prerequisites

In order to take this course, students should have studied the material in the precursor PHAS1245 mathematics course and preferably also some of that in PHAS1246, though this is not a necessary prerequisite.

Aims

This course aims to

- Provide the remaining mathematical foundations for all the second and third year compulsory Physics and Astronomy courses
- Prepare students for the second semester Mathematics option MATH6202
- Give students practice in mathematical manipulation and problem solving at second-year level

Objectives

The PHAS1245, PHAS1246, and PHAS2246 syllabuses together cover all the mathematical requirements of the compulsory Physics and Astronomy courses. The major areas treated in PHAS2246 are of special relevance to Quantum Mechanics and the applications of this to many other topics, including condensed matter, atomic, molecular, and particle physics. At the end of each section of the course, students should be able to appreciate when to use a particular technique to solve a given problem and be able to carry out the relevant calculations.

For Vectors, students should be able to:

- Understand the concepts of scalar and vector fields. Understand the significance of the div, grad, curl, and Laplacian operators
- Carry out algebraic manipulations with the vector operators in Cartesian coordinates
- Derive and apply the divergence and Stokes' theorems in physical situations, and deduce coordinate-independent expressions for the vector operators
- Use the gradient of a function of three variables to work out the change in the function when these variables change by small but finite amounts
- Be able to test for conservative forces and handle the corresponding potential energy
- Use expressions for the vector operators in cylindrical and spherical polar coordinates
- Manipulate triple vector products including differential operators

For Matrices, students should be able to:

- Find the eigenvalues and eigenvectors of a matrix up to 3×3 and understand the special properties of Hermitian matrices
- Diagonalise a matrix up to 3×3 and apply the technique to physical and mathematical problems

For Legendre Functions, students should be able to:

- Solve the Legendre differential equation by series method and find the conditions necessary for a polynomial solution
- Derive and apply the generating function and recurrence relations for Legendre polynomials
- Employ the orthogonality relation of Legendre polynomials to develop functions as

series of such polynomials
- Manipulate spherical harmonics up to l=2

In Fourier Analysis, students should be able to:
- Derive the formulae for the expansion coefficients for real and complex Fourier series
- Make analyses using sinusoidal and complex functions for both periodic and non-periodic functions and be aware of possible convergence problems
- Understand the possible complications when differentiating or integrating Fourier series
- Use Parseval's identity to deduce the values of some infinite series
- Derive the formulae for the expansion coefficients for real and complex Fourier transforms
- Perform Fourier transforms of a variety of functions and derive and use Dirac delta functions
- Apply the convolution theorem to physical problems

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

Textbooks

A book which covers most of this and the first-year PHAS1245 and PHAS1246 mathematics courses is *Mathematical Method for Physics & Engineering*, Riley, Hobson & Bence – C.U.P. This book will also be of use in the MATH6202 option given in the second semester. From a more advanced standpoint *Mathematical Methods in the Physical Sciences*, by Mary Boas (Wiley) is recommended.

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

Vector Operators **[10]**
Directional derivatives, gradient for functions of two or three variables; Gradient, divergence, curl and Laplacian operators in Cartesian coordinates; Flux of a vector field; Divergence theorem; Stokes' theorem; Coordinate-independent definitions of vector operators; Derivation of vector operators in spherical and cylindrical polar coordinates; Triple vector products including differential operators

Linear Vector Spaces, Determinants and Matrices **[5]**
Multiple transformations and matrix multiplication ; Properties of matrices; Special matrices; Matrix inversion; Solution of linear simultaneous equations; Eigenvalues and eigenvectors; Eigenvalues of unitary and Hermitian matrices; Real quadratic forms; Normal modes of oscillation

Partial Differential Equations **[5]**
Superposition principle for linear homogeneous partial differential equations; Separation of variables in Cartesian coordinates; Boundary conditions; One-dimensional wave equation; Derivation of Laplace's equation in spherical polar coordinates; Separation of variables in spherical polar coordinates; the Legendre differential equation; Solutions of degree zero

Series solution of Second-order Ordinary Differential Equations **[4]**
Series solutions: harmonic oscillator as an example; Ordinary and singular points; Radius of convergence; Frobenius method; Applications to second-order differential equations

Legendre Functions **[4]**
Application of the Frobenius method to the Legendre equation; Range of convergence, Quantisation of the l index; Generating function for Legendre polynomials; Recurrence relations; Orthogonality of Legendre functions; Expansion in series of Legendre polynomials; Solution of Laplace's equation for a conducting sphere; Associated Legendre functions; Spherical harmonics

Fourier Analysis **[5]**
Fourier series; Periodic functions; Derivation of basic formulae; Simple applications; Gibbs phenomenon (empirical); Differentiation and integration of Fourier series; Parseval's identity; Complex Fourier series; Fourier transforms; Derivation of basic formulae and simple applications; Dirac delta function; Convolution theorem

PHAS2423 – Mathematical Methods for Theoretical Physics (Term 1)

Compulsory module for Theoretical Physics students in year 2; optional module for all students in year 3

Prerequisites

PHAS1245, PHAS1246, PHAS2246 (may be taken concurrently) or equivalent

Aims

- To introduce theoretically-minded students to advanced areas in mathematics, with applications to various problems in physics, particularly in dynamics, and in quantum mechanics, solid mechanics and fluid mechanics
- To provide a deeper treatment of mathematical methods covered in PHAS2246 Mathematical Methods 3
- To provide mathematical underpinning for Theoretical Physics students taking PHAS2443 Practical Mathematics in term 2 of year 2

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (90%).

Syllabus

Cartesian tensors [5]
Transformation properties of scalars, vectors and rank-N tensors; Kronecker delta and Levi-Civita symbol; Quotient theorem; Applications in the elastic deformation of solids; Stress and strain tensors, elastic moduli

Numerical methods for initial value problems [3]
Explicit and implicit Euler method, errors and stability; Advanced methods, e.g. Runge-Kutta

Linear ordinary differential equations [4]
Solution of inhomogeneous equations by variation of parameters; Solution using Green's functions; Properties of the delta function

Sturm-Liouville theory [4]
Self-adjoint linear differential operators; Properties of eigenfunctions of Sturm-Liouville equations; Completeness of a basis set; Construction of Green's functions and representation of the delta function; Examples of orthogonal polynomials

Linear partial differential equations [4]
Categorisation of equations and classes of boundary condition; Diffusion equation, Laplace/Poisson equation, wave equation; Eigenfunction representation of solutions; Method of characteristics for first order PDEs

Fluid Mechanics [4]

Equations of motion of non-viscous and viscous fluids; Euler's equation, irrotational flow, potential flow; Bernouilli's theorem; Navier-Stokes equation; Poiseuille flow, Stokes flow past a sphere

Integral transforms [3]
Fourier and Laplace transforms and inversion (not to include the Bromwich integral); Applications in ordinary and partial differential equations

Recommended books

- *Mathematical Methods for Physics and Engineering, Third Edition,* Riley, Hobson and Bence (CUP)
- *Mathematical Methods in the Physical Sciences, 3rd Edition,* Boas *(Wiley)*
- *Physical Fluid Dynamics, Second Edition,* Tritton *(Oxford)*

PHAS2427 – Environmental Physics (Term 2)

Prerequisites

In order to take this course, students should be familiar with the basic principles of physics to a standard comparable with a grade B in GCSE Advanced Level, and to have a level of competence in mathematics consistent with having passed courses PHAS1245 and PHAS1246.

Aims of the Course

This course aims to provide:

- An introduction to the application of fundamental principles of physics to the environmental sciences
- A treatment of the basic physics establishing thermal and chemical balances in the Earth's atmosphere
- An explanation of the physics underpinning the topical problems of ozone depletion and global warming
- A description of the physics underpinning terrestrial weather patterns including cloud formation and wind patterns
- A discussion of current climate models and their predicative power for short and long term weather patterns
- To provide a description of the physical principles involved in the development of the technologies for adoption of renewable energy schemes
- Provide an explanation of heat transfer in current buildings and how they may be improved
- A description of the causes and consequences of pollutants in the atmosphere, ecosystems and human health

Objectives

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

- Describe the composition and structure of the terrestrial atmosphere
- Discuss the interaction of solar radiation with the terrestrial atmosphere
- Describe the transport of solar radiation through the atmosphere to the Earth's surface and subsequent emission of infra-red radiation and its transport back through the atmosphere into space
- Derive a model for thermal balance within the Earth's atmosphere and at the ground/atmosphere boundary
- Provide a critical discussion of the causes and consequences of ozone depletion and global warming and discuss possible remedial actions
- Discuss the basic mechanisms for the formation of global weather systems and their transport
- Demonstrate a physical understanding of the dynamics of cloud formation, including different precipitation patterns and the special properties of thunderstorms
- Discuss the global hydrological cycle
- Provide a simple physical model for water transport through soils
- Discuss the global energy budget and the reasons for current reliance upon fossil fuels
- Describe the potential for future energy sources including nuclear fusion

- Discuss the plausibility of renewable energies providing a significant input into future world energy needs
- Describe the basic physics underpinning wind, hydroelectric and solar energies
- Discuss heat transport through buildings and how current housing stocks may be made more energy efficient
- Describe new building designs that will allow renewable energies to be adopted
- Discuss the causes of local (urban) pollution and the possible consequences for human health

Methodology and Assessment

This is a half-unit course, with 27 lectures and 3 discussion classes: additional timetable slots are used to discuss additional topics of current interest, such material will not be examined. Continuous assessment is 20% of the total marks for this course. 10% is allocated to a single essay of 3000 words to be written on a topic related to the course. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (10%) and a final written examination (80%).

Textbooks

Most of the course material is covered in the basic text, *Environmental Physics* N J Mason and P Hughes (Taylor and Francis 1999). Other books which may be useful include the following, but note that they each cover only part of the material than is in the syllabus, and in some cases are more mathematical in approach.

- *Principles of Environmental Physics*. Second edition. Monteith, J.L. and Unsworth, M.L. (Arnold, London, 1990)
- *Environmental Physics*. Boeker, E. and Van Gronelle, R. (Chichester, Wiley, 1995)
- *Physics of the Environment and Climate*. Guyot, G. (Chichester, Wiley, 1998)
- *Environmental Science* Botkin , D.B and Keller E.A. (Chichester, Wiley, 1998)

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

(A) *Structure and Composition of the atmosphere* [4]
Principal layers – troposphere, stratosphere, mesosphere and thermosphere; Ideal gas model revisited; Exponential variation of pressure with height; Escape velocity; Temperature structure and lapse rate

(B) *Radiation* [5]
The sun as the prime source of energy for the earth; Solar energy input, cycles daily and annual; Spectrum of solar radiation reaching the earth; Total radiation and Stefan-Boltzmann, Wien's and Kirchoff's laws; Radiation balance at the earth's surface and determination of the surface temperature; Ozone layers and depletion; CO_2 methane, H_20 and Greenhouse effect

(C) *Fluid dynamics* [9]
How unequal heating leads to atmospheric circulation surface and high winds Hadley, Ferrel and Polar cells; Diurnal variation of pressure; Evaporation and condensation, thunderstorms; Coriolis force due to the rotation of the earth; Applied to atmospheric and ocean currents; Hydrological cycle and budget; Physical properties of water; Vapour pressure, dynamic equilibrium, evaporation and condensation; Saturated vapour pressure;

Cloud formation; Ocean currents as transporters of energy; Sea level changes and the greenhouse effect

(D) *Energy Resources* [9]

Fuels – fossil, nuclear power; Renewable energy sources; Power consumption; Annual energy budgeting, long term trends; Efficiency of systems; Energy audit for a building; Insulation of a building; Thermal conduction through materials; Noise pollution

PHAS2440 – Practical Physics 2A (Term 1)

Prerequisites

Normally PHAS1240, PHAS1241

Aim of the Course

All Physics Laboratory courses within the Department contribute to a continuing development of students' practical skills extending throughout the four/three years of the MSci/BSc degrees. Collectively the courses have the overall aim of equipping the student with those practical skills which employers expect to find in graduates in physics whether they are employed in scientific research or development, or in a wider context. Intended mainly for students following the Physics degree programme, course PHAS2440 aims to build on and extend the skills acquired in the First Year Lab course with the following objectives.

Objectives

By the end of the course the students should have:

- Improved skill and confidence in the acquisition and analysis of experimental data through the performance of experiments beyond the introductory level encountered in the first year lab course and become familiar with more complex instrumentation
- Improved ability to record their work concisely and precisely in the laboratory notebook, *as it is done,* through repeated practice guided by frequent feedback from teachers
- Improved appreciation of the validity of the data obtained and recorded; identification of the main sources of uncertainty; the ability to propagate random uncertainties through to estimate the uncertainty on the final result
- Improved ability to condense the information contained in the record made in the laboratory notebook into a concise, but precise and complete formal report of the experiment in word-processed form
- Gained greater insight into some of the phenomena treated in lecture courses in years 1 and 2 by performing related experiments

Course Contents

Treatment of Experimental Data: A short course of lectures on the treatment of experimental data and scientific communication. Building upon the first year practical courses, this examines some more aspects of good data-taking techniques to make students aware that bad practice in taking data can affect the precision of results. One problem sheet is set.

Set Experiments: Develops some basic techniques of laboratory physics as well as illustrating some aspects of lecture courses given in the Second Year via a number of "set" experiments which, although building on some techniques acquired in the First Year course, are generally less prescriptive and of a more challenging nature. Normally four experiments are completed.

Formal Reports: Two of the set experiments are made the subject of formal reports.

Methodology and Assessment

Assessment is continuous. In the laboratory sessions pairs of students share experimental equipment and follow scripts that are less prescriptive than in year one. Emphasis is placed on the formation of good habits in the keeping of a laboratory notebook for which students are given detailed advice. Lab sessions are supervised at the rate of about one demonstrator per 10 to 12 students. Demonstrators not only help students understand experiments and overcome difficulties as they arise, but can also inspect student notebooks to provide instant correctives to any bad practice arising.

Students' laboratory notebook records of experiments are periodically assessed and feedback provided on elements requiring improvement. Additionally, two formal reports are required to be produced according to the same criteria as in Year One, but make more demands on the student's scientific communication skills on account of the longer and more complicated nature of the experiments reported. The detailed advice given in the first year on how to approach the preparation of a report is reiterated. Students receive back their reports, assessed and with a detailed critique of features, which require improvement in future reports. The different course components contribute the total assessment with the following weights.

- Laboratory Notebooks (55% total)
- Formal reports (35% total)
- Data Analysis Problem Sheet (10%)

Recommended text (optional)

- I.G. Hughes and T.P.A. Hase*, "Measurements and their Uncertainties: A practical guide to modern error analysis",* 1st ed. Oxford University Press (2010)

PHAS2441 – Practical Physics and Computing 2 (Term 2)

Prerequisites

Pass in both laboratory physics and computing elements of PHAS1240 is essential. Normally PHAS2440, Practical Physics 2A

Aim of the Course

All Physics laboratory and computing courses within the Department contribute to a continuing development of students' skills. Collectively the courses have the overall aim of equipping the student with skills which employers expect to find in graduates in physics whether they are employed in scientific research or development, or in a wider context. Intended for students following degrees in Physics, course PHAS2441 aims to continue the development of students' skills, begun in PHAS1240, beyond the level reached in First Year courses with the following objectives.

Objectives

By the end of the course the students should have:

- Improved ability to record their work concisely and precisely in the laboratory notebook, as it is done
- Improved ability to take reliable data, to identify the main sources of uncertainty in it, and to propagate random uncertainties into an estimate of the uncertainty on the final result
- Increased ability and confidence to plan and undertake scientific investigation by completing a structured experiment extending over several weeks
- Increased their knowledge and understanding of electronics
- Increased their skills in computer programming using Python, and to have developed sufficient competence to be able to apply these skills to a wide variety of physical problems and models

Course Contents

Computing: The computing element of the module takes place in the first half of term, with each student attending two afternoon sessions per week. Using the IPython Notebook as the main format, Python programming skills acquired during PHAS1240 will be developed and extended, using structured coursework assignments based on a range of physical examples related to lecture and laboratory course material. The course will cover a range of topics in advanced data analysis, numerical analysis techniques and computational physics.

Electronics: Performed in the second half of the term, this gives the student the opportunity to plan and undertake an extended piece of structured experimental work. Students calibrate a temperature sensor and then build and test an operational digital thermometer, with display, and interface it to a computer for automatic collection of data.

Methodology and Assessment

Assessment is continuous.
During each computing session, students will complete a task under the close supervision of the course staff, and be given immediate verbal and written feedback. In addition to the

continuous assessment in the sessions, students will also complete a longer individual assignment, started in the final session and completed in their own time.

For the electronics project students normally work in pairs supervised by members of the academic staff and postgraduate demonstrators. Assessment is based on the contents of the notebook each student is required to keep. The different course components contribute to the total assessment with the following weights:

- Computing, 50% (continuous assessment 12.5%, final assignment 37.5%)
- Electronics, 50%

Textbooks

There is no textbook which the students are expected to buy. Reference books are available in the laboratory and links are provided to online information for the computing course.

PHAS2443 – Further Practical Mathematics and Computing (Term 2)

Prerequisites for the Course

The first year course PHAS1449 Practical Mathematics I is a prerequisite for this course. The programming and simulation techniques taught in this course will support, but are not a prerequisite for, the final year theoretical project course.

Aims of the Course

This course uses a modern system for solving mathematical problems by computer as a framework for modelling and simulation in physics. Through lecture-demonstrations and practical experience, students will use the integrated Mathematica environment and its graphics, numerics, algebra and calculus capabilities to learn basic numerical analysis and simulation techniques, and will apply them to problems in mathematical physics. The course unit establishes links between the mathematics, physics and computer programming which are taught in other course units and illustrates the benefit of algorithms and computer programming for problem analysis, for problem solving, and for displaying results. As well as short exercises to test their understanding as the course progresses, students will undertake an extended mini-project using Mathematica. The mini-project will increase a student's ability and confidence to undertake scientific investigation without the need for prescriptive instruction and to present the results in a written report.

Objectives of the Course

After completing this course, the student should:

- Be able to use the Mathematica language to solve problems in mathematical physics using appropriate analytical and numerical methods
- Understand the basic principles of the design of simple numerical algorithms
- Be able to design and implement a variety of simulations in mathematical physics
- Be capable of planning, writing, testing and documenting Mathematica code to solve a multi-step problem
- Be ready to tackle new problems in theoretical physics, to find appropriate mathematical techniques and to draw conclusions from the results
- Be able to write, in word-processed form, a precise and complete report of a scientific project

Brief Outline of Course

The topics which will be covered are:

- Coding techniques: procedural, rule-based and functional methods; Dynamic programming; Recursive methods; Add-on packages for Mathematica
- Convolutions: image processing and cellular automata
- Numerical methods: difference between exact and floating point arithmetic and relevance to algorithm design; Illustration of rounding errors
- Finite difference methods; Explicit and implicit methods; Stability analysis
- Classification of differential equations; Relaxation methods for elliptic equations
- Numerical models of the wave equations
- Systems of particles: from molecules to galaxies
- Monte Carlo methods: random numbers, integration and the Metropolis algorithm
- Mathematica and non-commuting operators: applications to quantum mechanics

- Fourier series and Fourier transforms; Applications to differential equations and data analysis

Methodology and Assessment

This course usually occupies nine 3½-hour practical sessions and a final session for the in-class examination. The central activity is hands-on experience with the Mathematica program, with each student having the use of a PC. There are three elements to the assessment of the course: problem sheets, most to be completed during the course with one due afterwards; a mini-project, to be carried out in the students' own time, which will use a large number of the concepts learnt; and a two-and-one-half hour computer-based examination, taken at the end of the term.

- Exam (30%)
- Mini project (45%)
- Continuous Assessment (25%)

Recommended Reading

It should not be necessary for students to consult any material apart from the course material which will be supplied and the on-line help files for the Mathematica program. Students who wish to extend their knowledge might consult any of the large number of guides to Mathematica (a good range is held in the DMS Watson Library). Particularly useful are:

- *The Mathematica Book*, Stephen Wolfram, Cambridge (various editions) (The comprehensive guide to the features of the program)
- *Applied Mathematica, Getting Started, Getting it Done*, W.T. Shaw and J. Trigg, Addison Wesley (1994)
- *Mastering Mathematica, Programming Methods and Applications*, J.W. Gray, Academic (1998)
- *Mathematica for Scientists and Engineers*, T.B. Bahder, Addison Wesley (1995)
- *Mathematica for Physicists*, R.L. Zimmerman and F.I. Olness, Addison-Wesley (1994)

MATH6202 – Mathematics for Physics and Astronomy (Term 2)

(Please note: This course is given by the Mathematics Department)

Prerequisites

In order to take this course, students should normally have obtained a good pass in the first year courses PHAS1245 – Maths I and PHAS1246 – Maths II Mathematics examination and achieved a good result also in the second year PHAS2246 – Maths III Mathematics mid-sessional examination.

Aims

This optional course aims to provide a treatment of advanced mathematical methods suitable for well-qualified students who intend to proceed further with theoretical studies.

Objectives

The course, which is taught by members of the Mathematics Department, is a mixture of subjects that may be useful in later (optional) modules, together with material which is of interest in its own right, especially when looked at from a mathematician's perspective. Complex variable theory is needed for many branches of mathematical physics, represented by such fourth year modules as scattering theory or quantum electrodynamics.

In the three major sections:

For Functions of a Complex Variable, students should be able to:
- Derive relationships between elementary functions of complex arguments;
- Represent functions in the cut complex plane and understand the significance of square root and logarithmic branch points;
- Find the radius of convergence of power series and regions of convergence in the complex plane for more complicated series;
- Apply the conditions of differentiablity to a given function;
- Understand complex mappings and derive and apply the Cauchy-Riemann equations to deduce the imaginary/real part of an analytic function from its real/imaginary part;
- Evaluate integrals over contours in the complex plane by using the Cauchy residue theorem;
- Apply Cauchy's integral formula;
- Obtain a Taylor-Laurent series for a function of a complex variable;
- Evaluate definite integrals over a real variable by continuing into the complex plane.

For Calculus of Variations, students should be able to:
- Show that the problem of finding the extremal of a functional may be recast in terms of solving Euler's equations;
- Use Euler's equations to find the stationary points of a line integral in two dimensions;
- Find also the stationary points when the path is subject to an integral constraint.

Group Theory:
The group axioms; Example of symmetries for finite groups; Subgroups and Equivalence classes; Representations of finite groups; Similary transformations; Reducible and irreducible representations; Characters; Orthogonality relation

Methodology and Assessment

There are 3 lectures per week in this second-term optional half-unit course in Mathematics, which is offered by the Mathematics Department almost exclusively to students from the Physics and Astronomy Department; the assessment is controlled by the Board of Examiners in Mathematics. The last 1.5 hours of the course are devoted to revision and the study of previous examination questions. The written examination counts for 90% of the assessment, with 10% being based on the best 6 results from the 8 homework sheets. Of the problems on the homework sheets, typically only two or three are set and marked for assessment, but there are many more "practice" questions, which are given in order to enhance the student's learning experience. There is a weekly one-hour problem class where a teacher and demonstrator help students who are having difficulty with the "practice" questions. The lecturer also arranges an office hour once per week at a mutually convenient time.

Textbooks

The book recommended for the first term PHAS2246 course, *viz. Mathematical Methods in the Physical Sciences*, Mary Boas (Wiley), is suitable for this course as well.

Syllabus

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

PART 1: Functions of a complex variable (4 exam questions)

WEEK 1: review of complex numbers, power series, convergence tests, radius of convergence

WEEK 2: Introduce functions F(z)=u+iv, single and multi-valued, branch cuts, roots, basic functions (exponential, trigonometric + using De Moivre, hyperbolic and log)

WEEK 3: continuity and differentiability, Cauchy-Riemann equations, harmonic functions, finding conjugate functions (i.e. given u(x,y) find v(x.y) such that f(z)=u+iv analytic), complex integration (line integration)

WEEK 4: integrating around singularities, Cauchy's Theorem + proof, Cauchy's Integral Formula + proof +examples, Cauchy's Integral Theorem for derivatives + proof, basic Laurent series expansions

WEEK 5: Types of singularities, finding residues, the Residue Theorem, Examples of real integrals done using contour integration (mapping to unit circle or semi-circle or strip), Jordan's Lemma

WEEK 6: READING WEEK

PART 2: Calculus of variations (2 exam questions)

WEEK 7: what is a functional (examples)? the Euler-Lagrange Equation derivation, solving simple second-order o.d.e.s, shortest-distance between two-points and min. surface of revolution, special forms of E-L equations, The Brachistochrone problem

WEEK 8: what is a Lagrange multiplier? problems with constraints (isoperimetric problems), examples (including a heavy-chain suspended between two points), E-L systems of equations

WEEK 9 – 11: Group theory

PHAS2901 – Developing Effective Communication 2 (Term 1)

Prerequisites

None

Aim of the Course

This is the second of two modules that aim to develop skills in getting a message across, and in understanding the messages of others. These skills are crucial not only for being an effective physicist, but also in functioning effectively in many career – or non-career – situations.

Objectives

After completing this module successfully, students should be able to:

- creatively and clearly explain concepts in physics
- write an article to describe scientific research, summarising scientific ideas succinctly and accurately
- orally present scientific ideas to a medium-sized group of peers using full visual aids
- write an effective CV and cover letter
- find and use appropriate resources with proper use of referencing
- choose communication style and material to suit different audiences
- communicate effectively in a professional environment
- use appropriate IT including drawing and formatting packages

Methodology and Assessment

This module runs in the first term, with one hour each week set aside for lectures. Students will practice the writing of articles, abstracts, lab reports, CVs and cover letters and will prepare and deliver oral presentations to small and medium sized audiences. Presentations take place in reading week in the second term.
Students will get the chance to find out about current research at UCL through a 'press conference' event, and to talk to PhD students through the 'PhD buddy' initiative. They will learn about communicating in a professional environment with the chance to practice networking. There will be careers information and information about related events. There will be guest speakers including science journalists, experts from the UCL careers service, and science comedians from the UCL public engagement department.

Assessment will be by coursework only. Students will get the chance to use their creativity and initiative with the designing and recording of a screencast video to describe a concept in physics (20%). This will be done in teams to give the opportunity to practice teamwork, with a prize for the best video. Students will write an article to describe scientific research based on a 'press conference' with a UCL researcher (40%). They will write and deliver an oral presentation to describe a scientific article (40%). This module is weighted 50% of the communications skills provision, which includes PHAS1901 in year 1. The two modules together will contribute to your assessment for honours at a level equivalent to approximately 5%.

Textbooks

Handbook of Science Communication compiled by Anthony Wilson, published by the Institute of Physics.

Getting the Message Across: Key Skills for Scientists, edited by Kristy MacDonald, and published by the Royal Society of Chemistry at £1.20 a helpful booklet.

Further electronic references will be provided during the course.