DEPARTMENT OF PHYSICS AND ASTRONOMY

1st Year
Course Descriptions

2014/15

INTRODUCTION

This handbook contains details about all the constituent courses for 1st year full-time undergraduate programmes which are planned to be offered by the Department of Physics and Astronomy in Session 2014/2015. 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 2014/2015.* If you do not have a copy of this, one may be obtained from the Undergraduate Teaching section of the Departmental website. The latter handbook gives information on how these courses fit into particular degree structures as well as brief descriptions of the courses themselves. Please note that it cannot be guaranteed that all courses offered will run and that only the most usual pre-requisites for courses are given.

If you need guidance on your choice of course(s), please contact the Departmental Programme Tutor, Dr. S Zochowski.

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

CONTENTS

PHAS1202 – Atoms, Stars and the Universe (Term 1)

Pre-requisites

A-level Maths & Physics, or equivalents.

Aims of the course

This course aims to give first-year Physics-related and Astronomy-related students an overview of modern ideas. They should meet, in an accessible form, the ideas of quantum mechanics, and acquire a broad view of the origin and evolution of the Universe as it is currently understood.

Objectives

Students should gain an historical perspective on quantum physics and an elementary comprehension of fundamental quantum concepts. They should also acquire a basic understanding of radiation processes and their applicability in stars, an appreciation of stellar evolution, and a grasp of the fundamentals of modern cosmology.

Methodology and Assessment

This course is based on lectures, supplemented by problem solving tutorials/discussion, with opportunities to visit University of London Observatory and research labs in the Department. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (15%) and a final written examination (85%).

Textbooks

- “Physics for Scientists and Engineers with modern Physics” (8th edition), J W Jewett & R A Serway
- "Introductory Astronomy and Astrophysics" (4th edition), Michael Zeilik & Stephen A. Gregory (Thomson Learning, ISBN 0030062284)
- "Universe" (7th edition), by Roger A. Freedman & William J. Kaufmann III, may provide useful supplementary reading

Syllabus
(Approximate allocation of lectures to topics given in brackets)

Part 1 – Atoms, Photons and the Quantum World

1) Introduction [3 hrs]
Light as a wave? Problems with wave view of light; Evidence for light as a particle; Black-body radiation and photo-electric effect; Relativistic energy, the Compton effect; Modern evidence for light as a particle; The Photon; Photons in a Mach-Zehnder interferometer

2) Atomic Theory from 400BC to 1913AD [2 hrs]
Development of the atomic model; Rutherford experiment and planetary model; Atomic Spectroscopy; Rydberg Formula; Bohr model (motivated by Rydberg formula); Successes and failings of the Bohr model

3) Particles as Waves [1 hr]

de Broglie waves, Photon Momentum, de Broglie Wavelength, Young's double slit experiment with electrons and molecules

4) Elements of Quantum Mechanics I – The wave-function [3 hrs]
Review of Probability theory for discrete and continuous variables; Probability Density; Wave-functions; Born Rule; Normalisation; Continuity; Expectation values; Heisenberg Uncertainty Relation

5) Elements of Quantum Mechanics II – Energy in quantum mechanics – [6 hrs]
Time-independent Schrödinger Equation (TISE): Potential Energy; Solving TISE for a free particle - sinusoidal ; Time-independent Schrödinger Equation (with a potential); Infinite Well; qualitative treatment of Finite Well; boundary conditions (from finite energy assumption); Tunnelling and applications (qualitative treatment); TISE for Hydrogen atom. Quantum numbers and shape of wavefunctions; Spin; Bosons and Fermions; Pauli exclusion principle; Quantum numbers and structure of the periodic table

Part 2 – Stars and the Universe

1) Radiation [2 hrs]
Planck, Stefan-Boltzmann, and Wien Laws; stellar luminosity, effective temperature

2) Stellar spectra [1 hr]
(absorption and emission processes); Stellar classification, H-R diagram

3) Energy generation [2 hrs]
Nuclear fusion, solar neutrinos

4) Stellar evolution [2 hrs]

5) End points of stellar evolution [2 hrs]
White dwarfs, neutron stars (pulsars), stellar-mass black holes

6) Galaxies [2 hrs]
Dark matter (evidence from clusters of galaxies; X-rays; virial theorem; gravitational lensing)

7) Redshift and Hubble's law [4 hrs]
Evidence for an evolving Universe (cosmic microwave background; Primordial nucleo-synthesis; evolution of large-scale structure); How does the Universe evolve? (Hubble flow; supernova cosmology; Dark Energy)

PHAS1130 – Practical Astronomy (Term 2)

Prerequisites

There are no formal prerequisites.

Aims of the Course

This course aims to:

- train students to an appropriate level of competence so they may operate the Observatory's first-year telescopes and ancillary equipment safely and efficiently;
- train students to use the Observatory's telescopes to locate celestial objects;
- train students to make visual observations of astronomical objects;
- teach students the principles of CCDs as astronomical detectors;
- train students to use CCD cameras mounted on the Observatory's telescopes to acquire astronomical image data;
- provide students with experience in the use of astronomical software and on-line data resources;
- give students experience of the following subjects or techniques: observations (visual, CCD, video) of the Sun, Moon, planets, comets, asteroids, stars (including spectra), and nebulae; astronomical coordinate systems; spectral classification of stars; morphological classification of galaxies; measurement and evaluation of planetary images; analysis of pulsar signals and variable star light curves; stellar photometry; extragalactic distance measurement using Cepheid variables; absorption-line measurement in spectra.
- reinforce and complement concepts from lecture courses, in particular, PHAS1202;
- develop a student's ability to carry out experiments independently or, when appropriate, in pairs or small groups, to analyse the data, and to report the results in written form;
- provide experience of basic experimental statistics, including estimating experimental uncertainties and their propagation.

Objectives

Students should, by the end of the course, be able to:

- demonstrate a reasonable working knowledge of astronomical coordinate systems and time;
- use the first-year telescopes safely, with minimal assistance, to locate celestial objects and make visual observations and record the results with notes and drawings;
- use a CCD camera and apply image corrections to render the images useful for scientific measurement;
- use the telescopes for recording CCD images, with some assistance, and reduce their CCD image data;
- keep an experimental notebook with accurate records of work done;
- find and extract information relevant to the acquisition or analysis of astronomical data from astronomical databases, books, charts, or journals;
- use confidently and competently software available for the display, measurement, and analysis of astronomical and other data;
- write clear and concise reports, in good English with appropriate legible and accurate tables, graphs, and pictures, describing in adequate detail experiments done in the laboratory or at the telescopes, including estimation of uncertainties on any numerical

results obtained.

Methodology and Assessment

Assessment is continuous. Students complete a number of practical exercises at the telescope or using prepared material in the laboratory, and prepare written reports for which credit is awarded. About 10 percent of the course marks are awarded for performance during telescope training exercises, for which no written work is submitted.

Textbooks

- D. Scott Birney, G. Gonzalez, D. Oesper, *Observational Astronomy (2nd edition)*, ISBN 0 521 853705 (Cambridge University Press, 2006)

Either of the following is recommended for statistical analysis of data:
- R.J. Barlow, *Statistics*, ISBN 0 471 92295 1 (John Wiley & Sons, 1989)
- L. Kirkup, *Experimental Methods*, ISBN 0 471 33579 7, (John Wiley & Sons, 1994)

Syllabus

The Observatory's principal instruments are the 24/18-inch Radcliffe refractor and the 24-inch (60-cm) Allen telescope, a reflector. Other instruments include a Celestron 14-inch reflector, the Fry telescope (an 8-inch refractor), Meade 7-inch and 10-inch reflectors, CCD cameras, and video cameras for astronomical observing. Students have access to the Observatory's computing facilities, which comprise a network of PCs running Win-XP and Linux and a direct link to the internet and computing facilities at UCL. Further information is available on the Observatory's website (http://www.ulo.ucl.ac.uk).

Instruction is given in the use of telescopes and the operation of CCD cameras, which are used by students to observe on clear evenings. There are also set experiments designed to demonstrate important concepts in astronomy, complementing the material taught in lecture courses at UCL, particularly PHAS1102, `Physics of the Universe', and introducing students to the techniques of measurement used by astronomers. The majority of the experiments involve the use of prepared material such as CCD images, photographic plates or prints, and spectra; this material has been obtained at ULO or other observatories around the world, and from satellites and spacecraft such as the Hubble Space Telescope. Various analytical methods are employed, such as classification of features and phenomena, measurements and calculations of size, speed or position, and statistical analysis of data.
A summary of each experiment is given in the course booklet.

PHAS1224 – Waves, Optics and Acoustics (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 at A level, and to have a level of competence in mathematics consistent with having passed course PHAS1245.

Aims of the Course

This course aims to provide:

- an account of the phenomenon of wave propagation and the properties of the wave equation in general, in a form which can be applied to a range of physical phenomena;
- an explanation of the way in which wave equations arise in some specific cases (transverse waves on a string; longitudinal sound waves in gases and solids);
- a discussion of reflection and refraction, illustrating the relationship between the wave and geometric (ray) pictures;
- a description of phenomena which arise from the superposition of waves, including interference and diffraction;
- an overview of simple optical devices in terms of geometric optics, including small numbers of lenses and curved mirrors, with a discussion of the limitations placed on such devices by diffraction;
- an introduction to simple optical devices which rely on interference;
- a description of the propagation of waves in free space and in simple enclosures;
- a foundation for the description of quantum mechanical wave phenomena in course PHAS2222 Quantum Physics and the theory of electromagnetic waves in PHAS2201 Electricity and Magnetism.

Objectives

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

- discuss the relationship between simple harmonic motion and wave motion, and make calculations of the motion of systems of masses connected by springs;
- make calculations on simple properties of wave motion, including wave packets, phase velocity, group velocity, and the propagation of waves in one, two and three dimensions;
- use the complex exponential representation for waves, and extract real values from it for the description of observable quantities;
- discuss the propagation of energy in waves;
- make calculations on and draw graphs illustrating the superposition of waves and the phenomenon of beats;
- Make calculations on systems with moving sources and receivers (the Doppler effect).
- sketch and describe standing waves, especially on strings and in pipes with various boundary conditions, and make calculations on them;
- draw phasor diagrams for systems of interfering waves and use these or complex number methods to derive general formulae and to describe specific cases;
- derive the wave equation for transverse waves on a stretched string, and for longitudinal waves in compressible materials;

- describe polarization of transverse waves, and discuss the phenomena which arise therefrom;
- derive formulae for the reflection and transmission coefficients of waves at barriers, express them in terms of impedances, and apply them;
- describe and make calculations on simple guided wave systems;
- describe what is meant by phase coherence, and explain the qualitative differences between light from different types of source;
- describe Huygens's principle and apply it to simple cases;
- derive formulae for the diffraction patterns of single and double slits, and for diffraction gratings with narrow and finite slits;
- derive the criterion for the resolving power of a grating;
- draw geometric ray diagrams for simple systems involving prisms, lenses, and plane and curved reflecting surfaces;
- make calculations in geometric optics for simple systems involving slabs, prisms, lenses, and plane and curved reflecting surfaces;
- describe the operation of simple optical instruments, derive object and image positions and magnifications, and discuss quantitatively their resolving power;
- calculate the properties of and describe applications of the Michelson and Fabry-Perot interferometers.

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 (15%) and a final written examination (85%).

Textbooks

Most of the course material is covered in the basic First Year text: *Physics for Scientists and Engineers with Modern Physics*, by Serway and Jewett, (Thomson).

Other books which may be useful include the following, but note that they cover more material than is in the syllabus, and in some cases are more mathematical in approach.

- R.W. Ditchburn, *Light*, Wiley (1963)
- O.S. Heavens and R.W. Ditchburn, *Insight into Optics*, Wiley (1991)
- F.G. Smith and J.H. Thomson, *Optics* (2nd edition), Wiley (1987)
- E. Hecht, *Optics* (2nd edition), Addison-Wesley (1974)
- S.G. Lipson and H. Lipson, *Optical Physics*, Cambridge (1969)
- R.S. Longhurst, *Geometrical and Physical Optics*, Wiley (1967)
- H.J. Pain, *The Physics of Vibrations and Waves* (4th edition), Wiley (1993).

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

Introduction [2 hrs]
Simple harmonic motion; phasors; complex number representation; beats

Basic Properties of Waves [2 hrs]

types of wave motion; progressive waves; simple harmonic form; definitions of amplitude, frequency etc.; phase and phase velocity; general differential equation of wave motion; superposition

Transverse waves [3 hrs]
stretched string; reflection and transmission at boundaries; impedance; energy and energy propagation; impedance matching; standing waves and normal modes

Longitudinal waves [1 hr]
sound in gases; sound in solid rod

Dispersion [2 hrs]
dispersion relations; phase velocity and group velocity

Doppler effect [1 hr]

General properties of light [3 hrs]
transverse nature; polarization; selective absorption and double refraction; waves and rays; Fermat's principle; Huygens's principle; interference and coherence

Interference by division of wavefront [3 hrs]
Fraunhofer and Fresnel limits; Young's slits; finite single slit; rectangular and circular apertures

Multiple beam interference [2 hrs]
diffraction gratings (narrow and finite slits); spectral resolving power; antenna arrays; Bragg reflection.

Interference by division of amplitude [3 hrs]
thin films; anti-reflection coatings; Newton's rings; Michelson spectral interferometer (including treatment of doublet source); Fabry-Perot interferometer; the etalon as a filter.

Resolution [1 hr]
Rayleigh criterion; Abbe theory.

Geometrical optics and instruments [4 hrs]
reflection at a spherical surface; mirror formulae; refraction at a spherical surface; thin lens formulae; formal aspects of thick lenses; systems of two thin lenses; magnifying glass; astronomical telescope, compound microscope, telephoto lens; aperture, stops and *f*-numbers.

PHAS1228 – Thermal Physics and the Properties of Matter (Term 2)

Prerequisites

A-level Physics and Mathematics

Aims of the Course

This course aims to:
- introduce and apply the laws of Classical Thermodynamics;
- introduce some very basic quantum mechanical concepts;
- obtain predictions from the kinetic theory, and derive and apply the Maxwell–Boltzmann distribution;
- dicuss the symmetry and stability of the three primary phases of matter.

Objectives

After completing this course, students will:
- be aware of the origin of covalent, ionic, and van der Waals interactions;
- be able to describe the structures of ideal gases, real gases, liquids and solids;
- understand the meanings of heat and thermal equilibrium, state variables, state functions and equations of state;
- understand what is meant by an ideal gas and the ideal gas equation of state;
- understand the role of Avogadro's number and the mole;
- be familiar with simple kinetic theory of gases
- understand the separation of electronic, vibrational and rotational energy scales for gas molecules and be able to obtain the mean energy of each degree of freedom (equipartition of energy).
- understand the concepts of internal energy, heat and work, and be able to apply the first law of thermodynamics;
- be able to define specific heats and latent heat, and understand and manipulate Cp and Cv for ideal and real gases;
- be able to define isolated, isothermal and adiabatic processes;
- be able to derive from thermodynamic arguments the form of the Maxwell-Boltzmann distribution, and obtain the normalized velocity and speed distributions in an ideal gas;
- be aware of the ubiquity of the Maxwell-Boltzmann distribution for systems in thermal equilibrium;
- be able to obtain expressions for the mean collision and diffusion lengths from simple kinetic theory;
- be able to distinguish between reversible and irreversible processes;
- understand the concept of entropy and its relationship to disorder and its role in the fundamental equation (e.g. for an ideal gas).
- be able to obtain the ideal adiabatic equation of state;
- understand free adiabatic expansion as an example of an irreversible process;
- be able to derive the efficiency of the Carnot cycle, and understand the ideal operation of heat engines, refrigerators and heat pumps;
- be able to state the Zeroth, First, Second and Third Laws of thermodynamics;
- be able to combine the First and Second Laws of thermodynamics;
- explain how certain macroscopic quantities such as latent heat, surface energy and the critical point may be related to parameters of the microscopic inter atomic/molecular potential;
- understand the van der Waals equation of state for a real gas, and the form of the Lennard-Jones model for atomic interactions;
- understand phase equilibria and the Gibbs and Helmholtz free energy;

- understand the concept of a phase and appreciate the diversity of the phases of matter.
- be able to sketch typical phase diagrams, including the triple and critical points.

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 (15%) and a final written examination (85%).

Textbooks

- *"Physics for Scientists and Engineers with Modern Physics",* Serway and Jewett
- *"Physics",* Thornton, Fishbane and Gasiorowitz, Prentice Hall
- *"Thermal Physics",* Finn, Chapman and Hall
- *"The Properties of Matter",* Flowers and Mendoza, Wiley
- *"Understanding the properties of Matter*", de Podesta, UCL
- *"Statistical Physics",* Mandl, Wiley

Course content

Part 1: Thermodynamics and Kinetic Theory [15 hrs] (recommended books; Finn, Podesta)

Temperature and the Zeroth Law [3 hrs]
Heat and thermal equilibrium; The Zeroth Law; Temperature scales; Macroscopic description of an ideal gas; State functions; Equation of state for an ideal gas; Boyle's Law; Charles's Law; The mole and Avogadro's number

Energy and the First Law [3 hrs]
Internal energy, work and heat; The First Law; Heat capacity, specific heat and latent heat; Isolated, isothermal and adiabatic processes; Transfer of energy; Thermal conductivity

Kinetic Theory of Gases [4 hrs]
Molecular model of an ideal gas; Kinetic theory and molecular interpretation of temperature and pressure; Specific heats, adiabatic processes; Equipartition of energy; Specific heat; Adiabatic processes; Maxwell-Boltzmann distribution of molecular speeds; Collision and diffusion lengths in gases, effusion; Law of atmospheres; Thermal conductivity of gases

Entropy and the Second Law [5 hrs]
Reversible and irreversible processes; Entropy, disorder on a microscopic scale; The Second Law, entropy as a state function; Fundamental equation; The arrow of time and the fate of the Universe; Ideal adiabatic expansion; The Carnot heat engine, refrigerators and heat pumps; Combined First and Second Laws

Part 2: The Properties of Matter [15 hrs] (recommended books; Podesta, Flowers and Mendoza)
Real gases and liquids [2 hrs]
Non ideality; The van der Waals equation of state; Structure of liquids

Phase equilibria [3 hrs]
Equilibrium between phases; Phase diagrams, triple point and critical point; Clausius-Clapeyron equation.

Bonding [2 hrs]
Covalent, ionic, metallic and van der Waals bonding; Classification of solids; Interaction potentials (Lennard Jones and other functional forms); Thermal expansion; Cohesive energy calculations for van der Waals and ionic crystals

Mechanical Properties of Solids [3 hrs]
Elastic properties; Definitions of stress and strain; Bulk modulus, Young's modulus (calculate from interatomic potentials)

Crystal Structures [5 hrs]
Crystal structures described in terms of the Bravais lattice and basis; Examples of crystal structures (hcp, bcc, fcc , diamond, ZnS and CsCl structures); Primitive and conventional unit cells; Crystal structures of ionic materials using models of packed spheres; Miller indices to designate lattices, planes and directions in crystals; X-ray diffraction; Bragg's law

PHAS1240 – Practical Skills 1C (Term 1)

Prerequisites

There are no pre-requisites.

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 physics-related 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 PHAS1240 is the first course encountered by students in making the transition from school to University level studies. It aims to take the first steps in this process of training in practical skills by addressing the following objectives.

Objectives

By the end of the course the students should:

- have become familiar with some basic items of laboratory equipment
- have acquired increased skill and confidence in the acquisition and analysis of experimental data through the performance of experiments at an introductory level
- have improved ability to record work concisely and precisely as it is done, through repeated practice in recording experiments in a laboratory notebook, guided by frequent feedback from teachers
- be conversant with, and able to use, the data analysis programs which are maintained on the laboratory computers (currently Easyplot, LsFit and Excel)
- have an increased understanding and ability in applying the principles of data and uncertainty analysis, introduced in lectures, to experiments
- have increased conceptual understanding of topics in the theoretical part of the degree via the performance of linked experiments
- have increased ability to condense the information in their personal lab book record of an experiment into a concise, but precise and complete, formal report of the experiment in word processed form
- have experience in mapping a physics problem onto a computational framework
- have used computers to analyse experimental data, and thus, by comparison with physical models, evaluated the appropriateness of the model
- have used computers to model, visualize and solve physical systems, particularly those relevant to core first-year lecture modules
- have used the Python programming language to produce documented computer code that is clear, efficient, reusable and follows good coding practice

Course Contents

Treatment of Experimental Data
Six lectures on good practice in obtaining good experimental data and an introduction to data analysis and the analysis of experimental uncertainties. One problem sheet is set.

Computer-based skills
An introduction to computer programming for the analysis of data and problem-solving in physics.

Introductory experimental skills
Familiarisation through the performance of basic experiments, with some basic laboratory equipment and with computer packages for the analysis of experiments. This takes three to four afternoons at the beginning of the course. This part of the course must be completed, but no marks will be awarded for it which counts towards the assessment of the course. This is to enable students to find their feet in the lab environment before being called upon to perform work on which they will be judged.

Experiments
Eight afternoons spent performing experiments of First Year standard, some of which illustrate principles encountered in the lecture curriculum.

Formal report
One of these must be prepared on an experiment which has been completed.

Methodology and Assessment

In the computer-based skills component, each of the 10 weekly sessions will consist of a short lecture followed by practical sessions in which students will work individually, closely supervised at the rate of one supervisor per 5 or 6 students. Assessment is continuous, and will also include two longer assessed problem sheets. In the laboratory sessions, both in the introductory experimental skills part and the main series of experiments, students work in pairs following prescriptive scripts for the experiments. At this stage in the students' development, these are deliberately kept short and straightforward taking between one and two periods to complete. 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. Laboratory notebook records of experiments are normally marked as soon as the student finishes the work, in the laboratory with the student present to provide rapid feedback on perceived shortcomings. The formal report element is the first time at University that the students are faced with the task of distilling the information in their personal laboratory notebook record of an experiment into a concise report to a third party in word-processed form. They are given detailed advice on how to approach this. All assessed work is both first and second marked. The different course components contribute the total assessment with the following weights:

- Computer-based skills and treatment of experimental data 50%
- Experiments, 35%
- Formal report, 15%

Textbooks

There is no textbook 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*" by Kaye and Laby
- "*Handbook of Chemistry and Physics*" CRC Press
- *"Experimental Methods"* by L. Kirkup
- *"Measurements and their Uncertainties: A practical guide to modern error analysis"* by Hughes and Hase, OUP

PHAS1241 – Practical Skills 1P (Term 2)

Prerequisites

Normally PHAS1240 Practical Skills 1C

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 physics-related 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 PHAS1241 follows on directly from course PHAS1240, Practical Skills 1C, and by further practice contributes to reinforcing and extending many of the same objectives. The objectives for PHAS1241 are listed below.

Objectives

By the end of the course the students should:

- have extended the range of basic items of laboratory equipment with which they are familiar
- have acquired increased skill and confidence in the acquisition and analysis of experimental data through the performance of experiments at an introductory level
- have improved ability to record work concisely and precisely as it is done, through repeated practice in recording experiments in a laboratory notebook, guided by frequent feedback from teachers
- be further practiced in using the data analysis programs which are maintained on the laboratory computers (currently Easyplot, LsFit, Excel and Matlab)
- have an increased understanding and ability in applying the principles of data and uncertainty analysis, introduced in lectures, to experiments
- have increased conceptual understanding of topics in the theoretical part of the degree via the performance of linked experiments
- have increased ability to condense the information in their personal lab book record of an experiment into a concise, but precise and complete, formal report of the experiment in word processed form

Course Contents

Experiments
22 afternoons spent performing experiments of First Year standard, some of which illustrate principles encountered in the lecture curriculum.

Formal report
One of these must be prepared on an experiment which has been completed.

Methodology and Assessment

Assessment is continuous. In the laboratory sessions students work in pairs following prescriptive scripts for the experiments. The experiments are of the same standard as those in the prerequisite course, PHAS1240, but more varied. Great emphasis is placed on the formation of good habits in the keeping of a laboratory notebook for which the 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. Laboratory notebook records of experiments are normally marked as soon as the student finishes the work, in the laboratory with the student present to provide rapid feedback on perceived shortcomings. The formal report element, for the preparation of which students are given detailed advice, enables the student to benefit from the feedback given for the first report written in PHAS1240. All assessed work is both first and second marked. The different course components contribute to the total assessment with the following weights:

- Experiments, 85%
- Formal report, 15%

Textbooks

There is no textbook 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*" by Kaye and Laby
- "*Handbook of Chemistry and Physics*" CRC Press
- "*Experimental Methods*" by L. Kirkup
- *"Measurements and their Uncertainties: A practical guide to modern error analysis"* by Hughes and Hase, OUP

PHAS1245 – Mathematical Methods I (Term 1)

Prerequisites

It is assumed that, in order to take this course, students should normally have achieved at least a grade B in A-level Mathematics or other equivalent qualification. Knowledge of A-level Further Mathematics is not required.

Aims

This course aims to:

- provide the mathematical foundations required for all the first semester and some of the second semester courses in the first year of the Physics and Astronomy programmes
- prepare students for the second semester follow-on mathematics course PHAS1246
- give students practice in mathematical manipulation and problem solving

Objectives

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

- appreciate the relation between powers, exponentials and logarithms and the more general concept of the inverse function in terms of a graphical approach
- derive the values of the trigonometric functions for special angles
- understand the relation between the hyperbolic and exponential functions
- differentiate simple functions and apply the product and chain rules to evaluate the differentials of more complicated functions
- find the positions of the stationary points of a function of a single variable and determine their nature
- understand integration as the reverse of differentiation
- evaluate integrals by using substitutions, integration by parts, and partial fractions
- understand a definite integral as an area under a curve and be able to make simple numerical approximations
- differentiate up to second order a function of 2 or 3 variables and be able to test when an expression is a perfect differential
- change the independent variables by using the chain rule and, in particular, work with polar coordinates
- find the stationary points of a function of two independent variables and show whether these correspond to maxima, minima or saddle points
- manipulate real three-dimensional vectors, evaluate scalar and vector products, find the angle between two vectors in terms of components
- construct vector equations for lines and planes and find the angles between them, understand frames of reference and direction for interception using vectors
- express vectors, including velocity and acceleration, in terms of basis vectors in polar coordinate systems
- understand the concept of convergence for an infinite series, be able to apply simple tests to investigate it
- expand an arbitrary function of a single variable as a power series (Maclaurin and Taylor), make numerical estimates, and be able to apply l’Hôpital’s rule to evaluate the ratio of two singular expressions
- represent complex numbers in Cartesian and polar form on an Argand diagram
- perform algebraic manipulations with complex numbers, including finding powers and roots
- apply de Moivre’s theorem to derive trigonometric identities and understand the relation between trigonometric and hyperbolic functions through the use of complex arguments

Methodology and Assessment

There are 40 scheduled periods in this half-unit course, and the lecturer aims to spend roughly 15% of the time on worked examples that are typical of the questions set in the end-of-session examination. In addition there is a revision lecture in Term-3. Though mathematical formalism is developed throughout the course, the emphasis in the weekly homework sheets and final examination is very much on problem solving rather than demonstrations of bookwork. Since it is important that students become fluent in the application of Mathematics to Physics and Astronomy, the lectures are supplemented by problem solving tutorials which are an integral part of the course. Here small groups of students are given a problem sheet which they attempt there and then as well as being able to discuss other aspects of the course. Demonstrators circulate around the class to give advice on how questions should be tackled. Attendance at the problems classes is considered vital and is closely monitored.

The course is given in the first semester and test examinations are held just before Reading Week and just before Christmas. The primary objective of these is diagnostic, but they also prepare students for the style of examination current at UCL. Roughly half of each test will be on seen material from the homework sheets and problem classes with the other half new problems. Additional classes on PHAS1245 material in term 2 are obligatory for students who do poorly in the tests. The final written examination counts for 85% of the assessment. The 15% continuous assessment component is based on the two tests with 10% for the seen material and 5% for the unseen material.

Textbooks

A book which covers essentially everything in both these and the second-year mathematics course from a more advanced standpoint is *Mathematical Methods for Physics & Engineering*, Riley, Hobson & Bence, C.U.P.

Syllabus

In total, 33 lectures, 7 discussion/examples classes and 5 problems solving tutorials (2 hours each).

Elementary Functions (mainly revision) **[3 hrs]**
Manipulation of algebraic equations; powers; exponentials and logarithms; inverse functions; trigonometric functions; sine, cosine and tangent for special angles; hyperbolic functions

Differentiation (mainly revision) **[4 hrs]**
Definition; product rule; function of a function rule; implicit functions; logarithmic derivative; parametric differentiation; maxima and minima

Integration (mainly revision) **[5 hrs]**
Integration as converse of differentiation; changing variables; integration by parts; partial fractions; trigonometric and other substitutions; definite integral; integral as the area under a curve; trapezium rule; integral of odd and even functions

Partial Differentiation **[4 hrs]**
Definition; surface representation of functions of two variables; total differentials; chain rule; change of variables; second order derivatives; Maxima, minima and saddle points for functions of two variables

***Vectors* [9 hrs]**

Definition, addition, subtraction, scalar and vector multiplication; Frames of reference [2 hrs]
Vector and scalar triple products; vector equations (third order determinants only very briefly) [2.5 hrs]
Vector geometry - straight lines and planes; appropriate direction for interception [1.5 hrs]
Vector differentiation; vectors in plane polar, cylindrical and spherical polar coordinates [3 hrs]

***Complex Numbers* [4 hrs]**

Representation; addition; subtraction; multiplication; division; Cartesian; polar exponential forms; De Moivre's theorem; powers and roots; complex equations

***Series* [4 hrs]**

Sequences and series; convergence of infinite series; Power series; radius of convergence; simple examples including the binomial series; Taylor and Maclaurin series; L'Hôpital's rule

PHAS1246 – Mathematical Methods II (Term 2)

Prerequisites

It is assumed that, in order to take this course, students should normally have completed satisfactorily the first semester PHAS1245 or other equivalent course. Knowledge of A-level Further Mathematics is not required.

Aims

This course aims to:

- provide, together with PHAS1245, the mathematical foundations required for all the first year and some of the second year courses in the Physics and Astronomy programmes
- prepare students for the second year Mathematics course PHAS2246 and MATHB6202
- give students further practice in mathematical manipulation and problem solving

Objectives

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

- Find the general solutions of first order ordinary linear differential equations using the methods of separation, integrating factor and perfect differentials, and find particular solutions through applying boundary conditions;
- Find the solutions of linear second order equations with constant coefficients, with and without an inhomogeneous term, through the particular integral complementary function technique
- Perform line integrals of vectors
- Set up the limits when integrating in 2 and 3-dimensions and evaluate the resulting expressions
- Change integration variables. In particular to judge when polar coordinates are appropriate and to be able to change to them
- Do matrix multiplication. Be able to evaluate the determinant, the trace, the transpose and the inverse of matrices of arbitrary dimension
- Manipulate vectors in a complex *n*-dimensional space and represent linear transformations in this space by matrices
- Perform matrix algebra, including multiplication and inversion, using a wide variety of matrices including unitary, Hermitian, and orthogonal matrices
- Solve linear simultaneous equations through the use of matrices and determinants
- Summarise the reasons for the failure of Newtonian mechanics as speeds approach that of light
- Understand the derivation of, and be able to use, Lorentz transformation equations in the special theory of relativity and apply them to the space-time and momentum-energy four-vectors
- Apply relativistic kinematics to high energy particle physics, so as to treat the Doppler effect for photons and determine the threshold energy for pair-production in different frames of reference

Methodology and Assessment

The methodology is very similar to the precursor first-semester PHAS1245 half-unit, with 40 scheduled periods, of which roughly 15% are used to go through worked examples. In addition there are four two-hour supervised problem solving tutorials in term 2 as well as two revision lectures in Term-3. Though mathematical formalism is developed throughout the course, the emphasis in the weekly homework sheets and final examination is very much on problem solving rather than demonstrations of bookwork.

Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (15%) and a final written examination (85%).

Textbooks

The book recommendations are similar to those given for the first semester precursor course, for example Riley, Hobson and Bence. A book which treats essentially everything in both these and the second-year PHAS2246 mathematics course from a more advanced standpoint is *Mathematical Methods in the Physical Sciences*, by Mary Boas (Wiley). However, many first year students have in the past found it to be too formal. The special relativity content should be found in most general physics texts, though the course does not follow any of these very closely.

Syllabus

33 lectures, 7 discussion classes and 4 problem-solving tutorials.

(The provisional allocation of lectures to topics is shown in brackets. The ordering an allocation is subject to change, outlined on the course info website)

Multiple Integrals **[5 hrs]**
Line integrals; area and volume integrals; change of coordinates; area and volume elements in plane polar; cylindrical polar and spherical polar coordinates

Differential Equations **[5 hrs]**
Ordinary first-order; separable, integrating factor; change of variables; exact differential; Ordinary second order homogeneous and non-homogeneous including equal roots

Matrices and Linear Transformations **[14 hrs]**
Matrix multiplication and addition; Finding the determinant, trace, transpose and inverse of a matrix; Matrices as a representation of rotations and other linear transformations; Definition of 2, 3 and higher order determinants in terms of row evaluation (no use is made of □$_{ijklm}$..); the rule of Sarrus; Manipulation of determinants; Cramer's rule for the solution of linear simultaneous equations

Revision of real 3-dimensional vectors; Complex linear vector spaces; Linear transformations and their representation in terms of matrices

Special Theory of Relativity **[9 hrs]**
Implications of Galilean transformation for the speed of light Michelson-Morley experiment; Einstein's postulates; Derivation of the Lorentz transformation equations and the Lorentz transformation matrix; length contraction, time dilation, addition law of velocities, "paradoxes"; Four-vectors and invariants; Transformation of momentum and energy; Invariant mass; Conservation of four-momentum; Doppler effect for photons, threshold energy for pair production, the headlight effect

PHAS1247 – Classical Mechanics (Term 1)

Prerequisites

In order to take this course, students should have achieved at least a grade B in A-level Mathematics or other equivalent qualification. Knowledge of A-level Further Mathematics is not assumed but it is expected that students will have shown a level of competence in the first term PHAS1245 mathematics course.

Aims of the Course

This course aims to:

- convey the importance of classical mechanics in formulating and solving problems in many different areas of physics and develop problem-solving skills more generally
- introduce the basic concepts of classical mechanics and apply them to a variety of problems associated with the motion of single particles, interactions between particles and the motion of rigid bodies
- provide an introduction to fluid mechanics

Objectives

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

- state and apply Newton's laws of motion for a point particle in one, two and three dimensions
- use the conservation of kinetic plus potential energies to describe simple systems and evaluate the potential energy for a conservative force
- understand an impulse and apply the principle of conservation of momentum to the motion of an isolated system of two or more point particles
- solve for the motion of a particle in a one-dimensional harmonic oscillator potential with damping and understand the concept of resonance in a mechanical system
- appreciate the distinction between inertial and non-inertial frames of reference, and use the concept of fictitious forces as a convenient means of solving problems in non-inertial frames
- describe the motion of a particle relative to the surface of the rotating Earth through the use of the fictitious centrifugal and Coriolis forces
- derive the conservation of angular momentum for an isolated particle and apply the rotational equations of motion for external torques
- solve for the motion of a particle in a central force, in particular that of an inverse square law, so as to describe planetary motion and Rutherford scattering
- describe the motion of rigid bodies, particularly when constrained to rotate about a fixed axis or when free to rotate about an axis through the centre of mass
- calculate the moments of inertia of simple rigid bodies and use the parallel and perpendicular axes theorems
- appreciate the influence of external torques on a rotating rigid body and provide a simple treatment of the gyroscope
- understand the basic properties of fluid mechanics, particularly hydrostatics and elementary aspects of fluid dynamics
- give a qualitative description of air flow over an aerofoil

Methodology and Assessment

In addition to the 27 lectures and 10 discussion periods, there are 4 two-hour problem-solving tutorials in which groups of approximately twelve students attempt to solve sets of problems under the supervision of two demonstrators. This exercise is specifically designed to help in the development of a student's problem-solving skills. There are 2 revision lectures in Term-3. Final assessment is by 2 In-Course-Assessment (ICA) tests during the term based on seen homework problems (15%) and a final written examination (85%).

Textbooks

The contents of the course and the general level of the treatment of topics, is similar to the material in *Physics* by Serway and Jewett (Thomson). A rather more advanced treatment of some topics may be found in *An Introduction to Mechanics*, by Kleppner and Kolenkow (McGraw-Hill).

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

Introduction to Classical Mechanics [1 hr]
Importance of classical mechanics, conditions for its validity; Statics, kinematics, dynamics; units and dimensions; Newton's laws of motion

Motion in one dimension [4 hrs]
Variable acceleration; Work, power, impulse; Conservation of momentum and energy: conservative force, potential and kinetic energy; Construction of equations of motion and their solutions; Simple harmonic motion: damped and forced oscillations, resonance

Motion in two and three dimensions [12 hrs]
Relative motion: Galilean and other transformations between frames of reference; Inertial and non-inertial frames of reference, fictitious forces; Motion in a plane: trajectories, elastic collisions; Constraints and boundary conditions; Rotation about an axis: motion in a circle, angular velocity, angular momentum, torques and couples; radial and transverse components of velocity and acceleration in plane polar coordinates, centrifugal and Coriolis forces; Orbital motion for inverse square law of force: statement of the gravitational force due to a spherically symmetric mass distribution; Kepler's laws of planetary motion (review of properties of conic sections)

Rigid Body Motion [5 hrs]
Centre of mass, its motion under the influence of external forces; moment of inertia, theorems of parallel and perpendicular axes; centre of percussion; rotational analogues of rectilinear equations of motion; simple theory of gyroscope

Fluid Mechanics [5 hrs]
Fluids at rest: pressure, buoyancy and Archimedes principle; Fluids in motion: equation of continuity for laminar flow; Bernoulli's equation with applications, flow over an aerofoil; brief qualitative account of viscosity and turbulence

PHAS1423 – Modern Physics, Astronomy and Cosmology (Term 1) *Natural Sciences students only*

Prerequisites

A-level Maths and Physics or equivalents. Students must be able to differentiate and be familiar with the basic principles of diffraction, electromagnetism, classical mechanics, force etc. No previous knowledge of Quantum Physics, Astronomy or Cosmology is required.

Aims of the Course

- To introduce new concepts in quantum physics which underlie much of Modern Physics (including Medical Physics) and Astronomy and Cosmology
- To approach the frontiers of understanding in Modern Physics (including Medical Physics) and Astrophysics and Cosmology
- To provide a basis of descriptive knowledge for Natural Sciences stream choices later in year 1

Objectives

Quantum and Atomic Physics
After taking the course the student should be able to:

- Explain the failures of classical physics at the atomic scale
- State the revised versions of relativistic momentum and energy obtained from Special Relativity
- Describe the hypotheses of Planck, Einstein and de Broglie on the duality of waves and particles, and the evidence supporting them
- State Heisenberg's uncertainty principle
- Write down the time-independent Schrödinger equation and its solutions for a free particle and a particle in an infinite square well, explaining how they give rise to quantum numbers
- Explain how this, in combination with the Exclusion Principle, gives rise to the observed structure of atoms

Medical Imaging
After taking the course the student should be able to:

- Describe the basic physical principles involved in the major medical imaging techniques, including: x-ray imaging, computed tomography, ultrasound, magnetic resonance imaging, radioisotope imaging, and electroencephalography
- Explain the contrast mechanisms in each of the above methods, and understand the difference between anatomical and functional imaging
- Differentiate between the clinical uses of the alternative techniques based on the information they provide and the risk/benefit to the patient

Astronomy and Cosmology
After taking the course the student should be able to:

- Describe the main stellar spectral classification scheme, with connection to the effective temperature and luminosity of the objects
- Explain the processes by which energy is generated in stars
- Outline the main evolutionary paths of stars, including properties of their end-states. Outline the main observational factors in support of the Big Bang model
- Explain simple 'world models' in cosmology

Laboratory Physics
After taking the course the student should:

- Have become familiar with some basic items of laboratory equipment
- Have acquired increased skill and confidence in the acquisition and analysis of experimental data through the performance of experiments at an introductory level
- Have improved ability to record work concisely and precisely as it is done, through repeated practice in recording experiments in a laboratory notebook, guided by frequent feedback from teachers

Methodology and Assessment

The course is based on 30 hours of timetabled lectures plus 5 hours of problem solving tutorials including in-course-assessments classes and discussion. There will also be three 3.5 hour laboratory sessions to introduce practical physics lab work.

The full assessment for the module will have three components:

- Examination 70%
- Two In Course Assessments 15%
- Physics labs 15%

Recommended Books

- *Physics for Scientists and Engineers with Modern Physics*, Serway and Jewett (Thomson)
- *Physics for Scientists and Engineers* (2nd Ed), Fishbane, Gasiorowicz and Thornton, Prentice Hall (1996)
- *Introductory Astronomy and Astrophysics* (4th Ed) Michael Zeilik and Stephen A. Gregory (Thomson Learning, ISBN 0030062284)
- *Universe* (7th edition), by Roger A. Freedman & William J. Kaufmann III, may provide useful supplementary reading
- *Medical Physics* by Emily Cook and Adam Gibson. Booklet available online at: www.teachingmedicalphysics.org.uk
- *Physics of Medical Imaging*, Edited by S. Webb, (Adam Hilger: Bristol), 1988. ISBN 0-85274-349-1

Background Reading for the Whole Course

- *The New Physics for the 21st Century* (2nd Ed), ed Gordon Fraser, Cambridge University Press

Syllabus
[Approximate allocations of lectures to topics are given in square brackets]

Quantum and Atomic Physics [14 hrs]

Breakdown of Classical Physics – Light [6 hrs]

Waves; superposition and coherence; Newtonian optics; Young double-slit experiment; Michelson-Morley experiment; Special Relativity; blackbody radiation and Planck quantization; photoelectric effect; particle/wave "duality"; Compton scattering; pair production; Bragg scattering for light

Quantum Theory – Particles and Waves [4 hrs]
The de Brogle conjecture; electron diffraction (Davison/Germer, Thompson, and Bragg); probabilistic interpretation of the wavefunction; Uncertainty Principle; particle in a box; Schrödinger equation; tunnelling

Atoms [4 hrs]
Thomson model of atomic structure; Rutherford model of Hydrogen (from Geiger and Marsden experiment); atomic spectra; Bohr model of Hydrogen; solution of Hydrogen atom with Schrödinger equation (spherical coordinates, eigenfunctions, quantum numbers); fine structure; Pauli exclusion; periodic table

Medical Imaging [6 hrs]
X-ray imaging, including angiography. X-ray computed tomography; Diagnostic ultrasound, including Doppler imaging; Magnetic resonance imaging; Medical imaging using radioisotopes; Electroencephalography

Astronomy and Cosmology [10 hrs]
Stellar luminosity, effective temperature and spectral types; Energy generation and the evolution of stars; Overview of galaxies, Hubble's law and the Big Bang model; Concepts of inflation

Laboratory Physics [10 hrs]
Familiarisation, through the performance of basic experiments, with some basic laboratory equipment and with computer packages for the analysis of experiments

PHAS1449 – Practical Mathematics 1 (Term 2)

Prerequisites

There are no prerequisites for this course, but it is itself a prerequisite for PHAS2443 Practical Mathematics II in the second year.

Aims

The course will introduce students to the use of modern computer packages for the solution, by both analytic and numerical methods, of a wide range of problems in applied mathematics in science. This skill is of particular importance for students on the Theoretical Physics course.

Objectives

The course helps to demonstrate the application of mathematical methods to physical problems, reinforcing the student's knowledge of both the physics and the mathematics, and preparing the student for the use of computer-based mathematical methods in problem-solving.

Methodology and Assessment

The course is based on the Mathematica programming language. Computing sessions will consist of demonstrations of the features of the language followed by application of the new material to problems under the guidance of the course teacher. The students' grasp of the subject will be tested in problem sheets to be tackled in the students' own time. Assessment will be based on an unseen computer-based examination on Mathematica (60%) and coursework problem papers (40%).

The topics covered are as follows:

- "Computer Algebra" systems in general and *Mathematica©* in particular; Basic algebra, differential and integral calculus; Power expansions of functions; Limits
- *Mathematica©'s* structures (especially lists) and their relationship with mathematical structures; Operations on lists; Lists as sets; Inner and outer products; Lists of data
- Rules, patterns, and how to apply them; *Mathematica©'s* pattern constructions; Rules as returned when solving equations; Manipulating expressions with rules; More general pattern-matching: sequences, types, criteria and defaults; RepeatReplace and delayed rules
- Defining functions; Overloading of functions; Recursive procedures; Loops and control structures
- Graphics: basic line graphs, contour and surface plots; Controlling graph layouts, combining and animating graphs; Applications to visualisation of fields; Conformal Mapping; Domains of functions
- Numerical solutions of algebraic equations using FindRoot and using graphs to control the process; Methods of root-finding by bisection and the Newton-Raphson method
- Numerical solution of differential equations by finite difference methods, including simple stability analysis; Use of NDSolve
- Repeated operations without loops: Nest, While, FixedPoint, Through
- Series solution of differential equations; Boundary value problems (shooting methods); Brief treatment of partial differential equations
- Analysis of data: linear and non-linear fitting; Goodness of fit; Reading and writing external data files; Simple image processing; (pixellisation; edge enhancement)

PHAS1901 – Developing Effective Communication 1 (Term 1)

Prerequisites

None

Aim of the Course

This is the first of two modules that aim to develop your skills in getting your messages 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:

- write short pieces for non-specialist and specialist audiences
- orally present scientific ideas to a small group of peers
- construct a personal web page
- use appropriate IT effectively

Methodology and Assessment

This module runs for the whole three terms, with one hour every week in the first two terms set aside for lectures, discussions, seminars, or surgeries. Some of the work is done as part of tutorials. Students will practise writing of short essays and reports, prepare, deliver and discuss short oral presentations to small and medium sized audiences, and construct a personal web page. The module continues in the third term, with some exercises taking place in the period after examinations and before the end of the third term.

Assessment will be of written coursework of different types, oral presentations and computational work (web pages). There will be an element of peer assessment. This module is weighted 50% of the two year communications skills provision, which includes PHAS2901 in year 2. The two modules together will contribute to your assessment for honours at a level equivalent to approximately 5%.

Textbooks

A range of textual material will be used. Students should find *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.