UNIVERSITY COLLEGE LONDON

Department of Physics and Astronomy

PROGRAMME STRUCTURE

Physics BSc (part-time) [with Birkbeck]

SESSION 2004/2005

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A copy of this document can be found on the Department web site: www.phys.ucl.ac.uk

CONTENTS

1 OVERALL COURSE STRUCTURE

The course leading to the degree of B.Sc. in Physics (part-time regulations) is structured into three levels which the student undertakes sequentially. All levels of the degree include physics lectures and physics practical classes. At levels 1 and 2 there are also lectures in mathematics.

LEVEL 1 Courses at this level are introductory.

LEVEL 2 Includes some courses of an introductory nature which complete a basic course in physics begun at level 1. The remainder are of an intermediate standard linking directly with more specialised courses taken at level 3.

LEVEL 3 Courses at this level are more advanced and cover all areas of physics. Students are required to include project work at this level.

2 DURATION OF DEGREE PROGRAMME AND SEQUENCE OF COURSES

The Course is normally spread over four years of part-time study involving attendance on three evenings per week (6pm to 9pm). One year is spent at each of levels 1 and 2 with two years required to take the courses at level 3. The degree comprises 11 course units of study with two-and-a-half being taken at levels 1 and 2 and three in each of the years devoted to level 3. Courses at levels 1 and 2 are given annually; courses at level 3 are divided between alternate years, as shown below. They may be entered in either year of the cycle.

Note: The timetable for the current year is provided as a separate sheet.

3 DETAILED STRUCTURE OF THE COURSE

3.1 AT LEVEL ONE

Unit Value	Course Number	Subject
$\frac{1}{2}$	1B28	Thermal Physics
$\frac{1}{2}$	1B72	Waves and Modern Physics
$\frac{1}{2}$	1B70	Physics Laboratory and Computing I
1	1B71	Mathematics for Physics

3.2 AT LEVEL TWO

Unit Value	Course Number	Subject
$\frac{1}{2}$	2B72	Mathematical Methods for Physics
$\frac{1}{2}$	1B47	Classical Mechanics
$\frac{1}{2}$	2B22	Quantum Physics
$\frac{1}{2}$	2201	Electricity and Magnetism
$\frac{1}{2}$	2B70	Physics Laboratory and Computing II

3.3 AT LEVEL THREE

Lecture courses (half of the courses are given every other year)

Beginning in odd year:

Unit Value	Course Number	Subject
$\frac{1}{2}$	2B27	Environmental Physics
$\frac{1}{2}$	2B24	Atomic and Molecular Physics
$\frac{1}{2}$	3C26	Quantum Mechanics
$\frac{1}{2}$	3C24	Nuclear and Particle Physics
$\frac{1}{2}$	3C75	Principles and Practice of Electronics

Beginning in even year:

Unit Value	Course Number	Subject
$\frac{1}{2}$	2B28	Statistical Thermodynamics and Condensed Matter Physics
$\frac{1}{2}$	2B29	Electromagnetic Theory
$\frac{1}{2}$	3C74	Topics in Modern Cosmology
$\frac{1}{2}$	3C25	Solid State Physics
$\frac{1}{2}$	3C43	Lasers and Modern Optics

Practical courses

Students in the third year of the degree also take the $\frac{1}{2}$ unit 3C70, Physics Practical.

Students in the fourth year of the degree also take the $\frac{1}{2}$ unit 3C80, Physics Practical and Project.

3.4 COURSE MODULE CODES AND NAMES

Please note that some of the module names given in the table above are not precisely the same as the official ones that appear on exam entry forms. The official names are as follows:

1B70: Practical (Laboratory) Skills I
1B71: Mathematics
2B70: Practical (Laboratory) Skills II
2B72: Mathematical Methods
3C70: Practical (Laboratory) Skills III
3C80: Practical (Laboratory) Skills IV

The codes used above (e.g. “1B28”) are in the abbreviated form commonly used within the department. On College documents the full codes must be used. These are different for UCL or Birkbeck.

At UCL, precede the abbreviated code by “PHYS”, e.g. “PHYS1B28”, except for the Level Two module *Electricity and Magnetism* whose full code is PHAS2201.

At Birkbeck, precede the abbreviated code by “17/680/”, e.g. “17/680/1B28”, “17/680/2201”.

4 TEACHING STAFF

Physics and Astronomy teaching staff involved with the Evening Physics Degree course

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Key to locations

Physics – Physics Building
Wolfson – Wolfson Building
Elec Eng – Electrical Engineering
KL – Kathleen Lonsdale Building

5 INDIVIDUAL COURSE INFORMATION

There follows detailed syllabuses for all of the courses. Each entry also includes the course prerequisites, a statement of the aims of the course, the course objectives, and the recommended textbooks for the course.

PHYS1B28 – Thermal Physics (Part-time Programme)

Prerequisites

A-level Physics and Mathematics

Aims of the Course

This course aims to:

- introduce and apply the laws of Classical Thermodynamics;
- obtain predictions from the kinetic theory, and derive and apply the Maxwell–Boltzmann distribution;
- show how the three primary states of matter result from competition between thermal kinetic energy and interparticle potential energy.

Objectives

After completing this course, students will:

- be familiar with the Bohr model of the hydrogen atom;
- 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;
- be able to state the Zeroth Law of thermodynamics;
- 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, and be able to obtain the mean energy of each degree of freedom (equipartition of energy) by combining with the ideal gas equation of state;
- understand the concepts of internal energy, heat and work, and be able to state and 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;
- be able to state the Second Law of thermodynamics;
- 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 combine the First and Second Laws of thermodynamics;
- be able to state the Third Law 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;
- be able to sketch typical phase diagrams, including the triple and critical points.

Methodology and Assessment

The course consists of 27 lectures covering main course material, and 6 hours of other activities, including discussion of problem sheets and advanced topics. Assessment is based on an unseen written examination (85%) and four sets of homework (15%)

Textbooks

- *Physics for Scientists and Engineers*, Serway and Jewett (Thomson/Brooks/Cole)
- *Physics*, Thornton, Fishbane and Gasiorowitz, Prentice Hall.
- *The Properties of Matter,* Flowers and Mendoza, Wiley
- *Understanding Matter,* de Podesta, UCL
- *Physical Chemistry*, Atkins, Oxford.
- *Statistical Physics*, Mandl, Wiley.

Syllabus

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

Introduction [1]
Introduction: context and scope of the course.
Atoms, ions and molecules as the building blocks of matter [3]
The structure of the atom. Bohr model of the hydrogen atom. Covalent, ionic, hydrogen and van der Waals bonds. Lennard-Jones interaction potential. Origin of solids, liquids, real gases and perfect gases.
Temperature and the Zeroth Law [3]
Heat and thermal equilibrium. The Zeroth Law. Temperature scales. Thermal expansion. 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]
Internal energy, work and heat. The First Law. Heat capacity, specific heat and latent heat. Isolated, isothermal and adiabatic processes. Transfer of energy.
Kinetic Theory of Gases [4]
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.
Entropy and the Second Law [6]
Reversible and irreversible processes. Entropy; disorder on a microscopic scale. The Second Law; entropy as a state function. The arrow of time. Ideal adiabatic expansion. The Carnot heat engine, refrigerators and heat pumps. Petrol engines. Combined First and Second Laws.
Low temperature physics and the approach to absolute zero: the Third Law *[1]*
Onset of quantum behaviour. The Third Law of thermodynamics.
Real gases [2]
The van der Waals equation of state.
Solids and liquids [2]
Simple solid structures; close-packing, coordination number, examples. Cohesive energy. Elastic properties; Young’s modulus. Melting and evaporation. Surface energy and surface tension.
Phase equilibria and free energy [2]
Equilibrium between phases; Gibbs and Helmholtz free energy. Phase diagrams; triple point and critical point.

PHYS1B47 (previously PHYS1B27) – Classical Mechanics (Part-time Programme)

Course Information

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 Level 1 PHYS1B71 course.

Aims
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 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 Corioli 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
27 lectures and 6 discussion periods. There are three revision lectures in Term 3.

Notes summarising the mechanics of a particle moving in one dimension, as covered in a course of A-level mathematics, are distributed to the class before the start of the course.

The written end-of-year examination counts for 85% of the assessment, whereas the continuous element is worth 15%.

Textbooks

The contents of the course, and the general level of the treatment of topics, is similar to the material in *Physics for Scientists and Engineers*, Serway and Jewett (Thomson/Brooks/Cole). A rather more advanced treatment of some of the 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.)

Classical Mechanics [20 lectures]

Introduction [1]

Importance of classical mechanics; conditions for its validity

Statics, kinematics, dynamics; units and dimensionsNewton' s laws of motion

Motion in one dimension [4]

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]

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]

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]

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.

PHYS1B71 – Mathematics for Physics

Course Information

Prerequisites
Though a pass in A-level Mathematics is desirable, a variety of other qualifications, such as the satisfactory completion of an appropriate ACCESS course, is also acceptable.

Aims of the Course
This course aims to:

- provide the mathematical foundations required for all the first level and some of the second level courses in the part-time Physics programme;
- prepare students for the second level PHYS2B72 Mathematics course;
- give students some practice in mathematical manipulation and problem solving.

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

- differentiate simple functions and use the product and chain rules;
- integrate simple functions and be able to use substitution and integration by parts;
- find numerical approximations for definite integrals;
- 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;
- 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, and evaluate the radius of convergence of a power series;
- 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, hyperbolic and logarithmic functions through the use of complex arguments;
- 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;
- evaluate the gradient of a function of three variables and work out the change in the function when these variables change by small but finite amounts;
- perform line integrals of vectors, be able to test for conservative forces and handle the corresponding potential energy;
- set up the limits when integrating in 2 and 3-dimensions and evaluate the resulting expressions;
- change integration variables, especially to polar coordinates;
- 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;
- evaluate a 3×3 determinant and use it to solve linear simultaneous equations;
- carry out simple manipulations on matrices, including addition and multiplication.
- evaluate means and standard deviations for discrete and continuous probability distributions.

Methodology and Assessment

This whole-unit course runs for 22 weeks over the first two terms, at the rate of 3 hours per week. In addition to these 66 scheduled hours, there are two 3-hour revision sessions at the beginning of Term-3. Since students taking courses in the evening have relatively little spare time for homeworks and additional study during the week, about a quarter of the 3 hours is taken up with going over examples and solutions to relevant previous examination questions. The homework sheets are six small ones done at regular intervals during term time and two larger ones to be handed in just after the Christmas and Easter vacations. Though mathematical formalism is developed throughout the course, the emphasis is very much on problem solving rather than demonstrations of bookwork. Revision notes are provided on what is expected of students from A-level on integration methods, and copies of the lecture notes are also made available.

The written examination counts for 90% of the assessment, with 10% coming from the Christmas and Easter homework sheets.

Textbooks

A book that covers essentially everything in both this and the second-year 2B72 mathematics course, is *Mathematical Methods in the Physical Sciences*, by Mary Boas (Wiley).

Good books on problem solving for students are *Engineering Mathematics* and *Further Engineering Mathematics* by K A Stroud (Macmillan). These are programmed texts that treat everything as a series of problems, in contrast to the presentation of standard textbooks. The first volume covers clearly and simply most of the course, including a lot of A-level revision. The main exceptions are stationary points, the differentiation of vectors and the use of the word "gradient" in vector calculus, but these are included in the author's second volume.

Syllabus
The time allocation for each topic, indicated by hours in square brackets below, includes that for worked examples and solutions to relevant previous examination questions.

***Preliminary* [8]**
Elementary functions: exponential, logarithmic, tringonometric, and hyperbolic. [3]
Differentiation of: polynomials, trigonometric and inverse functions, logarithms, products and quotients. [2]
Integration: as reverse of differentiation, by rearrangement, by substitution (change of variable), by parts, some special methods. [3]

***Numerical Integration* [2]**
Definite integrals, trapezium rule, Simpson’s rule.

***Determinants and Matrices* [6]**
Definition of a determinant, evaluation by expansion, alternating sign rule, manipulation rules for rows and columns, reduction of order, solution of linear simultaneous equations. [4]
Addition, subtraction and multiplication of matrices, zero matrix and unit matrix. Representation of linear simultaneous equations by a matrix equation. [2]

***Vectors* [13]**
Definition, addition and subtraction, scalar and vector multiplication. [2]
Vector and scalar triple products, vector equations. [4]
Vector geometry of straight lines. [3]
Vector differentiation, vectors in alternative coordinate systems: plane polar; cylindrical and spherical polar. [4]

***Series* [6]**
Infinite series, tests for convergence, differentiation of infinite series and convergence. [3]
Power series, Taylor and Maclaurin series expansions (functions of one variable) and L’Hôpital’s rule. [3]

***Complex Numbers* [5]**
Geometrical representation, addition, subtraction, multiplication, division. Cartesian, polar and exponential forms. De Moivre’s theorem, powers and roots. Complex functions and equations.

Partial Differentiation [5]
Definition, surface representation of functions of two variables, exact difference and total differentials. Chain rule, change of variables, 2nd order derivatives.

***Stationary Points* [4]**
Maxima, minima and saddle points for functions of two variables. Taylor and Maclaurin series for functions of two variables and definition of stationary points.

***Vector Calculus* [4]**
Directional derivatives, gradient for functions of two and three variables. Conservative fields.

***Multiple Integrals* [4]**
Line integrals, area and volume integrals, change of coordinates by substitution and Jacobean (without proof).

***Differential Equations* [5]**
Ordinary first order: separable variables, integrating factor and exact differential solutions. [2]
Ordinary 2nd order: homogeneous and inhomogeneous but not including solutions with equal roots. Imposition of boundary conditions. [3]

***Probability* [4]**
Definition, coins and dice, normalisation, mean value, variance, standard deviation, normal distribution, discrete and continuous distributions

PHYS1B72 – Waves and Modern Physics (Part-time Programme)

Course Information

Prerequisites
Students should have achieved good grades in A-level Physics, or an equivalent qualification. In addition, students are assumed to be taking 1B71: Mathematics.

Aims of the Course
This course aims to:

- develop an understanding of the wave nature of light, including the phenomena of reflection, refraction, interference and diffraction ;
- develop an understanding of the propagation of waves in solids and in air, and of the Doppler effect;
- develop an understanding of the photoelectric effect and hence the wave-particle duality of light;
- introduce the concept of quantization of energy levels;
- prepare students for the second year level course, 2B22: Quantum Physics.
- develop a good understanding of the concepts of the special theory of relativity.

Objectives
After completing this course students should be able to:

- understand and apply the laws of reflection and refraction, and the concept of dispersion.
- know the equations for standing waves and traveling waves, and the difference betweeen longitudinal and transverse waves;
- deduce the conditions for constructive interference in a two-slit experiment;
- deduce the velocity of transverse and longitudinal waves in solids;
- deduce the velocity of sound in air, and understand its temperature dependence;
- understand the Doppler effect;
- have studied the diffraction patterns from a circular aperture and from a diffraction grating, and be able to apply Rayleigh's resolution criterion in both cases;
- have studied the photoelectric effect and its implications for the particle-like behaviour of light;
- know and use de Broglie's relation $\lambda=h/p$;
- understand electron diffraction and neutron diffraction;
- understand the quantization of the energy levels of a particle in a box;
- understand the concept of a wave function and of probability density;
- know Heisenberg's Uncertainty Principle;
- understand the Bohr model of the atom, and deduce the energy levels for the H-atom;
- know the λ and T dependence of the black body radiation spectrum, the significance of Planck's explanation, and to be able to use $E=h\nu$;
- understand the Compton effect and its significance;
- know that electrons have an intrinsic spin;
- know the Exclusion Principle and understand the structure of the Periodic Table.
- discuss the failure of classical mechanics at speeds approaching that of light;
- state the postulates of the special theory of relativity and appreciate the significance of the Lorentz transformation equations;
- discuss ideas of simultaneity and time dilation including its experimental confirmation using muon decay and length contraction;
- define relativistic momentum and rest energy, relate these quantities to the total energy and discuss the equivalence of mass and energy.

Methodology and Assessment
27 lectures plus 6 discussion periods. Assessment is based on the results obtained in the written examination (85%) and in course work (15%).

Textbooks

- Much of the material is covered in *Physics for Scientists and Engineers*, Serway and Jewett (Thomson/Brooks/Cole)
- An alternative book is *"Fundamentals of Physics"* by Halliday, Resnick and Walker (Wiley)
- An excellent and more advanced treatment of the modern physics part of the course is given in *"Concepts of Modern Physics,* by Beiser (McGraw-Hill) .

Syllabus

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

***Waves* [4]**
Simple harmonic motion, wave equations for standing and travelling waves; reflection and refraction; Snell's law; wavelength dependence of refractive index; dispersion.

***Waves in solids and in air* [4]**
Longitudinal and tranverse sound waves in solids; sound waves in air; temperature dependence of sound velocity; Doppler effect.

***Interference and Diffraction* [4]**
Two-slit interference pattern; diffraction from circular aperture; diffraction grating; Rayleigh resoltion criterion.

***Special Relativity* [5]**
Inertial frames. Postulates. Galilean and Lorentz transformations. Time dilation. Length contraction. Relativistic momentum and energy. Rest energy.

***Black body spectrum* [1]**
Wavelength and temperature dependence of black body radiation spectrum; Planck's hypothesis.

***Wave-Particle duality* [3]**
Photolectric effect, de Broglie equation; electron diffraction; neutron diffraction; wave-particle duality.

***Energy Levels and Wave Functions* [5]**
Quantization of energy levels of particle in 1-dimensional box; Bohr's model of the atom; energy levels of 1-electron atom; concepts of wave function and probability density; orbital angular momentum.

***Electron spin and the Periodic Table* [1]**
Energy levels of atoms in magnetic field; electron spin; multi-electron atoms; the Periodic Table.

PHAS2201 (previously PHYS1B26) – Electricity and Magnetism (Part-time Programme)

Course Information

Prerequisites

Students should have achieved good grades in A-level Physics, or an equivalent qualification, the electricity and magnetism component of which provides the necessary background for this course. In addition, students are assumed to have taken 1B71: Mathematics, or an equivalent mathematics course.

Aims of the Course

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. He/she should be able to express them in mathematical form and solve simple problems, including an analysis of DC and AC circuits.

Methodology and Assessment

Lectures, presentation of worked examples, and personal learning from recommended texts. Success will be judged by performance in the final unseen written exam (90%) and home coursework (10%). The coursework mark is based on the results of problems given out either during the course or at the start of the Easter vacation, whichever mark is better.

Textbooks

Electromagnetism, 2nd edition by I.S. Grant and W.R. Phillips (Wiley)
Physics for Scientists and Engineers, Serway and Jewett (Thomson/Brooks/Cole)

Syllabus

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

Milestones in electromagnetism [1]

Coulomb's torsion balance and the inverse square law of electric charges. Biot-Savart law governing the force between a straight conductor and a magnetic pole. Introduction of the concept of field by Faraday. Maxwell's equations. Hertz's oscillating dipole experiment. Marconi's and Morse' invention of wireless communication.

Electrostatics [6]

Coulomb's law; electric field; Gauss' law; 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 charge distribution; electric dipole; potential of a continuous charge distribution. Electrostatic energy; energy for a collection of discrete charges, and for a continuous charge distribution.

Conductors [3]

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

Dielectrics [1]

Dielectrics: definition and examples. Energy of a dipole in an electric field. Dielectrics in capacitors: induced charge, forces on dielectrics in non-uniform fields.

DC circuits [3]

Current and resistance; Ohm's law; electrical energy and power. DC circuits: emf, Kirchoff's rules. Examples.

Magnetostatics [5]

Magnetic field, motion of a charged particle in a magnetic field and Lorentz force. Velocity selector, mass spectrometer, Hall effect. Ampere's law and Biot-Savart law. Magnetic field due to a straight wire, a solenoid, a toroid and a current sheet. Magnetic force between current carrying wires. Energy of a magnetic dipole in a uniform field.

Electromagnetic induction [4]

Magnetic flux. Gauss' law for magnetism. Ampère-Maxwell law. 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; eddy currents. Faraday's law in differential form. Transients in RLC circuits. Energy in the magnetic field.

AC circuits [3]

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.

Maxwell's equations [1]

Maxwell's equations in vacuo and plane wave solution.

PHYS2B22 – Quantum Physics (Part-time Programme)

Course Information

Prerequisites

PHYS1B71 - Mathematics for Physics or an equivalent course in other departments.

Aims of the Course

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 PHYS2B24 Atomic and Molecular Physics and PHYS3C26 Quantum Mechanics.

Objectives

In the following 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 (1.1.1)
- Describe Compton's X-ray scattering experiment and give the expression for the wavelength shift (1.1.2)
- Relate the energy and momentum of a photon to its frequency (1.1.3)
- State the de Broglie relation and apply it to the electron diffraction experiment of Davisson and Germer (1.2)
- 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)
- Know the operators representing position, momentum and kinetic energy in one dimension and what is meant by the Hamiltonian operator (4.2)
- 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)
- Show how the one-dimensional Schrödinger equation can be separated in time and space coordinates (2.4)
- State and explain the boundary conditions that must be satisfied by the wave-function (2.5)
- Solve the time-independent Schrödinger equation (TISE) for an infinite square well potential to obtain the wave functions and allowed energies (3.1)
- Understand the solutions of the 1D TISE in the presence of a constant potential, including the use of complex exponentials (3.2)
- Explain the relationship between the solutions of the TISE for free particles and the flux of particles (3.3)
- Solve the TISE for a potential barrier or step (3.4)
- Discuss barrier penetration and give examples from physics and astronomy (3.4)
- Understand the construction of wavepackets and their relationship to the Uncertainty Principle (3.5)
- 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 (3.6)
- Describe and explain the classical and QM probability distributions for the simple harmonic oscillator (3.6)
- 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)
- 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 (4.5, 4.6)

- Understand what is meant by a stationary state and a conserved quantity (4.7)
- Define mathematically an Hermitian operator and explain the expansion postulate
- 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 $\hat{\underline{L}}^2$ (5.1)
- 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)
- 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 (6.5)
- Solve the radial Schrödinger equation for an electron in a hydrogen atom at small and large distances (6.7)
- 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 (6.9)
- Understand the ideas of degeneracy and statistical weight in relation to the hydrogen atom (6.12)
- Recognise the treatment of a hydrogenic ion with nuclear charge Z (6.14)
- Describe and explain the Stern-Gerlach experiment
- Give, and explain the significance of the quantum numbers that describe the states of the hydrogen atom
- Know the rule for adding the orbital angular momentum and spin quantum numbers for the hydrogen atom to obtain the total angular momentum
- 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
- Know and understand the implications of the selection rules for radiative transitions in a one-electron atom, understand the distinction between allowed and forbidden transactions and, if given the selection rules, apply them to transitions between the levels of an atomic ion.

Methodology and Assessment

The course consists of 27 lectures of course material supplemented by 6 hours of other activities, which include discussion of problem sheets, computer demonstrations, short quizzes and an end-of-course test. For full-time students, the first 23 lectures of PHYS2B22 and ASTR2B11 are taught together, with the remaining 4 lectures taught separately to separate syllabuses.

The assessment is based on an unseen written examination (90%) and continuous assessment (10%), consisting of five problem sheets and the end-of-course test. The results of each problem sheet and the test are expressed as a mark out of 10 and the best four marks are taken.

Textbooks

- J.J.Brehm and W.J.Mullin, *Introduction to the Structure of Matter*, Wiley, (available at a discount from the Department - relevant to more than one course)
- A.I.M.Rae, *Quantum Mechanics*, Adam Hilger, (closest text to the lecture notes)
- F.Mandl, *Quantum Mechanics*, Wiley, (more advanced text useful in 3rd year quantum course)

Syllabus

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

The failure of classical mechanics [3]
Photoelectric effect, Einstein's equation, electron diffraction and de Broglie relation. Compton scattering
Steps towards wave mechanics [3]
Wave-particle duality, Uncertainty Principle (Bohr microscope). Time-dependent and time-independent Schroedinger equations. The wave function and its interpretation
One-dimensional time-independent problems [5]
Infinite square well potential. The potential barrier and step. Reflection and transmission. Tunnelling and examples in physics and astronomy. Finite square well. The simple harmonic oscillator

The formal basis of quantum mechanics [3.5]

The postulates of quantum mechanics - operators, observables, eigenvalues and eigenfunctions. Ehrenfest's theorem (without proof).

Angular momentum in quantum mechanics [2.5]

Operators, eigenvalues and eigenfunctions of the square of the angular momentum vector and its z-component

The hydrogen atom [6]

Separation of space and time parts of the 3D Schroedinger equation for a central field. The radial Schroedinger equation and its solution by series method. Degeneracy and spectroscopic notation

Electron spin [1]

Magnetic moment of electron due to orbital motion. The Stern-Gerlach experiment. Electron spin and complete set of quantum numbers for the hydrogen atom.

Total angular momentum [0.5]

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.

Emission and absorption of radiation by atoms [1.5]

Qualitative description of the interaction of atoms with an EM field. Selection rules for radiative transitions in hydrogen and, briefly, for complex atoms.

PHYS2B24 – Atomic and Molecular Physics (Part-time Programme)

Course Information

Prerequisites

PHYS1B26/PHAS2201 Electricity and Magnetism and Quantum Physics PHYS2B22 (or equivalent courses) including the quantum mechanical treatment of the hydrogen atom.

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 PHYS2B22 Quantum Physics. To prepare students for more advanced courses in atomic and molecular spectroscopy such as PHYS4431 - Molecular Physics and PHYS4421 Atom and Photon Physics.

Objectives

On successful completion of the course PHYS2B24 , the student should be able:

- To describe pioneering experiments by Thomson, Millikan, Herz and Rutherford which led to the discovery of the internal structure of the atom.
- 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 derive and understand the Bohr model of the hydrogen atom.
- To derive and understand the idea of reduced mass and to adapt the Bohr model 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 exclusion 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. Hence 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

The course consists of 27 lectures, with additional time for worked examples and revision of homework. Some of the material is delivered on overheads. Assessment is mainly by a written examination at the end of the course (90 %) and by means of homework problems. There are 4 problem sheets which provide the 10% continuous assessment component.

Syllabus

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

Introduction to atomic structure [3]

Introduction. Early evidence for the existence of atoms. Thomson's measurement of e/m. Millikan's measurement of e. Rutherford scattering. Total cross section. Differential cross section. Examples of electron-, positron -, and positronium- total cross-sections: dominant interactions. Quantum scattering. Franck-Hertz experiment

Review of one electron atoms and the Bohr model of the atom. [3]

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 [7]

Independent particle and central field approximations. Alkali atoms and quantum defect theory. Indistinguishable particles, Pauli Exclusion Principle. Helium atom and exchange. Configurations and terms. Spin-Orbit interaction. Levels and Spectroscopic notation. Overview of forces on isolated atom.

Atoms and Electromagnetic Fields [7]

Atoms in radiation: dipole allowed and forbidden transitions. Einstein coefficients. Metastable levels. Laser operation. Laser cooling. X rays and inner shell transitions. Antihydrogen. 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.

Molecular Spectra [7]
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.

PHYS2B27 – Environmental Physics (Part-time Programme)

Course Information

Prerequisites
In order to take this course, students should be familiar with the basic principles of physics to a standard comparable with a grade C in GCSE Advanced Level, and to have a level of competence in mathematics consistent with having passed course PHYS1B71.

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 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,
- a description of the physical principles involved in the development of the technologies for adoption of renewable energy schemes
- 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. The remaining 10% will be judged from three problem sheets during the course.

Textbooks
Most of the course material is now 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

PHYS2B28 – Statistical Thermodynamics and Condensed Matter Physics (Part-time Programme)

Course Information

Prerequisites
PHYS1B71 - Mathematics for Physics, and PHYS1B28 - Thermal Physics, or equivalent courses in other Departments.

Aims of the Course
This aim of this course is to:

- To present the basic concepts and methods appropriate for the description of systems containing very many identical particles, and to extend knowledge of classical thermodynamics.
- To compare and contrast the statistical mechanics of ideal gases comprised of bosons, fermions and classical particles.
- To consolidate microscopic understanding of the properties of gases, liquids and solids.

Objectives
After completing this course, the student should be able to:

- Understand and apply thermodynamic functions - enthalpy, availability and free energies.
- Explain the difference between a thermodynamic macrostate of a 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 any one of its accessible microstates are equal for an isolated system.
- To argue that the entropy is the logarithm of the statistical weight of the system, and give Boltzmann's definition of entropy.
- State the condition for equilibrium in an isolated system.
- Obtain statistical definitions of the temperature, pressure and chemical potential.
- Derive the Boltzmann distribution for a system in equilibrium with a heat bath.
- Delate 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.
- Apply the general definition of entropy.
- Describe an ideal gas in terms of the ratio of potential to kinetic energy of the particles.
- Derive the density of momentum and energy states of a single particle.
- State the definition of a Boson and a Fermion in terms of the spin of the particles, the symmetry of the two-particle wavefunction, and the occupation of single particle states.
- Follow the derivation and form of the Bose-Einstein (B-E) and Fermi-Dirac (F-D) distribution functions.
- Explain the role played by the chemical potential in these derivations, and be familiar with the grand partition function.
- Apply B-E statistics to the case of a photon gas, and obtain Planck's law for the energy density of black-body radiation.
- Sketch the temperature dependence of this energy spectrum. You will be able to apply F-D statistics to a free electron gas, and white dwarf and neutron stars.
- Compare and contrast ^3He and ^4He.
- Express the criterion for the validity of the classical regime in terms of the occupation of single particle energy levels.
- Obtain the M-B single partition function, and express the many particle partition function in terms of this single particle partition function.
- Determine the average kinetic energy of an ideal gas molecule, and obtain the equation of state of an ideal classical gas by differentiating the Helmholtz free energy with respect to volume.
- Separate the classical limit partition function into kinetic and potential energy terms.

- Apply the concepts of statistical mechanics to a real gas and derive the van der Waals equation of state.
- Describe the structure of a liquid by reference to the radial distribution function.
- Understand how liquefaction takes place in terms of the interatomic forces, liquid structure and radial distribution function. Obtain the partition function for liquids.
- Describe the approximations involved in the Einstein and Debye models of lattice vibrations, including the concept of a phonon.
- Interpret the Debye prediction for the specific heat of a crystal.

Methodology and Assessment

The course consists of 27 lectures covering main course material, and 6 hours of other activities, including discussion of problem sheets and advanced topics.
Assessment is based on an unseen written examination (90%) and four sets of homework: (10%)

Textbooks

Statistical Physics, F.Mandl (John Wiley).

Syllabus

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

Introduction [2]
historical background to thermodynamics and statistical physics; revision of main thermodynamic results
Principles of Statistical Physics [2]
macrostates and microstates, ensembles of macroscopic systems, statistical weight of a macrostate, direction of natural processes
Isolated systems [3]
microcanonical distribution, principle of equal a priori probability of accessible microstates, density of microstates, Boltzmann’s definition of entropy, equilibrium as most probable state, statistical definition of temperature, pressure and chemical potential. Schottky defects
Systems in contact with a heat bath [4]
Boltzmann’s (canonical) distribution, partition function, general definition of entropy, energy fluctuations, Helmholtz free energy. Paramagnetic salts
Ideal quantum gases [8]
definition of an ideal gas, examples of ideal gases. Density of momentum and energy states. Types of quantum particles: Bosons, Fermions and the classical limit. Quantum statistics. Bose-Einstein (B-E) distribution; B-E partition function, photon gases, Planckís Law, black-body radiation. B-E condensation. Fermi-Dirac (F-D) distribution; F-D partition function, electron gases, Fermi energy and temperature. White dwarf and neutron stars

Ideal classical gases [2]
validity of classical regime. Maxwell-Boltzmann distribution; single and many particle partition functions. Average kinetic energy, equation of state
Interatomic and intermolecular forces [2]
ionic and covalent bonds, van der Waals interactions, electron overlap interactions, Lennard-Jones form of the potential energy curve. Hierarchy of electrostatic interactions. Conditions for stability of solid, liquid and gas
Real Gases [2]
partition function for a system of interacting particles, critical temperature, van der Waals equation of state, law of corresponding states
Liquids [2]
liquefaction and the interatomic forces, liquid structure, radial distribution function. Partition function for a liquid; configuration integrals, calculating properties of liquids. Methods of computer simulation
Solids [2]
Phonons; Einstein and Debye specific heat of a crystal.

PHYS2B29 – Electromagnetic Theory (Part-time Programme)

Course Information

Prerequisites
Students taking this course should have taken 1B26: Electricity and Magnetism. The mathematical prerequisites are 1B71: Mathematics for Physics in the first year and 2B72:
Mathematical Methods in Physics the first term of the second year, or equivalent mathematics courses.

Aims of the Course

- to discuss the magnetic properties of materials;
- to build on the contents of the first-year course 1B26; Electricity and Magnetism, to establish Maxwell's equations of electromagnetism, and use them to derive electromagnetic wave equations;
- to understand the propagation of electromagnetic waves in vacuo, in dielectrics and in conductors;
- to explain energy flow (Poynting's theorem), momentum and radiation pressure, the optical phenomena of reflection, refraction and polarization, discussing applications in fibre optics, radio communication and wave guides;
- to give a simplified account of the radiation from an oscillating dipole.

Objectives
After completing this course students should be able to:

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

Lectures and Assessment
27 lectures plus 6 discussion periods. Assessment is based on the results obtained in the final examination (90%) and in the best 12 questions from 5 sets of 3 homework problems (10%).

Textbooks
Electromagnetism, 2nd edition, by I S Grant & W R Phillips (Wiley)
Electricity and Magnetism, 4th edition, by W.J. Duffin (McGraw-Hill)

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

Introduction [5]
Mathematical tools. Brief summary of results from 1B26 course; explicit revision of meaning of electric displacement D, relation between integral and differential forms of proto-Maxwell equations using Stokes' and Gauss' theorems, electric dipole field.

Magnetic media [4]
Magnetic dipole field from current loop. Magnetisation M as dipole moment per unit volume, magnetic field strength H, magnetic susceptibility • m. Diamagnetism, paramagnetism ; ferromagnetism. Ampere's law in magnetic media; differential and integral forms. Continuity conditions for B and H (c.f. D and E). Magnetic energy; forces in magnetic systems (linear media). Magnets; solenoid compared to uniformly magnetised bar; toroid; fluxmeter for B and H. Simple qualitative description of hysteresis.

Maxwell's equations and e.m. waves in vacuo [6]
Displacement current from continuity equation; generalised Ampere's law. Maxwell's equations in integral and differential form; the wave equation; transverse character of unbounded plane waves; polarisation, e.m. energy, the Poynting vector, Poynting's theorem; e.m. momentum and radiation pressure.

Electromagnetic waves in nonconducting media [4]
Refractive index; reflection and refraction at boundaries between dielectric media, Snell's law, reflection and transmission coefficients, Fresnel's relations, Brewster angle, critical angle, total internal reflection.

Propagation and surface reflection in conducting media [3]
Poor and good conductors; skin depth, reflection at a metal surface; plasma frequency, simple plasma dispersion relation, radio waves and ionosphere.

Waveguides [3]
Maxwell's equations in guides, boundary conditions, rectangular guides; the waveguide equation, TM, TE modes, cutoff wavelength, energy flow.

Emission of electromagnetic radiation [2]
Qualitative description of E and H fields around Hertzian dipole in near field. Vector potential A as link with far field. Definition of retarded time; statement without rigorous derivation of far field expressions for E and H with r and t. Radiated power.

PHYS2B72 – Mathematical Methods for Physics

Course Information

Prerequisites

In order to take this course, students should have shown competence in the precursor level-1 PHYS1B71 mathematics course.

Aims

This course aims to:

- provide the remaining mathematical support for all the second and third-level courses in the part-time BSc programme in Physics;develop in particular the tools necessary for an understanding of Quantum Mechanics and Electromagnetism;
- develop in particular the tools necessary for an understanding of Quantum Mechanics and Electromagnetism;
- give students some practice in mathematical manipulation and problem solving at level-2.

Objectives

The PHYS1B71 and PHYS2B72 syllabuses together cover all the mathematical requirements of the Physics courses in the part-time BSc programme. The major areas treated in 2B72 are of special relevance to Quantum Mechanics and Electromagnetism, and the applications of these subjects to many other topics, including condensed matter, atomic, 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 some of the relevant calculations. Specifically,

In Vector Calculus, students should be able to:

- understand the concepts of scalar and vector fields;
- carry out algebraic manipulations with the div, grad, curl, and Laplacian operators in Cartesian coordinates;
- derive and apply the divergence and Stokes' theorems in physical situations, and deduce coordinate-independent expressions for the vector operators;
- derive and use expressions for the vector operators in cylindrical and spherical polar coordinates.

For Differential Equations, students should be able to:

- solve a variety of second order linear partial differential equations, including the Laplace and wave equations, by the method of separation of variables, using Cartesian and polar coordinates, and impose boundary conditions;
- solve ordinary second-order linear and homogeneous differential equations by the series method, finding indicial equations and recurrence relations.

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 in order to obtain recurrence and orthogonality relations for Legendre polynomials;
- manipulate associated Legendre functions and 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;
- 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.

In Vector Calculus, students should be able to:

- understand the concepts of scalar and vector fields;
- carry out algebraic manipulations with the div, grad, curl, and Laplacian operators in Cartesian coordinates;
- derive and apply the divergence and Stokes' theorems in physical situations, and deduce coordinate-independent expressions for the vector operators;
- derive and use expressions for the vector operators in cylindrical and spherical polar coordinates.

Methodology and Assessment
This half-unit course is spread over 33 hours in the first term, with a 3-hour discussion period in the second term and a 3-hour revision lecture in the third. About 20 minutes are set aside every week for students to attack a problem individually with the lecturer's active assistance. Since students taking courses in the evening have relatively little spare time for homeworks and additional study during the week, only two short homework sheets are given out during the first term, with a larger one to be done over the Christmas vacation. The continuous assessment of 10% will be derived from the better of the long sheet and the sum of the two short ones. The end-of-session written examination counts for the remaining 90% of the assessment.

Textbooks
A book which covers essentially everything in both this and the level-1 1B71 course is *Mathematical Methods in the Physical Sciences*, by Mary Boas (Wiley). An alternative which treats most of the material in the two courses is the combination *Engineering Mathematics* and *Further Engineering Mathematics* by K.A. Stroud (Macmillan). These are programmed texts, which treat everything as a series of problems, in contrast to the approach of standard textbooks. They do not, however, discuss Legendre polynomials. A different viewpoint is presented in *Mathematical Methods for Physics and Engineering*, by K.F. Riley, M.P. Hobson and S.J. Bence (Cambridge University Press).

Syllabus
(The approximate allocation of lectures to topics is shown in brackets below.)
***Linear Vector Spaces and Matrices* [10]**
Definition and properties of determinants, especially 3×3. [2]
Properties of matrices, Matrix multiplication, Special matrices, Matrix inversion, Solution of linear simultaneous equations. [4]
Eigenvalues and eigenvectors, Eigenvalues of unitary and Hermitian matrices, Real quadratic forms, Normal modes of oscillation. [4]
***Partial Differential Equations* [4]**
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 Ordinary Differential Equations* [3]**
Derivation of the Frobenius method, Application to linear first order equations, Singular points and convergence, Application to second order 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. [2.5]
Fourier transforms, Derivation of basic formulae and simple application, Dirac delta function. [2.5]
***Vector Operators* [7]**
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.

PHYS3C24 – Nuclear and Particle Physics (Part-time Programme)

Course Information

Prerequisities
An introductory course in atomic physics, such as PHYS2B24, and an introductory course in quantum physics, such as PHYS2B22, or their equivalents in other departments.

Aims of the Course
The aim of the course is to:

provide an introduction to the physical concepts of nuclear and particle physics and the experimental techniques which they use.

Objectives
After completing the course, students should:

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

Specifically in nuclear physics, students should:

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

Specifically in particle physics, students should:

- appreciate the need for antiparticles
- understand the relationship between exchange of particles and the range of forces;
- know how to interpret interactions in terms of Feynman diagrams;
- know the roles and properties of each of the three families of particles (quarks, leptons and gauge bosons) of the standard model of particle physics;
- know the properties of hadrons and understand their importance as evidence for the quark model;
- understand the principles of the interpretation of the fundamental strong interaction via quantum chromodynamics (QCD), including the roles of the colour quantum number, confinement and asymptotic freedom;
- understand the evidence for QCD from experiments on jets and nucleon structure;
- understand the spin and symmetry structures of the weak interactions and tests of these from the decays of the μ, π and K^0 mesons;

- understand how unification of the electromagnetic and weak interactions comes about and the interpretation of the resulting electroweak interaction in the standard model;

After completing the accelerator and detector section, students should :

- understand the differences between linear and circular accelerators and their limits;
- understand the main principals of a synchrotron;
- understand the concepts of deep inelastic scattering for fixed target and colliding beams;
- know the main processes by which charged particles lose energy in matter;
- know the main processes by which photons lose energy in matter;
- understand the concepts of operation of a tracking detector, a calorimeter and a Cerenkov counter and the physics processes involved;
- explain how these detectors are used together and what properties of the particles they measure.

Specifically in experimental methods, students should:

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

Methodology and Assessment

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

Textbooks

Core texts:
Particles and Nuclei (2^{nd} Edn) –B Povh, K Rith, C Scholz and F Zetsche (Springer)
Particle Physics (2^{nd} Edn) – B R Martin and G Shaw (Wiley)
Other useful texts:
An Introduction to Nuclear Physics – W N Cottingham and D A Greenwood (Cambridge)
Nuclear and Particle Physics – W S C Williams (Oxford)
Introduction to Nuclear and Particle Physics – A Das and T Ferbel (Wiley)
Introduction to High Energy Physics (4^{th} Edn) – D H Perkins (Cambridge)

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

***1. Basic Ideas* (3)**

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

***2. Nuclear Phenomenology* (4)**

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

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

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

***4. Experimental Methods* (5)**

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

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

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

***6. Electroweak Interactions* (5)**

Charged and neutral currents; symmetries of the weak interaction; spin structure of the weak interactions; neutral kaons; $K^0 - \bar{K}^0$ mixing and CP violation; strangeness oscillations; $W^{\pm}$ and Z^0 bosons; weak interactions of hadrons; neutral currents and the unified theory; The Higgs boson

***7. Structure of Nuclei* (4)**

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

***8. Fission and Fusion* (2)**

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

PHYS3C25 – Solid State Physics (Part-time Programme)

Course Information

Prerequisites

PHYS2B28 – Statistical Thermodynamics and Condensed Matter Physics, or an equivalent course.

Aims of the Course

This course aims to:

- show how the diverse properties (mechanical, electronic, optical and magnetic) of solid materials can be related to interactions at the atomistic level, using theoretical models;
- show how the study of condensed matter plays a vital part both in other areas of physics and, more generally in science, technology and industry.

Objectives

After completing this course, students will be able to**:**

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

Methodology and Assessment

The course will consist of 27 lectures of course material, supplemented by 6 hours of other activities, which will include discussion of problem sheets. Students will be set five problems sheets, and the marks given for the best four will account for 10% of the course assessment. The remaining 90% will be awarded on the basis of the end of session exam.

Textbooks

- H. M. Rosenberg - *The Solid State* 3rd edition
- J.R. Hook and H. E. Hall - *Solid State Physics* 2nd edition

Hook and Hall is perhaps more advanced and mathematically rigorous, but does not contain anything on mechanical properties. Rosenberg, a readable and commendably slim book, does cover this topic well, but occasionally lacks sufficient mathematical detail, although these aspects should be adequately covered in the lectures. Copies of Hook and Hall are available from the Programme Tutors at a sizeable discount on the published price. There are a number of other books worth consulting. Some aspects of the course are treated well by:

- P. Sutton *Electronic Structure of Materials*.
- M. de Podesta *Understanding the Properties of Matter*.
- J. Walton *Three Phases of Matter 2nd edition*.

Three advanced texts for continued studies are:
C. Kittel *Introduction to Solid State Physics. 7th edition.*
J. S. Blakemore *Solid State Physics, 2nd edition*
N. W. Ashcroft and N. D. Mermin *Solid State Physics.*

Syllabus

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

3C25 part 0: Introduction to condensed matter

An introductory lecture in which the aims and content of the course will be discussed.

3C25 part 1: Structural properties of solids

1.1 Interatomic bonding and material structure (5 lectures)

Crystal structures will be described in terms of the Bravais lattice and basis. The hcp, bcc, fcc and diamond structures will be discussed, together with the related ZnS and CsCl structures. We shall introduce the idea of a primitive unit cell and contrast it with a conventional cell. We shall discuss the use of Miller indices to designate lattices, planes and directions in crystals.
The distinction between directional (covalent) and non-directional (van der Waals, ionic and metallic) bonding will be related to the kinds of structures seen.
We shall calculate cohesive energies of various structures for van der Waals and ionic bonded materials to determine which is most stable. We shall discuss the structures of ionic materials using models of packed spheres.

1.2 Diffraction methods and structural determination (2 lectures)

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

1.3 Lattice dynamics and phonons (4 lectures)

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

1.4 Thermal properties of solids (3 lectures)

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

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

1.5 Mechanical properties of solids (3 lectures)

We shall demonstrate that the theoretical yield stress is far greater than the observed yield stress for any material. We shall introduce the idea of a dislocation and show how it can lower the yield stress using the 'carpet ruck' analogy. We shall discuss the two pure types of dislocation (edge and screw) and introduce the concept of a Burgers vector. We shall derive the strain field, and hence the elastic energy, for a screw dislocation. The Frank-Read mechanism for dislocation multiplication will be briefly discussed and related to the phenomenon of work hardening.

3C25 part 2: Electrons in solids

2.1. Electronic and optical properties of solids (1 lecture)

The variety of electronic and optical properties of solids will be discussed briefly using simple ideas of valence and conduction band structure for the electronic energy spectrum in materials, with examples. We shall take as examples materials ranging from electrical insulators to semiconductors and conductors. Transparency and opacity of solids will be considered, together with field emission and contact potentials

We shall draw analogies between electron and phonon spectra, particularly with regard to band gaps.

2.2. Models of electrons in solids (7 lectures)

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

2.3. Semiconductors (4 lectures)

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

2.4. Magnetic properties of solids (2 lectures)

We shall interpret para-, dia-, ferro- and antiferromagnetism using ideas of electron spins. Using the free electron model we shall calculate the paramagnetic susceptibility of simple metals. We shall discuss the mutual interactions of spins in terms of the quantum mechanical exchange energy.

2.5. Superconductivity (1 lecture)

Some of the features of superconductivity will be discussed and explained using the ideas of Cooper pairs.

PHYS3C26 – Quantum Mechanics (Part-time Programme)

Course Information

Prerequisites
To have attended and, normally, to have passed PHYS2B22 (Quantum Physics) - or equivalent courses.

Aims of the Course
This course aims to:

- discuss formally some of the postulates of quantum mechanics introduced in PHYS2B22; to introduce algebraic operator treatments of the one-dimensional harmonic oscillator and angular momentum; to develop approximate methods for stationary systems time-independent perturbation theory and the variational method - and to apply them to physical examples; to introduce systems composed of two identical particles; to consider the role of measurement in quantum systems and the interpretations of quantum mechanics.
- provide the necessary preparation for advanced quantum mechanics courses to be taken in year 4, and the background required for applications of quantum mechanics in subsequent departmental courses in atomic and molecular physics; nuclear and particle physics; condensed matter physics and astrophysics.

Objectives
After completing the module the student should be able to:

- understand, express mathematically, and give a physical interpretation to the fundamental postulates of quantum mechanics etc;
- understand and use the Dirac notation for quantum states.
- give a mathematical description of the one-dimensional harmonic oscillator in the algebraic operator approach employing creation and annihilation operators.
- define orbital angular momentum and its associated operators in Cartesian and spherical polar coordinates and state the solutions of the eigenvalue equations and describe their physical interpretation.
- generalize the definition of angular momentum to include spin and solve the generalized angular momentum eigenvalue problem employing raising and lowering operator techniques.
- discuss the properties of spin-1/2 systems and use the Pauli matrices to solve simple problems.
- state the rules for the addition of angular momenta and outline the underlying mathematical arguments for them.
- formulate the time-independent perturbation theory approach for obtaining approximate solutions of the Schrodinger equation for both non-degenerate and degenerate levels.
- understand its application to a specific physical case, e.g. the Stark effect in atomic hydrogen; use the results of time-independent perturbation theory to solve for the discrete energies of simple systems.
- understand the basis of the variational method for the evaluation of the upper bound on the ground state energy of a stationary system with the helium atom as a specific example, apply the variational principle to the evaluation of the ground state energy upper bounds of other simple systems.
- discuss some properties of systems of two identical particles; be able to differentiate between bosons and fermions and construct the wave function for these particles taking account of the Pauli Exclusion Principle.
- discuss the superposition of states of different energies and show that such systems can undergo transitions; solve simple, time-dependent, two state problems such as a charged spin-1/2 particle, e.g. an electron, in a uniform magnetic field.
- discuss the various interpretations of quantum mechanics, outline the measurement problem and discuss qualitatively Bell's Inequality and experimental tests of it.

Methodology and Assessment
The course consists of 30 lectures supplemented by circulated notes on the part dealing with the interpretation and measurement problem. The assessment is based on an unseen written examination (90%) and five assessed coursework papers (10%). The results of the best four of the coursework papers are taken and expressed as a mark out of ten.

Textbooks
Any of the following are suitable:

- E.Merzbacher, *Quantum Mechanics*, Wiley, 1998.
- B.H.Bransden and C.J.Joachain, *Introduction to Quantum Mechanics*, Longman,
- P.C.W.Davies and J R Brown (eds.) *The Ghost in the Atom*, Canto, Cambridge University Press, 1986.

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

Formal Aspects of Quantum Theory [~7]
The wave function, principle of superposition, Time Dependent Schroedinger Equation, expectation values, Hermitian operators, eigenstates, expansion postulate and complete sets of eigenfunctions. Compatible observables, simultaneous measurement and commuting operators. The generalised uncertainty relations. Dirac notation. Matrix representation of states and operators. Time evolution of operators. Step-operator approach to harmonic oscillator.
Angular Momentum [8]
A refresher on commutation relations, eigenvalues and eigenfunctions of orbital angular momentum operators. Generalized angular momentum, step-up, step-down operators, step operator techniques in angular momentum theory; spectrum of angular momentun eigenvalues. Spin-1/2 angular momentum, Pauli matrices, magnetic moments. Combination of angular momenta, total angular momentum. Examples.
Approximate Methods [6]
Time-independent perturbation theory for non-degenerate systems to second order in the energy ; to first-order for degenerate systems. Examples. Variational principle, He ground state example. Examples will be chosen to illustrate the application of the general quantum mechanical principles in the areas of atomic, nuclear and solid state physics; e.g. two spin-1/2 particles, spin-dependent interactions, positronium, n-p system, isotopic spin (pi-N system); - anharmonic oscillator, spin-orbit interactions, Stark effect and relativistic corrections in atomic hydrogen.
Simple Time-dependent systems [3]
Superposition of states of different energies. Electron in magnetic field. Time evolution of entangled states of two spin-1/2 particles with total spin zero.
Identical Particles [2]
Systems of two identical particles. Pauli Exclusion Principle, fermions and bosons. Independent particle model of He atom, singlet and triplet states, exchange interaction.
The Interpretations of quantum mechanics and the measurement problem [4]
Copenhagen interpretation, hidden variables, non-locality and reality, EPR paradoxes, Bell's Inequalities, the Aspect experiments; the problem of measurement, Schrodinger's cat, alternative interpretations.

PHYS3C43 – Lasers and Modern Optics (Part-time Programme)

Course Information

Pre-requisites
Knowledge of quantum physics and atomic physics to second year level, e.g. UCL courses 2B22 and 2B24.

Aims of the course
The aim of the course is to:

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

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

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

Methodology and Assessment
The course consists of 30 lectures of course material which will also incorporate discussions of problems and question and answer sessions. Two hours of revision classes are offered prior to the exam. The assessment is based on an unseen written examination (90%) and continuous assessment (10%). The continuous assessment mark is determined using the four problem sheets.

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

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

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

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

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

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

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

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

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

PHYS3C74 – Topics in Modern Cosmology

Course Information

Prerequisites

There are no prerequisites for this course other than standard physics and mathematics taught at second year level of the Physics degree. In particular, students are not required to have any knowledge of astronomy or cosmology.

Aims of the Course

This course aims to:

- introduce the subject of modern cosmology using an approach that is grounded in physics rather than mathematics;
- present the basic theoretical framework of cosmology;
- compare the latest observations of the Universe with theoretical predictions.

Objectives

After completion of this course students should be able to:

- describe the constituents of the Universe;
- understand its evolution from the Big Bang to the present day;
- discuss the formation and importance of the Cosmic Microwave Background;
- discuss the problems of observational measurement, for example the Hubble constant and the density parameter;
- appreciate the controversies encountered in cosmology today; for example, the values of the density parameter and the cosmological constant;
- appreciate how these controversies may be resolved in the future with new observational techniques.

Methodology and Assessment

30 lectures and 3 problem class/discussion periods. Assessment is based on the results obtained in the final written examination (90%) and two problem sheets (10%).

Textbooks

- *An Introduction to Modern Cosmology*, Andrew Liddle, 1998, John Wiley & Sons, £14.99. (Recommended book)
- *Introduction to Cosmology*, 2nd Edn., Matts Roos, 1997, John Wiley & Sons, ISBN 0 471 97383 1, £24.95.
- *Cosmology*, 3rd Edn., Michael Rowan-Robinson, 1996, Oxford Univ. Press, ISBN 0 19 851884 6, £17.50.

Syllabus

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

Introduction and History of Cosmology [1]

Observational Overview of the Universe [5]

The Universe as seen in visible light: stars, galaxies, clusters of galaxies, superclusters and Quasars. The Universe as seen in other wavebands. The expansion of the Universe: redshift and the Hubble law. Homogeneity and isotropy. Olbers' paradox. Particles and radiation in the Universe.

The Basic Equations of Cosmology [3]

Newtonian gravity. The Friedmann, fluid and acceleration equations.

Cosmological Models [4]

The Hubble Law. Expansion and redshift. Solutions: matter-, radiation-dominated Universes and mixtures. The fate and geometry of the Universe.

Observational Parameters [6]

The Hubble constant: the distance scale and the value of H_o. The density parameter Ω_o. The deceleration parameter q_o. The cosmological constant Λ. Measuring the age and density of the Universe.

The Cosmic Microwave Background [2]

Properties and origin. The photon to baryon ratio.

The Early Universe [4]

Matter-radiation equality. Temperature vs. time relationship. Thermal evolution of the Universe. Primordial nucleosynthesis.

The Inflationary Universe [4]

Successes and failures of the Hot Big Bang cosmology. The flatness, horizon and monopole problems. Inflationary expansion as a solution. Inflationary models. Before inflation.

Structure in the Universe [1]

Observed structures. The origin and growth of structure.

PHYS3C75: Principles and Practice of Electronics

Course Information

Prerequisites
Basic electricity to level 2, e.g. PHYS1B26 or PHAS2201 – Electricity and Magnetism.

Aims of the Course
The aims of this course are to:
- provide a familiarity with the basic components of digital and analogue electronic circuits in terms of their characteristics, purpose, and symbolic representation;
- explain the functioning and purpose of a wide range of basic digital and analogue circuits;
- introduce the basic design principles required to analyse the behaviour of digital and analogue circuits and to obtain approximate component values;
- provide practical experience of constructing elementary digital and analogue circuits both in real hardware and through computer simulation.

Objectives
After completing this course the student will be able to:
- understand the circuit concepts of signal input and output, power supply and earth lines, and amplification;
- describe the function and circuit representations of basic binary logic gates;
- combine logic gates to form more complex combinational logic circuits;
- analyse and optimise combinational logic circuits using truth tables, Boolean algebra and Karnaugh maps;
- combine logic gates to form basic sequential logic circuits – flip-flops, registers and counters;
- analyse the function of sequential logic circuits using state diagrams and the “change function” method;
- understand the concepts of more advanced digital circuits such as memory, analogue-to-digital converters, computer interfaces and data communication highways;
- describe the function and circuit representations of basic discrete analogue components;
- understand the mode of operation of the junction transistor and basic transistor circuits;
- understand the concepts of AC and DC coupling, gain, input and output impedance and bandwidth;
- understand the principles of negative feedback and the virtual earth;
- use operational amplifiers with series and parallel negative feedback to construct a range of basic analogue signal processing circuits;
- calculate the gain, bandwidth, and input and output impedances of circuits using negative feedback;
- understand the concept of positive feedback and circuit instability;
- design simple oscillator circuits;
- design basic analogue computer circuits to solve equations.

Methodology and Assessment
The course will consist of 10 lectures and 10 two-hour practical sessions supplemented with comprehensive notes providing learning material and practice exercises. The practical sessions will be divided between simulated circuit construction and evaluation using computer software (*Crocodile Clips*) and bench-top circuit development using pre-fabricated plug-in boards. Four assessed problem sheets will be given, and these and other topics will be discussed in three hours of discussion class. The course assessment will consist of an unseen written examination (90%) and the three best coursework problem sheets (10%).

Textbook
Peter H Beards – *Analog and Digital Electronics*, revised 2nd edition (Prentice Hall).

Syllabus

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

Introduction to Basic Circuit Concepts [1]

Circuit symbols and circuit diagrams; circuit analysis (dc); ohm's law; Kirchhoff's 1st & 2nd laws; *PSpice* and *Crocodile Clips* software packages; equivalent circuits; Thevenin's theorem and voltage sources; Norton's theorem and current sources; input impedance and output impedance; power supplies; earth; the potential divider; analogue & digital circuits.

Binary Logic [1]

Binary states; logical operations and their symbolic representation – AND, OR, INV, NAND, NOR, XOR; truth tables; specifying performance using algebra; minimising logic functions; theorems of Boolean algebra; De Morgan's theorem; using Boolean algebra; using Karnaugh maps for minimisation.

Logic Applications [1]

"Can't Happen" states; pulse trains and static hazards; XOR logic on a *K*-map; using just one type of logic NAND and NOR; the half adder and the full adder; bits and bytes – adding bigger numbers; two's complement encoding – subtraction; binary coded decimal; Gray codes; error detection codes; encoding and decoding.

Sequential Logic [1]

SR latch; SR flip flop; JK flip flop; master slave JK flip flop; T and D flip flops; ripple counters; decade counters; synchronous counters; the "Change Function" method.

Registers, Memory, and Analogue to Digital Converters [1]

Shift registers – parallel in parallel out & serial in serial out; memory; voltmeters; analogue to digital converters; flash ADC; successive approximation ADC; integrating ADCs; computers and interfaces; RS232; IEEE488.

Discrete Analogue Components [1]

Transducers – the need for analogue circuits; devices used in analogue circuits; the diode; simple circuits using diodes; the Zener diode; the bipolar junction transistor; simple transistor circuits; simple common emitter voltage amplifier; improved common emitter voltage amplifier.

Transistor Circuits & Introduction to Feedback [1]

Notation – signal current and signal voltage; decibels; coupling a multi-stage transistor circuit; AC coupled transistor amplifier; single pole RC high-pass filter; a typical AC coupled transistor circuit; introduction to negative feedback; the common collector circuit and the power voltage stabiliser; current feedback.

Operational Amplifiers and Negative Feedback [1]

Mathematical treatment of feedback; input and output impedance with negative feedback; the operational amplifier; negative feedback configurations using op amps; non-inverting high-input resistance amplifier; parallel-voltage negative feedback – the virtual earth; the voltage difference amplifier; the inverting integrator; the inverting differentiator; the inverting analogue sum / mixer; the inverting rectifier.

High Frequency Behaviour, Positive Feedback, and Oscillators [1]

More on RC filters; bandwidth; instability with NFB; the multivibrator; the sine wave oscillator; the "phase shift" oscillator.

Analogue Computer Circuits [1]

Using an op amp to solve an equation; realising the terms of equations; a simple example – first order linear differential equation; more complicated example – the driven damped oscillator; the analogue multiplier.