The Faculty of Science

Department of Physics

COURSE OPTIONS FOR VISITING STUDENTS

ABOUT THE DEPARTMENT

The Physics Department is one of the major centres for physics in the University of London. It has an international reputation for its research and excellent record of teaching, being consistently ranked near the top of the league tables. The courses listed below are open to all Study Abroad, International Exchange, and Erasmus students, provided sufficient previous experience and knowledge as stated in the individual course descriptions can be evidenced. There is a diverse course range, covering all areas of the subject, including experimental, theoretical and computational physics.

ENTRY REQUIREMENTS

First year courses: There are no formal pre-requisites for first year courses. However a good mathematical background is seen as very beneficial to students.

Second year courses: A solid foundation Physics and Mathematics is required for year two courses, as well as completion of a first year undergraduate mathematics/statistics course for scientists.

Third year courses: Please note that these are advanced courses, typically equal to senior year/graduate level in the USA. Advanced knowledge and extensive experience in the subject area is *required* for year three courses.

Fourth year courses: These are intercollegiate courses. Details for the level of knowledge for these courses can be provided on application.

The information contained in the course outlines on the following pages is correct at the time of publication but may be subject to change as part of our policy of continuous improvement and development.

Level One:

PH1110	Mathematics for Scientists 1	½ unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH1120	Mathematics for Scientists 2	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH1140	Scientific Skills 1	1/2 unit	Term 1 or Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs either from September or from January. It lasts for one term only.

PH1150	Scientific Skills 2	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH1320	Mechanics and Relativity	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH1420	Fields and Waves	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH1620	Classical Matter	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH1920	Physics of the Universe – from Quantum to Astrophysics	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

Level Two:

PH2130	Mathematical Methods	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH2210	Quantum Mechanics	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH2310	Optics	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH2420	Electromagnetism	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH2510	Atomic and Nuclear Physics	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH2520	Particle Detectors and Accelerators	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH2610	Classical and Statistical Thermodynamics	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH2710	The Solid State	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH2900	Astronomy	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

Level Three:

PH3040	Energy	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH3110	Experimental or Theoretical Project	1/2 unit	Full Year

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course is only available to students who are staying for the full year.

PH3150	Further Mathematical Methods	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH3170	C++ and Object Oriented Programming	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH3180	Experimental Design	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH3210	Quantum Theory	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH3520	Particle Physics	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH3710	Semiconductors and Superconductors	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September.

PH3730	Modern Topics in Condensed Matter	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH3810	Frontiers of Metrology	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH3910	General Relativity and Cosmology	1/2 unit	Full Year

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH3920	Stellar Astrophysics	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September

PH3930	Particle Astrophysics	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

Level Four:

PH4100	Major Project	1 unit/ 1/2 unit*	Full Year/Term 1*

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs for the full year. Students staying for Term 1 only may enrol on the course and earn half the credit. Students starting in January are not permitted to enrol.

PH4110	Research Review	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September

PH4211	Statistical Mechanics	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH4450	Particle Accelerator Physics	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September

PH4475	Physics at the Nanoscale	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September

PH4512	Nuclear Magnetic Resonance	1/2 unit	Term 2

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 2. It begins in January.

PH4515	Computing and Statistical Data Analysis	1/2 unit	Term 1

- This course is available to **all** ERASMUS, INTERNATIONAL EXCHANGE and STUDY ABROAD students
- This course runs in Term 1. It begins in September

Course Descriptions

Course Title:	Mathematics for Scientists 1	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1110	**Course JACS Code:**	F340
Availability:	Autumn Term	**Status:**	Essential Core Pass required
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr S J Flockton		
Course Staff:	Dr S J Flockton and Professor D M Heyes		
Aims:	Introduce students to some of the basic mathematics and techniques relevant to undergraduate physics. Develop students' skills in solving problems.		
Learning Outcomes:	On completion of the course, students should be able to: • solve problems involving one variable (real or complex); • differentiate and integrate simple functions; • use vector algebra and geometry; • use the common probability distributions.		
Course Content:	Basic functions: exponential, logarithm, trigonometric functions, hyperbolic functions, their inverses. Differentiation and integration: limits, methods of differentiation, partial differentiation, Maclaurin and Taylor series, convergence, methods of integration, improper integrals; first and second order differential equations. Complex numbers: algebra, geometry of complex numbers, de Moivre's theorem, functions. Determinants, solution of linear equations. Vectors: vector algebra and geometry. Probability: addition and multiplication laws; mean, variance and standard deviation; binomial, Poisson and normal distributions.		
Teaching & Learning Methods:	36 lecture sessions 8 exit tests 22 supervised example classes Approximately 40 hours answering coursework problems Approximately 44 hours private study and revision		
Details of teaching resources on Moodle:	• Course outline and summary • Additional notes • Links to material of interest • Problem assignments • Links to past examination papers and selected solutions		
Bibliography:	**Reference**: Glyn James, Modern Engineering Mathematics with MyMathLab 4/E, Prentice Hall, 2010 ISBN-10: 0273734091 • ISBN-13: 9780273734093 (510.245 JAM) M L Boas, *Mathematical Methods in the Physical Sciences*, J Wiley, 2006. (530.15.BOA) Michael Tinker and Robert Lambourne, *Further Mathematics for the Physical Sciences*, Wiley, 2000 - ISBN 0-471-86723-3 (510.245 FUR) Associated with the previous book is the companion: Robert Lambourne and Michael Tinker, *Basic Mathematics for the Physical Sciences*, Wiley, 2000 - ISBN 0-471-85207-4 (510.245 BAS) You may also find the text books for PH2130 helpful for this course.		
Formative Assessment & Feedback:	Returned marked coursework and example classes. Also exit tests marked openly with comments.		
Summative Assessment:	**Exam:** (60%) (2 hours) All questions to be answered. To pass the course a mark of at least 25% must be achieved in the examination. **Coursework:** (20%) **Exit Tests/Example Classes:** (20%) **Deadlines:** Weekly Coursework		

Course Title:	Mathematics for Scientists 2	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1120	**Course JACS Code:**	F340
Availability:	Spring Term	**Status:**	Essential Core Pass required
Pre-requisites:	PH1110	**Co-requisites:**	
Co-ordinator:	Dr A Ho		
Course Staff:	Dr A Ho		
Aims:	Following on from PH1110, to introduce students to some more advanced mathematical concepts that are used in undergraduate physics courses and to develop further their problem solving skills.		
Learning Outcomes:	On completion of the course, students should be able to: • solve problems involving more than one variable; • use matrices and solve eigenvalue problems; • manipulate vector differential operators (grad, div and curl) and explain their physical significance.		
Course Content:	Functions of more than one variable: partial differentiation, differentiation of integrals, extension of Taylor series, multiple integrals. Fourier series: full and half range, extension of the interval. Coordinate systems. Matrices: eigenvalues and eigenvectors. Scalar and vector fields, differentiation of vectors, introduction to grad, div and curl, Gauss' and Stokes' theorems. (Stokes' theorem is taught but not examined.)		
Teaching & Learning Methods:	36 lecture sessions 8 exit tests 22 supervised example classes Approximately 40 hours answering coursework problems Approximately 44 hours private study and revision		
Details of teaching resources on Moodle:	• Course outline and summary • Additional notes • Links to material of interest • Problem assignments • Links to past examination papers and selected solutions		
Bibliography:	**Reference**: Glyn James, Modern Engineering Mathematics with MyMathLab 4/E, Prentice Hall, 2010 ISBN-10: 0273734091 • ISBN-13: 9780273734093 (510.245 JAM) M L Boas, *Mathematical Methods in the Physical Sciences*, J Wiley, 2006. (530.15.BOA) Michael Tinker and Robert Lambourne, *Further Mathematics for the Physical Sciences*, Wiley, 2000 - ISBN 0-471-86723-3 (510.245 FUR) Associated with the previous book is the companion: Robert Lambourne and Michael Tinker, *Basic Mathematics for the Physical Sciences*, Wiley, 2000 - ISBN 0-471-85207-4 (510.245 BAS) You may also find the text books for PH2130 helpful for this course.		
Formative Assessment & Feedback:	Returned marked coursework and example classes. Also exit tests marked openly with comments.		
Summative Assessment:	**Exam:** (60%) (2 hours) All questions to be answered. To pass the course a mark of at least 25% must be achieved in the examination. **Coursework:** (20%) **Exit Tests/Example Classes:** (20%) **Deadlines:** Weekly Coursework		

Course Title:	Scientific Skills 1	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1140	**Course JACS Code:**	F300
Availability:	Autumn or Spring Term	**Status:**	Core
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr V Antonov		
Course Staff:	Dr V Antonov, Dr T S Berry, Dr C P Lusher, Dr S Gibson		
Aims:	To introduce students to a range of skills in the scientific laboratory.		
Learning Outcomes:	On completion of the course, students should be able to: • Keep a laboratory notebook, recording experimental work as they do it; • Set up an experiment from a script, and carry out and record measurements; • Analyse data and plot graphs using a computer package; • Present results and conclusions including error estimations from their experiments; • Write a short review article and give a short talk on a scientific topic.		
Course Content:	Nine physics experiments/exercises, two formal laboratory reports, one review article, one talk.		
Teaching & Learning Methods:	60 hours of supervised laboratory time. Approximately 90 hours work outside laboratory on completing analysis of data, writing reports and a review article and preparing a talk.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest		
Bibliography:	As specified in the individual modules		
Formative Assessment & Feedback:	Returned marked laboratory exercises with comments.		
Summative Assessment:	**Coursework:** (100%) Laboratory notebooks, formal reports, an essay, oral presentation. **Deadlines:** End of each module		

Course Title:	Scientific Skills 2	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1150	**Course JACS Code:**	F300
Availability:	Spring Term	**Status:**	Core
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr V Antonov		
Course Staff:	Dr V Antonov, Dr T S Berry, Dr N Kauer, Dr C P Lusher, Dr S Gibson		
Aims:	To introduce students to a range of skills in the scientific laboratory, extending their knowledge and experience above that obtained in PH1140.		
Learning Outcomes:	On completion of the course, students should be able to: • carry out similar tasks to those in PH1140, but over a wider range of physics topics and apparatus; • use the computer algebra package Mathematica to solve simple problems; • work as part of a team to investigate an open-ended computational problem.		
Course Content:	Eight physics experiments (individually programmed), Mathematica exercises and a team project.		
Teaching & Learning Methods:	72 hours of supervised laboratory time. Approximately 78 hours work outside laboratory on completing analysis and reports.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest		
Bibliography:	As specified in the individual modules.		
Formative Assessment & Feedback:	Returned marked laboratory exercises with comments.		
Summative Assessment:	**Coursework:** (100%) Laboratory notebooks, teamwork reports. **Deadlines:** End of each module		

Course Title:	Mechanics and Relativity	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1320	**Course JACS Code:**	F300
Availability:	Autumn Term	**Status:**	Essential Core
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr P J Meeson		
Course Staff:	Dr P J Meeson		
Aims:	To provide a comprehensive treatment of classical mechanics that fully integrates the use of calculus and vector notation and to provide an introduction to the special theory of relativity.		
Learning Outcomes:	On completion of the course, students should be able to: • apply from first principles and from memory the techniques and formulae of mathematical analysis (in particular the use of vectors and calculus) to solve problems in classical mechanics, including statics, dynamics and kinematics as applied to linear and rigid body rotational dynamics; • implement the various techniques of physical analysis (such as force diagrams, conservation principles, etc) to solve problems; • apply, from first principles and from memory, the formulae of special relativity to obtain correct solutions to problems; • Explain from first principles and derive standard formulae in classical and special relativistic mechanics.		
Course Content:	Newtonian mechanics: Motion in 1,2 and 3 dimensions. The constant acceleration equations. Generalised motion. Calculus and vectors as analytical tools. Newton's laws. Basic concepts (force, mass, work, energy, power, conservation of energy). Conservative forces and the dot product. Reference frames: inertial and non-inertial reference frames, the Galilean transformation. Galilean and Einsteinian relativity. Special relativistic mechanics: Co-ordinate transformation, Lorentz contraction, time dilation, twin paradox, $E = mc^2$, $E^2 = c^2p^2 + m^2c^4$. Collisions, centre of mass, conservation of momentum. Rotational motion: The constant angular acceleration equations, Newton's laws for rotation. Conservation of angular momentum. The cross product. Moments of inertia. Kinetic and potential energy of rotating systems. Gyroscopic precession. Conditions for static equilibrium and stability. Central force fields: Newton's Gravitation and Coulomb's Electrostatic Force Laws, Kepler's laws, planetary and satellite motion, binary star systems		
Teaching & Learning Methods:	28 lectures with demonstrations + 3 feedback classes. 117 hours self-study, including answering coursework problems, consolidating lecture material, reading around the subject, learning the material and revision.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** D C Giancoli, *Physics for Scientists & Engineers* Pearson / Prentice Hall. (530.GIA) **Key Reading:** M L Boas, *Mathematical Methods in the Physical Sciences*, Wiley. (530.15 BOA) Also see other mathematics books recommended for first and second year.		

Formative Assessment & Feedback:	Fortnightly online problem sets + fortnightly tutorial problem sheets (alternating weeks). Feedback on tutorial problem sheets in weekly tutorials
Summative Assessment:	**Exam:** (60%) (2 hours) **Coursework:** (20%) Fortnightly online problem sets. (20%) One two hour in-class test under exam conditions. **Deadlines:** Coursework deadlines are within one week of issue of the problem sheets. **Weekly tutorials:** Attendance Fail

Course Title:	Fields and Waves	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1420	**Course JACS Code:**	F341/F300
Availability:	Spring Term	**Status:**	Essential Core
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr T S Berry		
Course Staff:	Dr T S Berry		
Aims:	Introduction to the physics of electricity, magnetism, vibrations and waves. Reinforcement of scientific thinking, reasoning and modeling. Training of problem solving ability and numeracy.		
Learning Outcomes:	On completion of the course, students should be able to: • solve problems in vibrations, resonance and wave phenomena; • be familiar with the concept of electric and magnetic fields and be able to solve problems in electricity and magnetism; • know about the passive components of electric circuits and be able to solve problems involving DC and AC circuits; • be able to apply the techniques of mathematical analysis, in particular the use of vectors, complex numbers and calculus to solve the problems detailed above.		
Course Content:	• Simple Harmonic Motion, damped, forced, resonant harmonic motion. Transients. LCR circuits. • Coupled oscillators, normal modes. • Wave motion, the wave equation, superposition, transmission, reflection, standing waves and beats, the Doppler effect, dispersion, phase and group velocity, waves on strings, sound waves: transverse and longitudinal waves, polarisation. • Coulomb's Law, Electric fields to the level $E_x = -\partial V/\partial x$ and grad. • Parallel plate capacitor formula, reactance. • Magnetic force between two currents. • B-field due to a wire, coil, solenoid etc. Biot-Savart Law, Amperes Law • Force between two parallel currents, Torque on a coil in a B-field • Faraday's law, self inductance, reactance. • D.C and A.C. circuits, complex impedance. Kirchhoff's laws.		
Teaching & Learning Methods:	26 lectures with demonstrations + 5 problem classes + 2 in class tests. 120 hours self-study, including answering coursework problems, learning the material and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** D C Giancoli, *Physics for Scientists & Engineers* Pearson / Prentice Hall. (530.GIA) **Key Reading:** H J Pain, *The Physics of Vibrations and Waves* Wiley. (530.141 PAI)		

Formative Assessment & Feedback:	Fortnightly online problem sets with answers and feedback available immediately online. In-class tests will be marked with comments; and solutions and opportunity for discussion/feedback provided in a lecture/class. In addition, classes provide an opportunity to discuss problems with the lecturer. Fortnightly tutorial problems (not-assessed) will also be discussed in weekly tutorials.
Summative Assessment:	**Exam:** (60%) (2 hours) **In-class tests:** (2 x 15%) Two one hour tests **Coursework:** (10%) Fortnightly problem sets **Deadlines:** Coursework deadlines are within one week of issue of the problem sets. **Weekly tutorials:** Attendance Fail

Course Title:	Classical Matter	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1620	**Course JACS Code:**	F321
Availability:	Autumn Term	**Status:**	Essential Core
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr P G Niklowitz		
Course Staff:	Dr P G Niklowitz		
Aims:	• Introduction to the science of matter • Reinforcement of scientific thinking, reasoning and modelling • Training of problem solving ability and numeracy		
Learning Outcomes:	On completion of the course, students should be able to: • understand the macroscopic properties of the various states of matter • have familiarity with the variables and properties used in the description of matter; • be able to describe microscopic models accounting for some of these properties; • understand changes of phase of matter.		
Course Content:	Elementary ideas: Macroscopic descriptions, ideal gases, temperature. Work, internal energy and heat capacity Thermodynamic equilibrium and processes, zeroth and first laws of thermodynamics. Microscopic models of gases: Kinetic theory, molecular speed distribution, equipartition, transport properties. Interatomic forces and properties of solids: forces between atoms, elasticity, expansion, tensile strength, elastic properties of real solids, metals, superconductors. Liquids: Properties of fluids, surface tension, liquid flow, viscosity and further properties. Changes of state and real gases: Phase equilibrium, van der Waals equation, liquefaction of gases. Other states of matter: Disordered systems, polymers, colloids, liquid crystals, plasmas.		
Teaching & Learning Methods:	27 lectures with demonstrations + 6 problem classes. 120 hours self-study, including answering coursework problems, learning the material and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** D C Giancoli, *Physics for Scientists & Engineers*, Pearson / Prentice Hall. (530.GIA) **Key Reading:** David Tabor, *Gases, Liquids and Solids - and Other States of Matter*, 3rd Ed., Cambridge University Press, 1991. (530.4 TAB) **Further Reading:** J Bolton, *Classical Physics of Matter,* IOP Publishing, 2000. B Flowers and E Mendoza, *Properties of Matter,* Wiley, 1970. (530.4 FLO) M. de Podesta, *Understanding the Properties of Matter,* Taylor & Francis, 2002. (530.4 POD). A J Walton, *Three Phases of Matter,* Clarendon Press, 1983. (530.4 WAL)		
Formative Assessment & Feedback:	Fortnightly problem sheets and in-class tests will be marked with comments and discussed during fortnightly problem classes. Problems will also be discussed in weekly tutorials.		

Summative Assessment:	**Exam:** (60%) (2 hours) **Coursework:** (10%) Fortnightly problem sheets **In-class tests:** (2 x 15%) Two one hour tests **Deadlines:** Coursework deadlines are within one week of issue of the problem sheets. **Weekly tutorials:** Attendance Fail

Course Title:	Physics of the Universe	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Certificate
Course Code:	PH1920	**Course JACS Code:**	F510/F342
Availability:	Spring Term	**Status:**	Essential Core
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr S West		
Course Staff:	Dr S West		
Aims:	The aim of the course is to introduce students to fundamental ideas of special relativity, quantum mechanics and astrophysics. All material is essential for more advanced courses in these areas.		
Learning Outcomes:	By the end of the course, students should have acquired knowledge of the basic ideas of special relativity, quantum mechanics, and astrophysics and should be able to carry out straightforward calculations on these topics.		
Course Content:	<u>Special Relativity</u>: Michelson-Morley experiment; Addition law of velocities; Transformation of energy and momentum under Lorentz transformations; Conservation of four momentum; Invariant mass; Simple kinematics: e.g. Threshold energy for pair production, decays in different frames of reference; Relativistic Doppler effect for photons. <u>Quantum Ideas</u>: Black body radiation and Planck's law; Photoelectric effect; Energy and momentum of the photon; Compton effect, Wave particle duality, de Broglie relation, Davisson-Germer; Simple model of atom: nucleus, atomic spectra, quantum numbers; Bohr model: success and limitations; Heisenberg uncertainty principles – application to simple problems; Time independent Schrödinger equation in 1D: wavefunction, probability, mean, solution in simple potentials; particle in a box; scattering at potential steps, tunnelling at a barrier, (applications e.g. Scanning Tunnelling Microscope); radioactive decay. <u>Astrophysics</u>: Simple observational ideas: Luminosity, flux, colour; Distance scales (distance modulus, apparent and absolute magnitudes), structure of our universe (solar, local group, galaxies, groups of galaxies etc.); H-R diagram (qualitative basic ideas), spectra, red-shift; Hubble expansion and Hubble's Law; Big bang theory, evidence. Friedmann equation and associated cosmological parameters; Composition of the Universe, Dark matter (evidence for, e.g. rotational velocity curves); observable universe and horizons; Thermal History of the Universe (qualitative description only).		
Teaching & Learning Methods:	33 contact hours (27 + 6 feedback classes). 117 hours self-study, including answering coursework problems, learning the material and revision.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** D C Giancoli, *Physics for Scientists & Engineers* Pearson / Prentice Hall. (530.GIA)		
Formative Assessment & Feedback:	Weekly problem will be marked with comments. Extra opportunity for discussion/feedback provided in feedback lectures. Five tutorial problems sheets (not-assessed) for discussion in tutorials.		
Summative Assessment:	**Exam:** (80%) (2 hours) **Coursework:** (20%) Weekly problem sets. **Deadlines:** Coursework handed in within one week of issue **Weekly tutorials:** Attendance Fail		

Course Title:	Mathematical Methods	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2130	**Course JACS Code:**	F340
Availability:	Autumn Term	**Status:**	Core for some programmes, optional for others
Pre-requisites:	PH1110, PH1120	**Co-requisites:**	
Co-ordinator:	Prof G D Cowan		
Course Staff:	Prof G D Cowan		
Aims:	To develop students skills in solving mathematical problems in physics. To introduce students to a range of techniques for achieving this.		
Learning Outcomes:	On completion of the course, students should be able to: • Solve a range of mathematical problems in physics, particularly those involving differential equations; • Appreciate the mathematical representation of physical problems and the physical interpretation of mathematical equations.		
Course Content:	Ordinary differential equations: physical origins, linear equations with constant coefficients, homogeneous and inhomogeneous equations, exact differentials, integrating factors, simple power series method, sines and cosines, Legendre's equation and Legendre polynomials, Frobenius method, Bessel's equation and Bessel functions, Sturm-Liouville theorem and orthogonality, orthogonal expansions, Fourier series and other examples. Partial differential equations: physical origins, the Laplacian, separation of variables, boundary conditions, Cartesian coordinates, polar coordinates, circular membrane, spherical coordinates, Legendre's equation. Integral transforms: Fourier transform and its physical meaning, solutions with Fourier transforms. Gamma function and Dirac delta function.		
Teaching & Learning Methods:	33 lectures + 22 hours of supervised problem classes. Approximately 95 hours spent on problems, exercises and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** M L Boas, *Mathematical Methods in the Physical Sciences*, J Wiley, 2006. (530.15.BOA) **Further Reading:** E Kreyszig, *Advanced Engineering Mathematics*, 9th Ed., J Wiley, 2006. (510.245.KRE) K F Riley, M P Hobson & S J Bence, *Mathematical Methods for Physics and Engineering*, 3rd Ed., CUP, 2006. (510.245.RIL)		
Formative Assessment & Feedback:	Marked problem assignments and coursework exercises		
Summative Assessment:	**Exam:** (60%) (2 hours) One compulsory question + two others to be answered out of four **Coursework:** (20%) problem class exercises (20%) independent problem assignments **Deadlines:** deadline dates determined by timetabling, announced at the commencement of the course.		

<table>
<tr><td>Course Title:</td><td>Scientific Computing Skills</td><td>Course Value:
Level:</td><td>0.5 cu / 7.5 ECTS
Intermediate</td></tr>
<tr><td>Course Code:</td><td>PH2150</td><td>Course JACS Code:</td><td>F343</td></tr>
<tr><td>Availability:</td><td>Autumn Term and post exam period of Term 3 of Year 1</td><td>Status:</td><td>Core</td></tr>
<tr><td>Pre-requisites:</td><td>None</td><td>Co-requisites:</td><td></td></tr>
<tr><td>Co-ordinator:</td><td colspan="3">Dr A J Casey</td></tr>
<tr><td>Course Staff:</td><td colspan="3">Dr A J Casey and other Physics Department staff</td></tr>
<tr><td>Aims:</td><td colspan="3">Students will be introduced to the computing language Python. Practice with the language will allow students to:
• plot and analyze experimental data,
• gain insight into some of the phenomena treated in 1st and 2nd year physics lectures courses,
• solve a real scientific problem, which is then submitted as a report.</td></tr>
<tr><td>Learning Outcomes:</td><td colspan="3">On completion of the course, students should be:
• familiar and fluent with some of the high-level data analysis packages within Python,
• able to plot multidimensional data in different ways (histograms, parametric plots),
• able to write computer programs that demonstrate the concepts and equations behind physics covered in the 1st and 2nd years.
• able make comparisons between different fits and approximations.</td></tr>
<tr><td>Course Content:</td><td colspan="3">Topics to be covered:
Basics of numerical calculation on computers: Types of computing. Numerical, symbolic, procedural, object orientated.
Arrays and Matrices: Arrays for storing data, manipulating arrays. Using arrays and matrices (Eigenvector, inversion).
Plotting and visualization: Scatter plots, Histograms, Multi-dimensional plots.
Data analysis: Mean/mode/median; Variance, RMS, kertosis, moments; Fitting (least squares); Regression.
Advanced data analysis: Fourier series, Fourier transform, Smoothing.
Programming: Control structures (if, for, while, return etc). Functions, program layout
Simulation: Evaluation of simple and complex expressions. Monte Carlo. Numerical integration.
Differential equations: Difference methods. Leap-frog method. Runge Kutta.
Monte Carlo methods: Metropolis algorithm. Integrals, integral estimation
Linear equations: Solutions, eigenvalues. Diagonalisation. Factorisation.
Project report: example illustrating physics from 2nd year core.</td></tr>
<tr><td>Teaching & Learning Methods:</td><td colspan="3">11 hours of lectures, 16 hours in teaching laboratory at end of First year Term 3
11 hours of lectures, 44 hours in the teaching laboratory.
68 hours of private study, reading, program development, and report writing.</td></tr>
<tr><td>Details of teaching resources on Moodle:</td><td colspan="3">• Course outline and details of work to be submitted
• Additional notes and web links
• Links to material of interest.</td></tr>
<tr><td>Bibliography:</td><td colspan="3">Notes provided.</td></tr>
<tr><td>Formative Assessment & Feedback:</td><td colspan="3">Fast written feedback given on the 10 weekly problem sets.
Written report marked.</td></tr>
<tr><td>Summative Assessment:</td><td colspan="3">Coursework: 10 problem sets (70%); written report (30%). Three of the problem sets will be covered in lab sessions which will take place after Summer exams in the previous academic year; they will contribute 20% of the final mark.
Deadlines: Problem sets from Term 3 to be submitted by beginning of Autumn term. Remaining problem sets in Autumn term at the end of each week's sessions. Written report at end of term.</td></tr>
</table>

Course Title:	Quantum Mechanics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2210	**Course JACS Code:**	F342
Availability:	Autumn Term	**Status:**	Essential Core
Pre-requisites:	PH1320, PH1920	**Co-requisites:**	
Co-ordinator:	Dr J T Nicholls		
Course Staff:	Dr J T Nicholls		
Aims:	To study in depth the use of Schrödinger's equation to solve problems involving the motion of a particle in a potential in one and three dimensions. To demonstrate how the solution predicts quantisation of the energy of the particle and the need to introduce other quantum numbers to describe its behaviour. To demonstrate the solution to Schrödinger's equation for the hydrogen atom and to provide a simple understanding of the periodic table. To introduce the concept of mixed states.		
Learning Outcomes:	On completion of the course, students should be able to: • demonstrate a sound understanding of the use of Schrödinger's equation; • solve the equation for a number of simple potentials including the square well, the simple harmonic oscillator and the hydrogen atom. For each of these they should be able to sketch the potential, the energy level diagram and typical wave functions; • provide the definition of terms such as normalisation and parity of wave functions, and degeneracy and to explain quantitatively the phenomenon of quantum mechanical tunnelling.		
Course Content:	Review of photoelectric effect, Compton effect, matter waves, and atomic spectra. Schrödinger equation - DSE and TISE Stationary states. Potential step, particle in a box. Finite square well and 1D quantum harmonic oscillator. Transmission over potential barrier and well. Hermitian operators, postulates of quantum mechanics. Commutators. Ehrenfest's theorem. Introduction to angular momentum. Definition of L_x, L_y, L_z, and L^2, and their commutator relationships. Central potentials. Magnetic moment. Orbital and spin angular momentum. Stern-Gerlach experiment. The Pauli spin matrices S_x, S_y, S_z, and S^2 Schrödinger equation in dimensionless form. The radial solutions and probability density functions for hydrogen atom. Electron configurations in simple atoms. Identical particles. Singlet and triplet states. Multielectron atoms: screening, Aufbau principle, Periodic Table. Time-independent perturbation theory. Wavepackets and the uncertainty principle.		
Teaching & Learning Methods:	27 lectures and approximately 6 problem classes Approximately 118 hours private study time, to be used for learning the material in detail, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline. • Lecture summaries. • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** A I M Rae, *Quantum Mechanics*, McGraw Hill 1986. (530.12 RAE) **Key Reading:** B H Bransden and C J Joachain, *Quantum Mechanics*, Pearson/Prentice Hall, 2nd edition 2000. (530.12.BRA)		

Formative Assessment & Feedback:	Student answered problem sheets that will be marked, returned and discussed during problem classes.
Summative Assessment:	**Exam:** (100%) (2 hours) One compulsory question + two others to be answered out of four. **Coursework:** Six coursework assignments (0%). **Deadlines:** Stated with each problem sheet and normally about 10 days from the date issued.

Course Title:	Optics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2310	**Course JACS Code:**	F360
Availability:	Spring Term	**Status:**	Essential core
Pre-requisites:	PH1320, PH2420	**Co-requisites:**	
Co-ordinator:	Dr P Karataev		
Course Staff:	Dr P Karataev		
Aims:	An appreciation of the wide range of applicability of Maxwell's equations in understanding physical phenomena. Understanding fundamental optical phenomenon by means of lectures, practical experience and problem solving. A basic understanding of the physics of lasers and modern optics.		
Learning Outcomes:	On completion of the course, students should be able to: • understand how Maxwell's equations provide the description for many optical phenomena; • have gained practical experience and an understanding of the basics of both physical and geometric optics; • apply these theoretical and experimental techniques in the solution of simple problems.		
Course Content:	Definition of Fourier transforms and their properties; Convolution and Transfer functions; Various applications of Fourier Transforms; Solutions of Differential Equations using Fourier Transforms. Geometrical optics. Fraunhofer and Fresnel diffraction. Optical instruments: image formation and quality. Rayleigh criterion and resolving power, aberrations. Interference. Two-beam and multiple-beam effects. Interferometers. Thin films. Dispersion in dielectric media. Normal and anomalous dispersion. Scattering of e-m radiation. Polarisation by scattering and other means. Masers and lasers: history; spontaneous and stimulated emission; Einstein coefficients; practical details of lasers and laser systems; properties of laser light. Fourier optics and diffraction; Huygens-Fresnel theory of diffraction; Gaussian beams; spatial and temporal coherence; applications to optical imaging, image processing and Fourier Transform spectroscopy.		
Teaching & Learning Methods:	22 lectures, 18 hours supervised laboratory, 6 hours problem solving class. Approximately 117 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** F Graham-Smith and T A King, *Optics and Photonics*, Wiley, 2000. (535.SMI) **Key Reading:** M L Boas, *Mathematical Methods in the Physical Sciences*, J Wiley, 2006. (530.15.BOA) D C Giancoli, *Physics for Scientists & Engineers* Pearson / Prentice Hall. (530.GIA) R S Longhurst, *Geometrical and Physical Optics*, 3rd Ed., Longman, 1974. (535.32.LON) F A Jenkins & H E White, *Fundamentals of Optics*, 4th Ed., McGraw Hill, 1981.(535.JEN)		

Formative Assessment & Feedback:	Fortnightly problem classes will discuss marked coursework assignments. Coursework assignments will also be discussed in weekly tutorials.
Summative Assessment:	**Exam:** (70%) (2 hours) One compulsory question + two others to be answered out of four **Coursework:** (10%) **Labwork:** (20%) **Deadlines:** Fortnightly coursework exercises

Course Title:	Electromagnetism	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2420	**Course JACS Code:**	F341
Availability:	Autumn Term	**Status:**	Essential core
Pre-requisites:	PH1110 and PH1120, or MT2220	**Co-requisites:**	
Co-ordinator:	Dr C P Lusher		
Course Staff:	Dr C P Lusher		
Aims:	An understanding of the development from elementary ideas of electromagnetism up to Maxwell's equations and the existence of electromagnetic waves.		
Learning Outcomes:	On completion of this course, students should be able to: • calculate electric fields and electric potentials from given fixed charge distributions; • calculate magnetic fields and vector potentials from given steady current distributions; • understand, and be able to explain and perform calculations on electromagnetic induction and displacement currents; • synthesise the above phenomena into the Maxwell equations; • derive properties of electromagnetic waves.		
Course Content:	Vector calculus treatment of Electrostatics: the electric field, Coulomb's and Gauss' laws, electric field energy, equations of Poisson and Laplace. Steady currents: continuity equation, Kirchhoff's laws, Laplace's equation in conductors. Vector calculus treatment of the magnetic effects of currents: Biot-Savart law, magnetic field, Ampère's law, Lorentz force, energy of a magnetic field. Induction; Faraday's law, Lenz's law. Displacement current. Electric and magnetic dipoles and the electromagnetism of matter. Macroscopic fields **E**, **D**, **B** and **H**; their boundary conditions at interfaces. Maxwell's equations; plane waves in free space and in media; reflection, refraction, polarisation. Poynting vector. The EM spectrum. Radiation pressure. Propagation in lossy media: dielectric loss, ohmic loss, skin depth; electromagnetic screening. Electromagnetic potentials. Gauge freedom. Scalar and vector potentials for stationary and time varying problems. Radiation from dipoles. Incompatibility of Maxwell's equations and Newton's laws. Resolution by Lorentz transformation and special relativity.		
Teaching & Learning Methods:	27 lectures, 9 hours supervised laboratory, 6 hours problem classes Approximately 108 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		

Bibliography:	**Key Reading:** G L Pollack & D R Stump, *Electromagnetism*, Addison Wesley, 2002. (537.POL) D J Griffiths, *Introduction to Electrodynamics,* 3rd Ed. Prentice Hall, 1989. (537.6.GRI) W J Duffin, *Electricity and Magnetism*, 3rd Ed., McGraw-Hill, 1980. (537.DUF)
Formative Assessment & Feedback:	Fortnightly problem classes will discuss marked coursework assignments. Coursework assignments will also be discussed in weekly tutorials.
Summative Assessment:	**Exam:** (80%) (2 hours) One compulsory question + two others to be answered out of four **Laboratory**: (10%) **Coursework:** (10%) The best four of five fortnightly homework exercises **Deadlines:** Fortnightly, depending on timetabling. Announced at the commencement of the course and posted on Moodle.

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Course Title:	Atomic and Nuclear Physics	Course Value: Level:	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2510	Course JACS Code:	F370
Availability:	Spring Term	Status:	Essential core
Pre-requisites:	PH1920, PH2210	Co-requisites:	
Co-ordinator:	Dr G Ithier		
Course Staff:	Dr G Ithier		
Aims:	To introduce and explain the principles, models, and methods required to understand the behaviour of multi-electron atoms. To introduce and explain the models that account for the properties of nuclei. To review the several types of nuclear reaction. To explain the basics of nuclear radiation detection.		
Learning Outcomes:	On completion of the course, students should be able to: • understand the basic theoretical and experimental physics of atoms and nuclei; • understand the importance of models in describing the properties and behaviour of atoms and nuclei; • be able to solve related problems.		
Course Content:	Single-electron atoms. Multi-electron atoms. Atomic spectra. X-ray spectra. Hyperfine structure. Experimental techniques. Nuclear models. Radioactive decay: alpha, beta and gamma decay. Nuclear reactions. Fission, fusion, chain reaction. Interaction of radiation with matter. Nuclear radiation detectors.		
Teaching & Learning Methods:	22 lectures, 18 hours supervised laboratory, 6 hours problem solving class Approximately 104 hours spent completing analysis of experimental work, learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture summaries • Handouts • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** R Eisberg and R Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles*, 2nd edition, John Wiley & Sons, 1985. (530.12.EIS) **Key Reading:** K S Krane, *Introductory Nuclear Physics*, John Wiley, 1988. (539.7.KRA)		
Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during problem classes.		
Summative Assessment:	**Exam:** (70%) (2 hours) One compulsory question + two others to be answered out of four **Coursework:** (10%) **Labwork:** (20%) **Deadlines:** Fortnightly homework exercises		

<table>
<tr><td>Course Title:</td><td>Particle Detectors and Accelerators</td><td>Course Value:
Level:</td><td>0.5 cu / 7.5 ECTS
Intermediate</td></tr>
<tr><td>Course Code:</td><td>PH2520</td><td>Course JACS Code:</td><td>F370</td></tr>
<tr><td>Availability:</td><td>Spring Term</td><td>Status:</td><td>Core for BSc & MSci Physics with Particle Physics;
Optional for others</td></tr>
<tr><td>Pre-requisites:</td><td>None</td><td>Co-requisites:</td><td></td></tr>
<tr><td>Co-ordinator:</td><td colspan="3">Dr J A Nikkel</td></tr>
<tr><td>Course Staff:</td><td colspan="3">Dr J A Nikkel & other Physics Department staff and NET</td></tr>
<tr><td>Aims:</td><td colspan="3">To introduce and explain the principles, techniques and apparatus behind particle detection.
To introduce the basic principles behind particle accelerators. To provide an overview of the accelerators and multipurpose particle detectors used in the current research in high-energy physics.</td></tr>
<tr><td>Learning Outcomes:</td><td colspan="3">On completion of the course, students should be able to demonstrate an understanding of
the basic principles involved in the main types of detectors;
the main indicators of detector performance and be able to evaluate them;
the functionality of the several components of a typical large multipurpose particle detector;
the basic processes underlying the acceleration, bending and focussing of particle beams;
the advantages and disadvantages of different accelerator types;
and be able to solve problems related to the subject matter of this course.</td></tr>
<tr><td>Course Content:</td><td colspan="3">Part I / Detectors: Interaction of particles in matter, energy loss processes. General characteristics of detectors: sensitivity, resolution, efficiency, dead time. Principles of operation of ionisation, scintillation, semiconductor and Cherenkov detectors. Applications to the tracking, energy measurement and identification of particles in particle physics experiments. Study of al multi-purpose detector in high energy physics, integrating several of the detection methods above.

Part II / Accelerators: Introduction to the basic physical principles underlying the operation of modern accelerators. Transverse motion of particles in a beam; beam optics: bending and focusing elements. Accelerating cavities. Synchrotron radiation. Circular and linear accelerator designs. Methods for measurement of energy, luminosity and polarisation in colliders. Study of the design and the operation of e^+e^- and hadron colliders. Introduction to some applications in the area of medical physics.</td></tr>
<tr><td>Teaching & Learning Methods:</td><td colspan="3">Lectures (22 × 1h) and problem classes. One field-trip to a particle physics facility, after which each student will prepare and submit a report to be assessed.
Private study time, including problem solving and other coursework, and examination preparation.

! Note: This course includes a fieldtrip: a visit to a national or international particle physics, particle detectors and/or accelerators facility. Attendance of the fieldtrip is compulsory. The Department subsidises the cost of the fieldtrip. The total funds are limited and do not cover all expenses. Students must be prepared to pay all fieldtrip expenses in excess of the departmental subsidy; the extra cost can be up to £120 per student.</td></tr>
<tr><td>Details of teaching resources on Moodle:</td><td colspan="3">Course outline
Lecture summaries
Links to material of interest
Problem assignments and solutions (at the appropriate time)
Links to past examination papers and selected solutions</td></tr>
</table>

Bibliography:	Lecture notes will be handed out at the beginning of the course. **References:** For more detailed references, see for instance: W R Leo, *Techniques for Nuclear and Particle Physics Experiments*, Springer, 1994. (539.721.LEO) E Wilson, *An Introduction to Particle Accelerators*, OUP, 2001. (539.73.WIL)
Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during problem classes.
Summative Assessment:	**Exam:** (70%) (2 hours) **Report:** (20%) Report of field trip **Coursework:** (10%) A number (~3) of sets of assessed problems are completed during the course. **Deadlines:** Coursework deadlines are normally within 2 weeks from the issue of the problem set. Report deadline is 1 month from completion of field trip.

PCourse Title:	Classical and Statistical Thermodynamics	Course Value: Level:	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2610	Course JACS Code:	H311
Availability:	Spring Term	Status:	Essential Core
Pre-requisites:	PH1620	Co-requisites:	
Co-ordinator:	Professor J P Goff		
Course Staff:	Professor J P Goff		
Aims:	To introduce students to the methods of thermodynamics and statistical mechanics. To lay the foundation for the application of these methods in other areas of physics.		
Learning Outcomes:	Upon completion of this course, students should be able to: • understand the methods of thermodynamics and statistical mechanics and their interrelationship as tools for condensed matter physics; • to apply this understanding to simple problems.		
Course Content:	Thermodynamic equilibrium and processes. The zeroth and first law of thermodynamics. Temperature, heat and work. Properties of ideal gases. Counting microstates, order and entropy. The second law of thermodynamics. The statistical mechanics of localised systems: the spin ½ paramagnet, Einstein model of a solid. Boltzmann distribution, partition function. Entropy in thermo-dynamics. Cyclic processes and heat engines. Thermodynamic potentials: equilibrium, Maxwell's relations and their applications. Statistical mechanics of gases, density of states. Calculation of properties of gases in the classical limit, partition function, entropy, equation of state, Maxwell-Boltzmann velocity distribution. Collisions and transport properties. Fermi gases: the Fermi Dirac distribution function. Application to electrons in metals and liquid ^{3}He. Bose gases: The Bose-Einstein and Planck distribution functions. Applications to photons (black body radiation), phonons (Debye model), liquid ^{4}He. Phase equilibrium. Generic phase diagram. Conditions for phase coexistence. Clausius-Clapeyron equation. Applications to real systems, including ^{3}He. The third law of thermodynamics and the unattainability of absolute zero.		
Teaching & Learning Methods:	27 lectures, 6 hours supervised laboratory, 5 hours problem classes Approximately 108 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** C Finn, *Thermal Physics*, Chapman & Hall, 1993. (536.7.FIN) A M Guenault, *Statistical Physics*, Chapman & Hall, 1995. (530.13.GUE)		
Formative Assessment & Feedback:	Fortnightly problem classes will discuss coursework assignments. Coursework assignments will also be discussed in tutorials.		
Summative Assessment:	**Exam:** (60%) (2 hours) One compulsory question + two others to be answered out of four **In-class tests:** (2 x 10%) Two one-hour in-class tests **Laboratory:** 10%) **Coursework:** (10%) **Deadlines:** Fortnightly homework exercise		

Course Title:	The Solid State	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2710	**Course JACS Code:**	F321
Availability:	Spring Term	**Status:**	Essential core
Pre-requisites:	PH1620, PH1920 and PH2210	**Co-requisites:**	
Co-ordinator:	Professor M Eschrig		
Course Staff:	Professor M Eschrig		
Aims:	The aim of the course is to provide an overview of the basic physical properties of solids.		
Learning Outcomes:	On completion of the course, the students should be able to: • demonstrate an understanding of the basic physical properties solids; • apply this understanding to simple problems.		
Course Content:	The aim of the course is to provide an overview of the basic physical properties of solids including: • general concepts, types of bonds; • electrons and nuclei in periodic potentials; • adiabatic approximation, crystal structure; reciprocal lattice and Brillouin zone; • electron theory of solids; • crystal vibrations; • collective properties of electrons in solids; • transport in metals and semiconductors; • types of order in solids, spontaneous symmetry breaking; examples: magnetism, superconductivity; • new developments;		
Teaching & Learning Methods:	33 lectures and problem classes. 18 hours of laboratory experiments. 99 hours private study time, including problem solving and other coursework, and examination preparation.		
Details of teaching resources on Moodle:	• Course outline • Lecture summaries • Links to material of interest • Problem assignments (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** N W Ashcroft and N D Mermin, *Solid State Physics*, Holt, Rinehart & Winston,1977. (530.41 ASH) C Kittel, *Introduction to Solid State Physics* 7th Ed., Wiley, 2005. (530.41 KIT)		
Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during problem classes. Students receive verbal feedback on lab measurements and written feedback on lab reports.		
Summative Assessment:	**Exam:** (70%) (2 hours) One compulsory question + two others to be answered out of four **Coursework:** (10%) A number (~5) of sets of assessed problems are completed during the course **Laboratory:** (20%) Practical skills assessment via three experimental laboratory reports **Deadlines:** Coursework deadlines are normally within 2 weeks from the issue of the fortnightly problem set. Laboratory report deadline is 1 week from completion of experiment		

Course Title:	Astronomy	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Intermediate
Course Code:	PH2900	**Course JACS Code:**	F500
Availability:	Spring Term	**Status:**	Core for BSc and MSci Astrophysics programmes, optional for others
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr S T Boogert		
Course Staff:	Dr S T Boogert		
Aims:	To understand how astronomical observations and made and interpreted, leading to astrophysical measurements. To provide the necessary theoretical background to astronomy in order to make full use of observing time on a telescope. To introduce our nearest celestial neighbours in the solar system and to understand current theories on how these bodies formed and what processes shaped their surfaces.		
Learning Outcomes:	On completion of the course, students should be able to: • Understand the experimental and calculation techniques of astronomy as an observational science; • Use fundamental physics to understand astronomical observations; • Apply of astronomical ideas to simple problems; • Be able to apply order of magnitude methods to evaluate complex problems; • Use the observatory, including the telescope, CCD cameras and associated software.		
Course Content:	Observing the Universe: Observations in different wavelengths. Earth and space-based telescopes (and related instruments) and their merits and limitations. Basic parameters and measurements in Astronomy: coordinate systems, timekeeping systems, magnitude, angular size, luminosity, colour, mass, distance, temperature, standard candles, redshift. The solar system. The structure and dynamics of the solar system. The contents of the solar system: the planets and their moons, rings, asteroids, comets, dust, the solar wind. An introduction to planetary geology.		
Teaching & Learning Methods:	27 lectures + 6 problem classes + 12 hours observations Approximately 105 hours spent learning material, astronomical observation, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** M Zeilik & S A Gregory, *Introductory Astronomy and Astrophysics,* 4th Ed., Saunders, 1998. (520.ZEI) H Karttunen *et al*., *Fundamental Astronomy*, Springer, 2000. (520.FUN)		
Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during problem classes.		
Summative Assessment:	**Exam:** (70%) (2 hours) One compulsory question + two others to be answered out of four **Coursework:** (10%) **Practical reports:** (20%) **Deadlines:** Fortnightly problem sheets		

Course Title:	Energy	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3040	**Course JACS Code:**	F330
Availability:	Spring Term	**Status:**	Optional
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr V Antonov		
Course Staff:	Dr V Antonov		
Aims:	• To give students an overall view of the generation, transmission, storage and usage of energy. Introduce students to a wide range of established and alternative energy sources and measures to improve energy efficiency. • To examine the relationship between energy, politics, economics and pollution, particularly as regards global warming. • To provide a course suitable for both managers and scientists.		
Learning Outcomes:	By the end of this course, students should be able to demonstrate an understanding of: • the sources from which the various forms of energy are generated • the technical, political, economic and environmental problems associated with each form • the importance large-scale storage of energy has for the use of renewables. • the main arguments for attributing global warming to greenhouse gases Students should be able to interpret data and to solve problems related to the content of the course.		
Course Content:	Generation, transmission and supply of energy. Conventional energy sources; fossil fuels and nuclear fission. Renewable sources of energy; fuel cells, fusion, hydroelectric, solar-thermal and solar-electric, geothermal, wind, wave, tidal, biomass. Storage of energy, efficient use of energy. Choice of an energy source for the UK taking into account technical, economic, political and environmental considerations, and particularly as regards climate change.		
Teaching & Learning Methods:	11 lectures, 6 seminar sessions and 5 problem classes and at least 5 feedback sessions Approximately 123 hours private study time, including problem solving and essay preparation and writing.		
Details of teaching resources on Moodle:	• Course outline and schedule • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** Sustainable Energy - Without the Hot Air, David J.C. MacKay, UIT Cambridge, 2008. (electronic version free on the internet) Renewable Energy - Power for a Sustainable Future, 2nd ed., Ed Godfrey Boyle OU +Oxford Press, 2004 (333.7.REN)		
Formative Assessment & Feedback:	Problems sheets will be marked at 2 week intervals and the answers to the questions on the problem sheets discussed during lectures. Extended essays will be discussed in fortnightly seminar sessions.		
Summative Assessment:	**Coursework:** (20%) **Two extended essays:** (80%) Worth 40% each **Deadlines:** First essay due end of week 5 and second essay due end of week 10		

Course Title:	Experimental or Theoretical Project	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3110	**Course JACS Code:**	F300
Availability:	Mid-Autumn to mid-Spring Terms	**Status:**	Core for BSc programmes, apart from programmes including another subject for which a project course is taken in that other subject
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Dr C P Lusher		
Course Staff:	Academic staff of the Physics Department		
Aims:	To provide the high point of the three year physics degree, which enables students to use their scientific knowledge, their ability to plan and execute an extended experimental or theoretical investigation and use all their communication skills to describe their results. To provide an understanding of some techniques of research, including the presentation of results.		
Learning Outcomes:	On completion of the course, students should be able to: • appreciate the principals of research methodologies gained under individual supervision by a member of academic staff; • design and execute a project, write a report and give a talk on it; • produce an impressive report on their project, which they can show at career interviews and discuss its content with confidence.		
Course Content:	The student chooses the project in consultation with a member of staff. The subject of the project may be in physics, electronics or astrophysics and may be experimental or theoretical in emphasis.		
Teaching & Learning Methods:	11 hours with supervisor 80 hours spent in laboratory or computing with supervision, 59 hours private study, writing report and preparing talk.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest		
Bibliography:	As agreed with supervisor.		
Formative Assessment & Feedback:	Students must plan and schedule their work in consultation with their supervisor and adviser. There is an oral presentation in week 5 of term 2. A draft of the final report (beginning of week 6) is read by the supervisor, prior to submission of the final report.		
Summative Assessment:	**Project report:** (90%) 5,000 words maximum. **Oral Presentations:** (10%) 15 minute talk **Deadlines:** Aims of project and schedule for work - end of wk 4 of term 1. Oral presentation - Fri of wk 5 of term 2. Report draft - Mon wk 6 term2. Final report - Fri of wk 7 of term 2.		

Course Title:	Further Mathematical Methods	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3150	**Course JACS Code:**	F340
Availability:	Spring Term	**Status:**	Core for MSci and BSc Theoretical Physics; otherwise optional
Pre-requisites:	PH1110, PH1120, PH2130	**Co-requisites:**	
Co-ordinator:	Dr N Kauer		
Course Staff:	Dr N Kauer		
Aims:	Introduce students to advanced mathematical topics and methods used in physics. Develop students' skills in applying these methods.		
Learning Outcomes:	On completion of the course, students should be able to: • understand selected advanced mathematical topics and methods relevant to physics in the areas of complex analysis, calculus of variations, linear transformations and matrix theory; • solve related problems.		
Course Content:	• COMPLEX ANALYSIS • Holomorphic functions • Laurent series and singularities • Methods of contour integration and Cauchy's residue theorem • CALCULUS OF VARIATIONS • Euler-Lagrange equation • Principle of stationary action and Hamilton's equations • Canonical transformation • Constraints and the method of Lagrange multipliers • LINEAR TRANSFORMATIONS AND MATRIX THEORY • Matrix representation of linear transformations • Equivalence relations and canonical forms • Normal matrices and unitary diagonalisation		
Teaching & Learning Methods:	33 lectures Approximately 117 hours of study time, working on coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to sample examination papers and selected solutions		
Bibliography:	**Further Reading:** J M Howie, Complex Analysis, Springer, 2003 (515.24 HOW) I M Gelfand and S V Fomin, Calculus of Variations, Dover Publications 2000 (515.64 GEL) M Anthony and M Harvey, Linear Algebra: Concepts and Methods, Cambridge University Press, 2012 (512.5 ANT) R A Horn and C R Johnson, Matrix Analysis, Cambridge University Press, 1985 & 2013 (512.3 HOR) P Lancaster and M Tismenetsky, The Theory of Matrices, Academic Press, 1985 (512.3 LAN)		
Formative Assessment & Feedback:	Written and verbal comments on problem sheet assignments.		

Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six **Coursework:** (10%) problem sheet assignments **Deadlines:** weekly or fortnightly as noted on Moodle

<table>
<tr><td>Course Title:</td><td>Non-Linear Dynamical Systems – Routes to Chaos</td><td>Course Value:
Level:</td><td>0.5 cu / 7.5 ECTS</td></tr>
<tr><td>Course Code:</td><td>PH3160/MT3280</td><td>Course JACS Code:</td><td></td></tr>
<tr><td>Availability:</td><td>Spring Term</td><td>Status:</td><td>Optional</td></tr>
<tr><td>Pre-requisites:</td><td>PH2130/MT1720 and MT1820</td><td>Co-requisites:</td><td></td></tr>
<tr><td>Co-ordinator:</td><td colspan="3"></td></tr>
<tr><td>Course Staff:</td><td colspan="3"></td></tr>
<tr><td>Aims:</td><td colspan="3">To introduce the fundamentals of the analysis of nonlinear dynamical systems and, in particular, to investigate whether the behaviour of a nonlinear system can be predicted from the corresponding linear system.</td></tr>
<tr><td>Learning Outcomes:</td><td colspan="3">On completion of the course, students should be able to:
• identify and classify the critical points for both discrete and continuous dynamical systems;
• understand when and why the direct and indirect Liapunov methods are appropriate and use them both;
• understand when a limit cycle can, and cannot, occur and prove the non-existence as appropriate;
• recognise the role of the linear system in predicting the long-term behaviour of the non-linear system.</td></tr>
<tr><td>Course Content:</td><td colspan="3">Systems of first order linear differential equations: Similarity types for 2× 2 matrices and their connection with linear systems. Classification of two-dimensional linear phase portraits. Extension to three dimensions.
Nonlinear differential equations: Liapunov's stability analysis, periodic solutions and limit cycles, Poincaré-Bendixson theorem. Applications to problems from physics, biology and economics.
Non-linear difference equations: Poincaré surface of section, stability of critical points, routes to chaos.</td></tr>
<tr><td>Teaching & Learning Methods:</td><td colspan="3">33 hours of lectures and examples classes.
117 hours of private study, including work on problem sheets and examination preparation.
This may include discussions with the course leader if the student wishes.</td></tr>
<tr><td>Bibliography:</td><td colspan="3">Dynamical Systems, Differential Equations, Maps and Chaotic Behaviour – D K Arrowsmith and C M Place (Chapman & Hall). Library Ref. 515.41 ARR
Differential Equations, Dynamical Systems and an Introduction to Chaos – M W Hirsch, S Smale and R Devaney (Academic Press). Library Ref. 515.41 HIR
Elementary Differential Equations and Boundary Value Problems – W E Boyce & R C di Prima (Wiley). Library Ref. 515.41 BOY</td></tr>
<tr><td>Formative Assessment & Feedback:</td><td colspan="3">Formative assignments in the form of 10 problem sheets. The students will receive feedback as written comments on their attempts, and discussion within classes.</td></tr>
<tr><td>Summative Assessment:</td><td colspan="3">Exam (100%) Four questions out of five in a two-hour paper

Coursework (%) None

Deadlines: n/a</td></tr>
</table>

Course Title:	C++ and Object Oriented Programming	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3170	**Course JACS Code:**	F343
Availability:	Autumn Term	**Status:**	Optional
Pre-requisites:	PH2150	**Co-requisites:**	
Co-ordinator:	Dr S T Boogert		
Course Staff:	Dr W Panduro Vazquez and Dr J Walding		
Aims:			
Learning Outcomes:	On completion of the course, students should be able to: • design and build C++ programs and contribute to larger projects. Ability to solve physics problems using a C++ programming solution. Familiarity with the syntax, construction and operation of a C++ based program. Ability and motivation to self-learn more advanced concepts. • Possess knowledge of general programming concepts, such as arrays, strings, memory, functions and classes and objects applicable to other languages, including Java and Python.design and build C++ programs and contribute to larger projects.		
Course Content:	C++ Basics: • Declaration and assignment of variables and scope. Comments and naming. • Program control structures (if, for, while, switch and case) and functions • Input/Output, file operations and iostreams • Arrays, indexing of arrays, passing arrays • Memory representations of variables and memory management C++ Object oriented programming: • Classes and objects (methods and data together) • Inheritance (reusing classes and methods) • Polymorphism and abstraction C++ Techniques: • Introduction to the templates and the standard template library • Containers (e.g Vectors and Maps) Algorithms (for example sorting) • Exceptions (dealing with errors) • External libraries to perform more complex problems, data acquisition, database interaction, plotting and numerical libraries.		
Teaching & Learning Methods:	11 lectures and 22 laboratory classes Approximately 117 hours of study time, working on coursework problems and revision (approx. 10 hours weekly)		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Further Reading:** C++ Primer (5th Edition)		
Formative Assessment & Feedback:	Verbal and demonstration during classes in Teaching Lab.		

Summative Assessment:	**Exam:** (25%) (2 hours) Three questions to be answered out of six **Coursework:** (50%) Eight problem sheets highlighting aspects of programming and algorithms (25%) Short Physics based project **Deadlines:** Problem sheet assignments must be submitted every two weeks

Course Title:	Experimental Design	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3180	**Course JACS Code:**	F311
Availability:	Autumn Term	**Status:**	Optional
Pre-requisites:	PH1420	**Co-requisites:**	
Co-ordinator:	Dr P J Meeson		
Course Staff:	Dr J Williams		
Aims:	To introduce the principles and practice of electronic measurement in the field of experimental physics.		
Learning Outcomes:	On completion of the course, students should be able to: • Understand the principal techniques by which modern electronic measurements are made in the field of experimental physics. • Choose appropriate methods of measurement in a given experiment • Appreciate the design considerations involved in achieving appropriate accuracy, precision and reliability of data. • Appreciate the probable inherent quality of experimental data in unfamiliar experiments. • Understand the fundamental advantages and limitations of measurement using electronic circuits. • Embark on practical implementations of electronic measurement circuitry.		
Course Content:	To introduce the principles and practice of electronic measurement in the field of experimental physics. The course will prepare students for the design of practical experiments and will cover all the principal stages of measurement including sensors and transducers, electronic amplification and noise, filters, analog to digital conversion and signal processing.		
Teaching & Learning Methods:	22 lectures, 5 feedback sessions and 5 hours of tutorials Approximately 123 hours of guided independent study		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time)		
Bibliography:	**Further Reading:** Martin Hartley Jones, A Practical Introduction to Electronic Circuits, Cambridge University Press 3rd Ed. 1995. Paul Horowitz and Winfield Hill, The Art of Electronics, Cambridge University Press, 2nd Ed. 1989.		
Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during feedback sessions.		
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six **Coursework:** (10%) Five problem sheets **Deadlines:** Problem sheet assignments must be submitted every two weeks		

Course Title:	Quantum Theory	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3210	**Course JACS Code:**	F342
Availability:	Autumn Term	**Status:**	Core for all programmmes, except BSc Physics, BSc Physics with Music or Philosophy,MSci and BSc Mathematics and Physics.
Pre-requisites:	PH2210	**Co-requisites:**	
Co-ordinator:	Dr A Ho		
Course Staff:	Dr A Ho		
Aims:	To explain the main principles and ideas of non–relativistic quantum mechanics, its structure and its formalism. To examine both exact and approximate methods of solving quantum problems.		
Learning Outcomes:	On completion of the course, students should be able to: • understand and use the bra-ket (Dirac) notation for quantum states; • understand and use the vector space and matrix representation of operator formalism, expansion of any states in terms of some complete set, the ladder operator approach to the harmonic oscillator; • 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; understand the concept and consequences of identical particles for fermions and bosons; • state the rules for the addition of angular momenta and to outline the underlying general, mathematical arguments, applying them in particular to two spin-1/2 particles; • formulate first order and second order time-independent perturbation theory, and apply to some simple examples; • formulate the variational and WKB methods and apply to some simple systems; • formulate first-order and second order time-dependent perturbation theory. Show, as an example, how it can lead to Fermi's Golden Rule.		
Course Content:	**Formal Aspects of Quantum Mechanics**: Wavefunctions, principles of superposition, interference, state vectors and bra-ket notation (Dirac notation), delta function. Compatible observers, simultaneous measurement and commuting operators. Expansion postulate and complete sets of states. The generalised uncertainty relations. Matrix Representation of states and operators. Time dependent Schrödinger equation, expectation values, Hermitian operators, eigenstates, time evolution of operators. Periodic potential; Bloch theorem. Step-operator/ladder operator approach to the harmonic oscillator, derivation of energy eigenvalues and wavefunctions (explicit forms for $n = 0, 1$). **The Hydrogenic Atom**: Solution of the non-relativistic Schrödinger equation for an electron in the field of a stationary nucleus in spherical polar coordinates, obtain normalised eigenfunctions. Energy levels, angular momentum quantum numbers and their allowed values. **Angular Momentum**: Review of commutation relations, eigenvalues and eigenfunctions of angular momentum operators, generalised angular momentum, step operator techniques in angular momentum theory; spectrum of angular momentum eigenvalues. Rules for combining angular momenta in general. Representation of spin ½ operators by Pauli matrices, magnetic moments, Stern-Gerlach experiment. **Approximate Methods**: Time independent perturbation theory for non-degenerate system to second order in the energy; to first-order for degenerate systems. Examples. Variational principle, He ground state example. WKB approximation. Further examples of applications of quantum mechanics to atomic, nuclear and solid state physics: spin-dependent interactions, interaction of a hydrogen atom with a strong uniform external magnetic field, the stark effect, anharmonic oscillator.		

	Identical Particles: Exchange symmetry for a system with identical fermions or bosons; derivation of the Pauli principle. Independent particle model of He, singlet and triplet states, exchange interaction. **Simple time-dependent systems**: Time dependent perturbation theory, interaction of a hydrogen atom with an oscillating electric field. Superposition of states of different energies. Electron in a magnetic field. Time evolution of entangled states of two spin 1/2 particles with total spin zero. Transition to a continuum; density of states, Fermi's golden rule.
Teaching & Learning Methods:	22 lectures and at least 5 feedback sessions 123 hours spent learning material, answering coursework problems and revision.
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions
Bibliography:	**Recommended Purchase:** B H Bransden & C J Joachain, *Introduction to Quantum Mechanics*, Longman, 2nd edition 2000. (530.12.BRA) **Further Reading:** Other books that will be useful: C Cohen-Tannoudji, B Diu, F Laloe, *Quantum Mechanics, vols 1 and 2,* John Wiley 1977. (530.12 COH) S Gasiorowicz, *Quantum Physics,* John Wiley, 2003. (530.12 Gas) F Mandl, *Quantum Mechanics,* John Wiley, 1992. (530.12 Man)
Formative Assessment & Feedback:	Students answer assessed problem sheets, which will then be discussed during feedback sessions.
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six **Coursework:** (10%) **Deadlines:** Normally within 2 weeks from issue of the problem sheets.

Course Title:	Electromagnetic Theory	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3420/MT3240	**Course JACS Code:**	F341
Availability:	Autumn Term	**Status:**	Core for MSci and BSc Mathematics and Physics and BSc Physics with Philosophy
Pre-requisites:	PH1110 and PH1120, or MT2220	**Co-requisites:**	
Co-ordinator:	Dr C P Lusher		
Course Staff:	Dr C P Lusher		
Aims:	An understanding of the development from elementary ideas of electromagnetism up to Maxwell's equations and the existence of electromagnetic waves.		
Learning Outcomes:	On completion of the course, students should be able to: • calculate electric fields and electric potentials from given fixed charge distributions; • calculate magnetic fields and vector potentials from given steady current distributions; • understand, explain and perform calculations on electromagnetic induction and displacement currents; • synthesise the above phenomena into the Maxwell equations; • derive properties of electromagnetic waves; • solve Laplace's equation and the wave equation in a variety of cases.		
Course Content:	Vector calculus treatment of Electrostatics: the electric field, Coulomb's and Gauss' laws, electric field energy, equations of Poisson and Laplace. Steady currents: continuity equation, Kirchhoff's laws, Laplace's equation in conductors. Vector calculus treatment of the magnetic effects of currents: Biot-Savart law, magnetic field, Ampère's law, Lorentz force, energy of a magnetic field. Induction; Faraday's law, Lenz's law. Displacement current. Electric and magnetic dipoles and the electromagnetism of matter. Macroscopic fields **E**, **D**, **B** and **H**; their boundary conditions at interfaces. Maxwell's equations; plane waves in free space and in media; reflection, refraction, polarisation. Poynting vector. The EM spectrum. Radiation pressure. Propagation in lossy media: dielectric loss, ohmic loss, skin depth; electromagnetic screening. Electromagnetic potentials. Gauge freedom. Scalar and vector potentials for stationary and time varying problems. Radiation from dipoles. Incompatibility of Maxwell's equations and Newton's laws. Resolution by Lorentz transformation and special relativity.		
Teaching & Learning Methods:	27 lectures, 6 hours problem classes/feedback sessions Approximately 117 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** G L Pollack & D R Stump, *Electromagnetism*, Addison Wesley, 2002. (537.POL) D J Griffiths, *Introduction to Electrodynamics,* 3rd Ed. Prentice Hall, 1989. (537.6.GRI) W J Duffin, *Electricity and Magnetism*, 3rd Ed., McGraw-Hill, 1980. (537.DUF)		

Formative Assessment & Feedback:	Fortnightly problem classes will discuss marked coursework assignments.
Summative Assessment:	**Exam:** (80%) (2 hours) One compulsory question + two others to be answered out of four **Coursework:** (20%) The best four of five fortnightly homework exercises plus an extended set of problems. **Deadlines:** Fortnightly, depending on timetabling. Announced at the commencement of the course and posted on Moodle.

Course Title:	Particle Physics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3520	**Course JACS Code:**	F370
Availability:	Autumn Term	**Status:**	Core for MSci and BSc Physics with Particle Physics and Astrophysics Optional for others
Pre-requisites:	PH2210	**Co-requisites:**	
Co-ordinator:	Dr V Boisvert		
Course Staff:	Dr V Boisvert		
Aims:	Introduce the principal concepts of particle physics, analyse the properties of the basic constituents of matter and their interactions, discuss experimental methods and technologies used in high-energy physics.		
Learning Outcomes:	On completion of the course, students should be able to: • have an understanding of the physics of elementary particles and the experimental techniques of particle physics; • answer related problems.		
Course Content:	Energy loss processes, particle detectors, accelerators, spin-off applications. Strange particles, quantum numbers, the simple quark model. Heavy quarks. Leptons and lepton number. Electroweak unification, W and Z bosons, the Higgs mechanism, QCD. Extended topics selected from: deep inelastic scattering, supersymmetry, beyond the Standard Model, dark matter, Neutrino oscillations, applications to industry and medicine.		
Teaching & Learning Methods:	22 lectures and 11 feedback sessions 117 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** B R Martin & G Shaw, *Particle Physics*, Wiley, 2nd Ed., 1997. (539.72.MAR) **Further Reading:** D H Perkins, *Introduction to High Energy Physics*, 3rd Ed., Addison-Wesley, 1989. (539.721.PER) (Optional) W S C Williams, *Nuclear and particle Physics*, OUP, 1991. (539.7.WIL) (Optional)		
Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during lectures and problem classes.		
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six. **Coursework:** (10%) **Deadlines:** Fortnightly problem sheets		

Course Title:	Semiconductors and Superconductors	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3710	**Course JACS Code:**	F321
Availability:	Autumn Term	**Status:**	Core for MSci & BSc Experimental Physics. Optional for others
Pre-requisites:	PH2610	**Co-requisites:**	
Co-ordinator:	Dr P G Niklowitz		
Course Staff:	Dr P G Niklowitz and Dr J T Nicholls		
Aims:	To learn about the physics and applications of semiconductors and superconductors. To enhance problem solving skills and self study skills.		
Learning Outcomes:	On completion of the course, students should be able to: • have an understanding of the physics and applications of these two important classes of materials; • answer related problems.		
Course Content:	Semiconductors: elemental and compound semiconductors; doping; extrinsic and intrinsic semiconductors; carrier concentration; transport properties; optical properties; the p-n junction; MBE growth of semiconductors; low-dimensional electronic systems. Superconductors: basic superconducting properties; Meissner effect; thermodynamics; critical field and current; flux quantisation; type II superconductors; two-fluid model; macroscopic wavefunction; simple Ginzburg-Landau theory; BCS theory; Josephson effect; SQUIDs and applications; high-T_C superconductivity.		
Teaching & Learning Methods:	22 lectures and 6 feedback sessions 122 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** J R Hook & H E Hall, *Solid State Physics,* 2nd Ed., Wiley, 1991. (530.41.HOO) **Further Reading:** M Tinkham, *Introduction to Superconductivity*, 2nd Ed., McGraw Hill, 1996 (537.623 TIN) A C Rose-Innes & E H Rhoderick, *Introduction to Super-conductivity*, Revised 2nd Ed., Pergamon, 1994. (537.623.ROS)		
Formative Assessment & Feedback:	Regular coursework marked with comments. Problems then worked through in class.		
Summative Assessment:	**Exam:** (90%) (2 hours) Two sections of three questions each. Students must answer three questions including at least one from each section. **Coursework:** (10%) **Deadlines:** Fortnightly deadlines for coursework		

Course Title:	Modern Topics in Condensed Matter	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3730	**Course JACS Code:**	F321
Availability:	Spring Term	**Status:**	Core for MSci & BSc Experimental Physics. Optional for others
Pre-requisites:	PH2610	**Co-requisites:**	
Co-ordinator:	Dr P G Niklowitz		
Course Staff:	Dr P G Niklowitz, Professor D M Heyes and Dr G Tancredi		
Aims:	To introduce students to three frontier areas in Condensed Matter Physics.		
Learning Outcomes:	On completion of the course, a student should be able to: • understand some of the research topics in condensed matter physics, including applications. • write a dissertation on a modern topic related to the course content. • solve related problems.		
Course Content:	Circuit QED: simple circuit elements (capacitors, inductors, waveguides), planar circuits, equivalent electronic circuits, resonators and quantum harmonic oscillators (LC circuits, waveguide cavities), quantum microwave fields, Fock states, coherent states, travelling and standing waves, nonlinear oscillators, simple qubits as artificial atoms, optical readout, qubit interactions via cavity, quantum gates and entanglement Magnetism - correlated electrons self-organise. 2000 years of magnetism. Phenomena: Magnetisation and magnetic susceptibility, hysteresis, Curie-Weiss law, Arrott plots, magnetic structures: ferro- and antiferromagnetism. Origin of magnetism: exchange interaction, Heisenberg model, Stoner model. Modern topics in magnetism: magnetism and superconductivity, magnetic storage, spintronics. Colloidal liquids. Interactions between colloidal particles. Colloidal phase diagrams. Dynamics of colloidal particles. Stokes' law Brownian motion. Stokes-Einstein equation. Fractal aggregates. Rheology. Shear thinning. Polymer solutions and melts. Dilute, semi-dilute and concentrated polymer solutions. Coarse-graining of polymers. A polymer as a random walk. Excluded volume and solvent effects. Theta temperature. Linear viscoelasticity. Reptation. Dependence of properties on the degree of polymerisation.		
Teaching & Learning Methods:	22 lectures + at least 6 feedback sessions. 122 hours spent learning material, writing a dissertation, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** R.A.L Jones, *Soft Condensed Matter*, Oxford University Press, 2002. **Key Reading:** J-P Hansen and I R McDonald, *Theory of Simple Liquids*, Academic Press, 1976 (532 HAN) **Further Reading** C Kittel, *Introduction to Solid State Physics*, 8th Ed., J Wiley, 2004. (530.41.KIT) G Burns, *Solid State Physics*, Academic Press, 1985. (530.41.BUR) R Rubinstein and R H Colby, *Polymer Physics*, OUP, 2003 D F Walls and G J Milburn, *Quantum Optics*, 2nd Ed., Springer 2008		

Formative Assessment & Feedback:	Marked and coursework assignments.
Summative Assessment:	**Exam:** (50%) (2 hours) Three questions to be answered out of six. **Coursework:** (25%) Six coursework assignments – two for each module **Dissertation:** (25%) 3000 words **Deadlines:** end of each module

Course Title:	Frontiers of Metrology	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3810	**Course JACS Code:**	F321
Availability:	Spring Term	**Status:**	Core for MSci & BSc Experimental Physics. Optional for others
Pre-requisites:	PH2310, PH2420	**Co-requisites:**	
Co-ordinator:	Prof B P Cowan, Professor A Tzalenchuk (National Physical Laboratory)		
Course Staff:	Prof B P Cowan, Professor A Tzalenchuk		
Aims:	To introduce the fundamental concepts of metrology. To develop the general metrological approach through a series of special topical studies. To gain an understanding of the subject matter and to appreciate its use in solving physical and measurement problems.		
Learning Outcomes:	An understanding of the fundamental role of metrology in Physics and the wider world. An understanding of the relevant physical phenomena as applied to measurement and the definition of standards. The ability to apply metrological concepts and understanding to problem solving in metrology and physics.		
Course Content:	General metrological considerations: S.I.; Units and Standards; Uncertainty; Noise; Precision and Accuracy; Reproducibility; Assumed Truths; Quantum Standards vs Artifacts; Limits of Precision; Universal Physical Laws and their Applications; Constancy of Physical Laws and Constants ($\dot{\alpha}$); The concept of the error budget. Advanced Metrology Special Topics: 1) Frequency (Time) – The supremacy of frequency measurement. Long and short term stability. Maser and Atom Clocks. Microwave and Optical (atoms and ions) 2) Ion Traps, Bose-Einstein condensation – applications to frequency and time. 3) Interferometry and Spectroscopy – frequency combs. 4) Radiometry (Photons) – single photon sources and detectors, Hanbury-Brown and Twiss 5) Moving on from the kg, the Watt balance. 6) Electrical Standards (Josephson Junction Volt, Quantum Hall Standard Ohm, the metrological triangle and the missing current standard) 7) Nano-metrology 8) Beating the quantum limit 9) Temperature		
Teaching & Learning Methods:	22 lectures and at least 5 feedback sessions 123 hours spent reading the literature; learning material; problems and other coursework; revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** A Hebra, *The Physics of Metrology*, Springer (2009) **Reference:** B Petley, *Fundamental Physical Constants and the Frontier of Measurement*, IoP Adam Hilger (1985)		

Formative Assessment & Feedback:	Students answer assessed problem sheets which will be discussed during lectures and problem classes.
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six. **Coursework:** (10%) **Deadlines:** As noted on moodle.

Course Title:	General Relativity and Cosmology	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3910	**Course JACS Code:**	F340/F510
Availability:	Autumn and Spring Term	**Status:**	Core for MSci and BSc Astrophysics and Theoretical Physics programmes, optional for others
Pre-requisites:	PH1920	**Co-requisites:**	
Co-ordinator:	Dr J C Hargreaves		
Course Staff:	Dr J C Hargreaves		
Aims:	To introduce students to the theory of tensors and applications to general relativity. The major aims of the course are to examine geodesics, black holes and relativistic cosmological models *etc*. and to study the theoretical models which attempt to explain the observed features.		
Learning Outcomes:	On completion of the course, students should be able to: • understand the basic of general theory of relativity and applications to cosmological models; • solve simple related coursework problems.		
Course Content:	• Postulates of general theory. • Principles of equivalence and covariance. • Tensor calculus for a Riemannian space. • Field equations of general relativity. • Black holes. • Relativistic cosmological models. • Distance measurements in the Universe, and recent observations.		
Teaching & Learning Methods:	22 lectures and at least 5 feedback sessions. 123 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Further Reading:** R A D'Inverno, *Introducing Einstein's Relativity*, Clarendon Press, 1992. (530.11.DIN) J N Islam, *An Introduction to Mathematical Cosmology*, CUP, 1992. (520.151.ISL) A K Banerji & A Banerjee, *General Relativity, Astrophysics and Cosmology*, Springer-Verlag, 1992. B Ryden, *An Introduction to Cosmology*, Addison-Wesley, 2003. (523.1 RYD) L Ryder, *An Introduction to General Relativity*, CUP, 2009.		
Formative Assessment & Feedback:	Students will answer assessed problem sheets that will be discussed during problem classes.		
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six. **Coursework:** (10%) **Deadlines:** Fortnightly problem sheets		

Course Title:	Stellar Astrophysics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3920	**Course JACS Code:**	F510
Availability:	Autumn Term	**Status:**	Core for MSci and BSc Astrophysics programmes, optional for others
Pre-requisites:	PH2510, PH2610	**Co-requisites:**	PH2900
Co-ordinator:	Dr S T Boogert		
Course Staff:	Dr S T Boogert		
Aims:	To introduce a complete first theory of the physics of stars, based on mechanics, thermodynamics, statistical mechanics and atomic physics. To gain an understanding of the physics of stellar interiors and stellar evolution.		
Learning Outcomes:	On completion of the course, students should be able to: • Understand and apply fundamental physics (mechanics, quantum mechanics, thermodynamics, nuclear physics and atomic physics) to the processes occurring the birth, life and death of stars; • Construct a complete (but simplified) model of the physics of a star; • Perform simplified calculations in stellar physics; • Understand the numerical or computational models based on the physics studied the course; • Perform order of magnitude estimations for derived quantities, for example stellar lifetime; • Compare observational results with stellar models.		
Course Content:	Basic available observational information available for stellar objects, including luminosity, temperature, spectra, radius and mass. Physical processes in stellar atmospheres and interiors: hydrostatic equilibrium, energy transport and energy sources, reaction rates for thermonuclear processes and transport of energy from stellar core to surface, both radiative and convective. Stellar structure: the main sequence, pre- and post-main sequence evolution, including physical processes in supernovae and nucleosynthesis. Solutions and limiting cases to the equations of Stellar structure. The role of the interstellar medium in the life cycle of stars.		
Teaching & Learning Methods:	**Lectures**: 22 hours **Feedback sessions**: 11 hours, 5 covering problem sheets. The majority of the taught material is delivered via whiteboard in a lecture environment. The sections of the course that rely on simulation results are delivered as either computer demonstrations, videos of animated plots and graphs and computer presentations. 117 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest (including advanced topics available at MSci • *Mathematica* notebooks for complex concepts (Emden-Lane equation solution) • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase**: D Prialnik, *An Introduction to the Theory of Stellar Structure and Evolution*, Cambridge University Press, 2000. (523.8.PRI) **Further Reading:** George W. Collins II, *The Fundamentals of Stellar Astrophysics* (online book). Erika Bohm-Vitense, *Introduction to Stellar Astrophysics, Volumes 1,2 and 3*,		

	Cambridge University Press, 1989. (523.8.BOH)
Formative Assessment & Feedback:	Students answer assessed problem sheets, which will then be discussed in feedback sessions.
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six. **Coursework:** (10%) **Deadlines:** Fortnightly problem sheets

Course Title:	Particle Astrophysics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Honours
Course Code:	PH3930	**Course JACS Code:**	F370/F510
Availability:	Spring Term	**Status:**	Core for MSci& BSc Astrophysics & Physics with Particle Physics, optional for others
Pre-requisites:	PH1920, PH3520	**Co-requisites:**	
Co-ordinator:	Professor J R Monroe		
Course Staff:	Professor J R Monroe		
Aims:	To introduce students to very early cosmology and to explore the connection with particle physics.		
Learning Outcomes:	On completion of the course, students should be able to: • understand very early cosmology and the connection with particle physics; • make order-of-magnitude estimates of cross sections and decay rates and relate these to processes at work in the early universe; • solve related problems.		
Course Content:	Particle Physics: review of standard model, simple use of Feynman diagrams to estimate cross-sections and decay rates. Cosmology: the Friedmann equations, history of the early universe, photon/baryon ratio and the matter/antimatter imbalance, primordial nucleosynthesis, decoupling of matter and radiation, dark matter, the cosmic microwave background, inflation. Cosmic rays: detection, composition and energy spectrum, origin. Neutrino astrophysics: neutrino oscillations; solar, atmospheric and supernova neutrinos.		
Teaching & Learning Methods:	22 lectures and at least 5 feedback sessions 123 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Recommended Purchase:** D.H.Perkins *Particle Astrophysics*, Oxford 2004. (530.01972 PER) **References:** L Bergstrom & A Goobar, *Cosmology and Particle Astrophysics*, Wiley, 1999. (523.1.BER) R Tayler, *The Hidden Universe*, Wiley, 1991. (523.1.TAY) D Sciama, *Modern Cosmology*, CUP, 1982. (523.1.SCI) H V Klapdor-Kleingrothaus & K Zuber, *Particle Astrophysics*, IoP, 1997. (530.01972.KLA)		
Formative Assessment & Feedback:	Marked and annotated coursework assignments.		
Summative Assessment:	**Exam:** (90%) (2 hours) Three questions to be answered out of six. **Coursework:** (10%) Best four of five coursework assignments **Deadlines:** Fortnightly problem assignments		

Course Title:	Major Project	**Course Value:** **Level:**	1 cu / 15 ECTS Masters
Course Code:	PH4100 / PH5100	**Course JACS Code:**	F300
Availability:	Autumn & Spring Term	**Status:**	Core for MSci Students
Pre-requisites:	PH3010	**Co-requisites:**	
Co-ordinator:	Dr A J Casey		
Course Staff:	Academic staff of the Physics Department		
Aims:	To provide a suitable preparation for physicists engaged in project work in industry or as research workers in any physics-related discipline. To provide an understanding of some techniques of research, including the presentation of results. To provide the high point of the four year physics degree, which enables students to use their scientific knowledge, their ability to plan and execute a lengthy investigation and use all their communication skills to describe their results.		
Learning Outcomes:	On completion of the course, students should be able to: • Feel confident that they can succeed with any physics-related project work in industry or university. • Have an understanding of some techniques of research, including the presentation of results. • Be aware of the importance of teamwork in complex scientific work. • Produce an impressive report on their project, which they can show at career interviews and discuss its content with confidence.		
Course Content:	This course is a major individual project making up one quarter of the workload of the final year students taking MSci degrees. Projects are associated with the research efforts of the Department and may be experimental, theoretical or computational.		
Teaching & Learning Methods:	22 hours (one hour per week) of guidance from the supervisor. 176 hours practical or theoretical work in the laboratory and 102 hours of private study, of which 20 hours spent in writing report and preparing talks.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest		
Bibliography:	As agreed with supervisor.		
Formative Assessment & Feedback:	Students must plan and schedule their work in consultation with their supervisor and adviser. There is a short oral presentation at the end of term 1 and a longer oral presentation towards the end of term 2. A draft of the final report is read by the supervisor, prior to submission of the final report.		
Summative Assessment:	**Project report:** (80%) Should not exceed the equivalent of 10,000 words **Oral and poster presentation:** (20%) **Deadlines:** Short oral presentation - Wed of wk 12 of Term 1. Oral presentation - Wed of wk 9 of Term 2. Report draft - Wed wk 10 Term2. Final report - Friday of wk11 Term2. Submission of final report will be done electronically via Turnitin.		

Course Title:	Research Review	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Masters
Course Code:	PH4110	**Course JACS Code:**	F300
Availability:	Autumn Term	**Status:**	Core for MSci programmes
Pre-requisites:	PH3010	**Co-requisites:**	
Co-ordinator:	Dr A J Casey		
Course Staff:	Dr A J Casey		
Aims:	To develop a range of transferable skills. To examine and explain a current research topic in physics.		
Learning Outcomes:	On completion of the course, students should be able to: • Carry out effective independent learning, showing initiative and resourcefulness, with more efficient library skills; • Demonstrate improved management, organisational and presentational skills; • Demonstrate a deeper understanding of an area of current research in physics.		
Course Content:	Students choose a topic related to problems of current research interest in physics. They consult original papers and write a report, complete with references, which is expected to be well presented and demonstrate a high level of understanding.		
Teaching & Learning Methods:	11 hours (one hour per week) tutorial session with Adviser. 140 hours spent searching for and assimilating source material, writing a draft and a final report, preparing presentations.		
Details of teaching resources on Moodle:	• Course outline • Additional notes • Links to material of interest		
Bibliography:	As agreed with Co-ordinator and Adviser.		
Formative Assessment & Feedback:	Weekly contact with the Adviser, with feedback to the student. Week one and five, group meeting with the Co-ordinator to receive feedback on assignment of review topic and to provide structure for the report.		
Summative Assessment:	**Report:** (80%) Should not exceed the equivalent of 10,000 words **Oral presentation of report:** (20%) To advisor and 2nd marker **Deadlines** The deadline for submission of the Research Review report will be 09:00 on Monday morning of Week 8 of the autumn term. Submission will be done electronically via Turnitin.		

Course Title:	Statistical Mechanics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Masters
Course Code:	PH4211 / PH5211 / PH5911	**Course JACS Code:**	H311/F340
Availability:	Spring Term	**Course Code:**	Optional
Pre-requisites:	PH2610	**Co-requisites:**	
Co-ordinator:	Professor B P Cowan		
Course Staff:	Professor B P Cowan		
Aims:	Consolidation of previous knowledge and understanding of Statistical and Thermal Physics within the context of a more mature framework. Introduction to the ideas and concepts of interacting systems. Introduction to the ideas and concepts of phase transitions including some specific examples. Introduction to the ideas and concepts of irreversibility: non-equilibrium statistical mechanics and irreversible thermodynamics.		
Learning Outcomes:	On completion of the course, students should be able to: • explain the difference between the macroscopic and the microscopic descriptions macroscopic phenomena; • explain the essential concepts in the laws of thermodynamics from both macroscopic and microscopic perspectives; • apply the methods of statistical mechanics to simple non-interacting systems; • demonstrate how weakly-interacting systems may be studied through approximation schemes; • describe the phenomena and classification of phase transitions; explain and demonstrate some of the approximate methods of treating phase transitions, including the van der Waals method, mean-field approaches; • describe and demonstrate how the Landau theory provides a general framework for the understanding of phase transitions; • explain how irreversibility and the transition to equilibrium may be understood in terms of fluctuations; • show how the Langevin equation provides a link between transport coefficients and equilibrium fluctuations.		
Course Content:	Review of equilibrium statistical mechanics. The grand canonical ensemble. Bose and Fermi distribution functions. Classical partition functions. Weakly Interacting Systems: The imperfect gas and the virial expansion, second virial coefficient for various models. The van der Waals gas and mean field theory for magnetic systems. Strongly Interacting Systems: Phenomenology of phase transitions, Scaling ideas, corresponding states. The Ising model. Magnetic case, lattice gas and phase separation. Landau theory. First and second order transitions. Ferroelectrics. Broken symmetry, Goldstone bosons, fluctuations, Ornstein Zernike, soft modes. Dissipative Systems: Fluctuation-dissipation theorem, Brownian motion, Langevin equation, correlation functions.		
Teaching & Learning Methods:	26 lectures + 4 seminars/tutorials. 120 hours spent learning material, answering coursework problems and revision.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	B. Cowan, *Topics in Statistical Mechanics*, Imperial College Press 2005 (530.13.COW) R. Bowley and M. Sànchez, *Introductory Statistical Mechanics*, 2nd ed. OUP 1999 (530.13.BOW) P Chaikin & T Lubensky, *Principles of Condensed Matter Physics*, CUP 1995 (530.14.CHA)		

Formative Assessment & Feedback:	Written and verbal comments on coursework assignments.
Summative Assessment:	**Exam:** (90%) (2½ hour) Three questions to be answered out of five. **Coursework:** (10%) Best six of the eight coursework assignments. **Deadlines:** Coursework assignments to be submitted every two weeks.

Course Title:	Particle Accelerator Physics	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Masters
Course Code:	PH4450 / PH5450 / PH5950	**Course JACS Code:**	F370
Availability:	Autumn Term	**Status:**	Optional
Pre-requisites:	PH2420	**Co-requisites:**	
Co-ordinator:	Dr P Karataev		
Course Staff:	Dr P Karataev		
Aims:	To introduce students to the key concepts of modern particle accelerators. To apply previously learned concepts to the acceleration and focussing of charged particle beams. To appreciate the use of particle accelerators in a variety of applications including particle physics, solid state physics, and medicine.		
Learning Outcomes:	On completion of the course, students should be able: • Understand the principles and methods of particle acceleration and focusing; • Describe the key elements of particle accelerators and important applications; • Understand the key principles of RF systems and judge their applicability to specific accelerators; • Understand the key diagnostic tools and related measurements that are crucial to accelerator operation and evaluate their expected performance in key sub-systems.		
Course Content:	• Introduction: history of accelerators, basic principles including centre of mass energy, luminosity, accelerating gradient • Characteristics of modern colliders; LEP, LHC, b-factories • Transverse motion, principles of beam cooling • Strong focusing, simple lattices • Circulating beams, synchrotron radiation • Longitudinal dynamics • Multipoles, non-linearities and resonances • Radio Frequency cavities, superconductivity in accelerators • Applications of accelerators; light sources, medical uses • Future: ILC, neutrino factories, muon collider, laser plasma acceleration.		
Teaching & Learning Methods:	26 lectures + 4 seminars/tutorials. 120 hours private study time, including problem solving and other coursework, and examination preparation.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	**Key Reading:** E. Wilson, *An Introduction to Particle Accelerators* OUP **Reference:** S. Y. Lee *Accelerator Physics* World Scientific (2nd Edition).		
Formative Assessment & Feedback:	Written and verbal comments on 5 coursework assignments.		
Summative Assessment:	**Exam: (**90%) (2½ hour) Three questions to be answered out of five. **Coursework:** (10%) 5 sets of assessed problems. **Deadlines:** Coursework deadlines are within 2 weeks from the issues of the problem set, unless otherwise advised by the lecturer.		

Course Title:	Physics at the Nanoscale	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Masters
Course Code:	PH4475 / PH5475 / PH5975	**Course JACS Code:**	F321
Availability:	Autumn Term	**Status:**	Optional
Pre-requisites:	PH2210, PH2710	**Co-requisites:**	
Co-ordinator:	Professor V T Petrashov		
Course Staff:	Professor V T Petrashov		
Aims:	To provide an introduction to the rapidly growing area of nano-science. To introduce the physics and technology of nano-structures, discuss their special properties, methods of fabricating them, and some of the methods of analysing them.		
Learning Outcomes:	On completion of the course, students should be able to: • Appreciate the difference between the physics on the classical (macro-) scale and on the quantum (nano-)scale. • Understand the properties of nanostructures in 'zero', one and two dimensions. • Understand the fabrication and characterisation of nano-devices.		
Course Content:	• *Miniaturisation, Moore's law, electronics, microelectronics, nanoelectronics.* • *Single electronics:* Coulomb blockade. Single Electron Transistor (SET). Applications of SET. Cooper-pair box. • *Overview of key electron transport properties of metals/semiconductors:* Electron energy spectrum, energy bands, density of electron states. Effective mass. Fermi surface. Landau quantization and the role of electron scattering, Dingle temperature. De Haas-van Alphen and Shubnikov-de Haas effects. • *Quantum interference of conduction electrons:* Weak localisation, spin-orbit scattering and anti-localisation. Aharonov-Bohm effect. Mesoscopic regime. h/e and $h/2e$ quantum oscillations. Universal conductance fluctuations. • *Josephson effect in superconductors and Josephson quantum bits.* Flux and phase qubits. Read-out using Superconducting Quantum Interference Devices (SQUIDs) and Hybrid Normal/Superconducting nano-interferometers. Andreev reflection. • *Electrons in a one- and two-dimensional systems: formation in GaAs/AlGaAs:* Diffusive and ballistic conduction. Quantised conduction. • *Electrons in a zero-dimensional system: Quantum dots* • *Carbon Nanoelectronics.* Carbon nanotubes. Graphene. • *'Top down' nanofabrication:* Physical vapour deposition (PVD) thin layer deposition techniques by thermal and e-beam evaporation, laser ablation and ion sputtering. Chemical vapour deposition (CVD) and MOCVD, plasma-assisted deposition, epitaxy. • *Nano-lithography:* Resolution limits. Electron-beam lithography. Proximity effect. Electron beam resists. Negative and positive lithographic processes. Ion beam etching (IBE) and Reactive Ion beam etching (RIBE). Plasma-assisted etching. Alignment and self-alignment, Dolan technique. Focussed ion beam (FIB) nanotechnology, ion-beam lithography. • *Nano-analysis:* SEM- and STEM-based methods. X-ray and electron spectroscopy. Scanning tunnelling microscopy. Atomic force microscopy and other scanning probe-based methods, including scanning near field optical microscopy. • *'Bottom up' Fabrication:* Scanning probe based nano-technology, molecular manufacturing. Self-organised nano-structures. • *Clean room environment.*		
Teaching & Learning Methods:	22 lectures and 8 seminars 120 hours private study time, including problem solving and other coursework, and examination preparation.		

Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions
Bibliography:	Marc K. Madou, *Fundamentals of Microfabrication, The Science of Miniaturization*, 2nd ed, CRC Press, LLC (2002). S Washburn and R A Webb, *Quantum transport in small disordered samples from the diffusive to the ballistic regime*, Rep. Prog. Phys.55, 1311-1383 (1992). Michel Devoret and Christian Glatti, *Single-electron transistors*, Phys. World. Sep 1, 1998. Roland Wiesendanger, Scanning Probe Microscopy and Spectroscopy, Cambridge University Press, 1994.
Formative Assessment & Feedback:	Written and verbal comments on coursework assignments
Summative Assessment:	**Exam:** (90%) (2½ hours) Three questions to be answered out of five. **Coursework:** (10%) **Deadlines:** Coursework deadlines are normally within 2 weeks from the issue of the problem set.

<table>
<tr><td>Course Title:</td><td>Nuclear Magnetic Resonance</td><td>Course Value:
Level:</td><td>0.5 cu / 7.5 ECTS
Masters</td></tr>
<tr><td>Course Code:</td><td>PH4512 / PH5512 / PH5912</td><td>Course JACS Code:</td><td>F341/F350</td></tr>
<tr><td>Availability:</td><td>Spring Term</td><td>Status:</td><td>Optional</td></tr>
<tr><td>Pre-requisites:</td><td>PH2210, PH2420</td><td>Co-requisites:</td><td></td></tr>
<tr><td>Co-ordinator:</td><td colspan="3">Dr C P Lusher</td></tr>
<tr><td>Course Staff:</td><td colspan="3">Dr C P Lusher</td></tr>
<tr><td>Aims:</td><td colspan="3">To introduce students to the principles and methods of nuclear magnetic resonance.
To apply previously learned concepts to magnetic resonance.
To appreciate the power and versatility of this technique in a variety of applications</td></tr>
<tr><td>Learning Outcomes:</td><td colspan="3">On completion of the course, students should be able to:
• show how Larmor precession follows from simple microscopic equations of motion;
• explain how the Bloch equations provide a phenomenological way of describing magnetic relaxation;
• describe the duality of pulsed NMR and CW NMR;
obtain solutions of the Bloch equations in the pulsed NMR and CW NMR cases;
• describe and discuss the instrumentation used for the detection of NMR in the CW and pulsed cases;
• demonstrate the production and utility of spin echoes;
• explain the principles underlying magnetic resonance imaging;
• describe the different methods of MRI.</td></tr>
<tr><td>Course Content:</td><td colspan="3">• Introduction: static and dynamic aspects of magnetism, Larmor precession, relaxation to equilibrium, T1 and T2, Bloch equations.
• Pulse and continuous wave methods: time and frequency domains. Manipulation and observation of magnetisation, 90° and 180° pulses, free induction decay.
• Experimental methods of pulse and CW NMR: the spectrometer, magnet. Detection of NMR using SQUIDs.
• Theory of relaxation: transverse relaxation of stationary spins, the effect of motion. Spin lattice relaxation.
• Spin echoes: ‘violation’ of the Second Law of Thermodynamics, recovery of lost magnetisation. Application to the measurement of T2 and diffusion.
• Analytical NMR: chemical shifts, metals, NQR.
• NMR imaging: Imaging methods. Fourier reconstruction techniques. Gradient echoes. Imaging other parameters.</td></tr>
<tr><td>Teaching & Learning Methods:</td><td colspan="3">22 lectures.
8 hours seminars.
120 hours private study time, including problem solving and other coursework, and examination preparation.</td></tr>
<tr><td>Details of teaching resources on Moodle:</td><td colspan="3">• Course outline
• Lecture notes/summaries
• Additional notes
• Links to material of interest
• Problem assignments and solutions (at the appropriate time)
• Links to past examination papers and selected solutions</td></tr>
<tr><td>Bibliography:</td><td colspan="3">B P Cowan, Nuclear Magnetic Resonance and Relaxation, CUP, 2nd ed. 2005. (541.45.COW)
Journal and web references given during course.</td></tr>
<tr><td>Formative Assessment & Feedback:</td><td colspan="3">Written and verbal comments on coursework assignments and seminar presentations.</td></tr>
</table>

Summative Assessment:	**Exam:** (90%) (2½ hours) Three questions to be answered out of five. **Coursework:** (10%) A number (~5) of sets of assessed problems are completed during the course. **Deadlines:** Coursework deadlines are normally within 2 weeks from the issue of the problem set.

Course Title:	Computing and Statistical Data Analysis	**Course Value:** **Level:**	0.5 cu / 7.5 ECTS Masters
Course Code:	PH4515 / PH5515 / PH5915	**Course JACS Code:**	F343
Availability:	Autumn Term	**Status:**	Optional
Pre-requisites:	None	**Co-requisites:**	
Co-ordinator:	Professor G D Cowan		
Course Staff:	Professor G D Cowan		
Aims:	To introduce students to programming techniques using the C++ language. To introduce students to techniques of probability and statistical data analysis. To study applications of data analysis using C++ based computing tools.		
Learning Outcomes:	On completion of the course, students should be able to: • write and run procedural C++ programs; • understand the basic concepts of object oriented programming; • use effectively the statistical tools needed for postgraduate research in physics, through familiarity with the concepts of probability and statistics and their application to the analysis of experimental data; • have acquired practice of these methods on a computer using C++ based tools.		
Course Content:	• Introduction to C++ and the Unix operating system. • Variables, types and expressions. • Functions and the basics of procedural programming. • I/O and files. • Basic control structures: branches and loops. • Arrays, strings, pointers. • Basic concepts of object oriented programming. • Probability: definition and interpretation, random variables, probability density functions, expectation values, transformation of variables, error propagation, examples of probability functions. • The Monte Carlo method: random number generators, transformation method, acceptance-rejection method. • Statistical tests: significance and power, choice of critical region, goodness-of-fit. • Parameter estimation: samples, estimators, bias, method of maximum likelihood, method of least squares, interval estimation, setting limits, unfolding.		
Teaching & Learning Methods:	22 lectures and 8 seminars (approximately 8 lectures on computing, 14 on data analysis). 128 hours private study time, including problem solving and other coursework, including computer-based assignments, and examination preparation.		
Details of teaching resources on Moodle:	• Course outline • Lecture notes/summaries • Additional notes • Links to material of interest • Problem assignments and solutions (at the appropriate time) • Links to past examination papers and selected solutions		
Bibliography:	W. Savitch, *Problem Solving with C++: The Object of Programming*, 4th Ed., Addison-Wesley, 2003. (001.6424.SAV) G D Cowan, *Statistical Data Analysis*, Clarendon Press, 1998. (530.0285.COW) R J Barlow, Statistics: *A Guide to the Use of Statistical Methods in the Physical Sciences*, John Wiley, 1989. (530.13.BAR)		
Formative Assessment & Feedback:	Written and verbal comments on coursework assignments and seminar presentations.		

Summative Assessment:	**Exam:** (70%) (2½ hours) Three questions to be answered out of five. **Coursework:** (30%) Problems on computing and statistical data analysis (approximately half computer based work). **Deadlines:** Coursework deadlines are normally within 2 weeks from the issue of the problem set.