Imperial College London

Department of Physics

Undergraduate Syllabuses_2005–06

This publication refers to the session 2005–06. The information given, including that relating to the availability of courses, is that current at the time of going to press, October 2005, and is subject to alteration.

For details of **postgraduate** opportunities go to www.imperial.ac.uk/pgprospectus.

Physics

Imperial College London offers six physics degree programmes leading to the MSci (Master in Science) and BSc (Bachelor of Science) Honours degrees of the University of London. Graduates are also awarded the Associateship of the Royal College of Science (ARCS). One programme includes a year spent carrying out a research project at a host university in continental Europe. The Department also offers a joint programme with the Royal College of Music. Each year about 200 new undergraduate students join the Department.

The Department of Physics, one of the largest in the UK, is housed in the Blackett Laboratory, Prince Consort Road and in the adjoining Huxley Building. Lectures are given in three main lecture theatres which are well-equipped with audio visual services. In addition there are several lecture colloquium rooms, seating 30–60. Practical instruction is mainly given in three large teaching laboratory suites. There are over 100 computers available to students.

Details of postgraduate opportunities can be found in the online Postgraduate Prospectus at www.imperial.ac.uk/pgprospectus.

Undergraduate courses

Four-year programmes
MSci Physics
MSci Physics with Theoretical Physics
MSci Physics with a Year in Europe
BSc Physics with Studies in Musical Performance

Three-year programmes
BSc Physics
BSc Physics with Theoretical Physics

The majority of students follow the four-year MSci Physics or the three-year BSc Physics programmes. The first two years of all the programmes are largely the same, allowing appropriate student transfers between programmes during the early stages.

The degree structure of the University is based upon a series of course units made up of lectures, practical work or project work with written examinations or other appropriate assessment, including assessed problem sheets in the first year.

The first year core lecture courses account for three units and are examined by written papers taken in the third term. For most candidates the fourth unit consists of computing, laboratory practical and project work assessed throughout the year. Candidates who fail a first year written examination may resit it in the September immediately following, but not more than the minimum pass mark will be awarded for any examination so retaken.

The second year is similar in structure. MSci Physics and BSc Physics students select one option at level two, while students on other programmes take a language or an extra maths course.

The third and fourth years contain a wide range of specialised physics options. Some students devote most of their third (and fourth) year options to theoretical physics. Option courses provided by the Humanities Programme and Tanaka Business School give additional breadth to the degree programmes. In their third (or fourth) year, students take two comprehensive examination papers aimed at assessing their general understanding of physical principles and their applications.

The Honours classification for the MSci and BSc programmes is based upon a student's performance in all the course units taken and in the comprehensive papers, which carry a large weighting in the assessment for Honours. An unclassified (pass) BSc degree may be awarded if Honours standard is not achieved.

The Department of Physics determines the conditions under which a student is allowed to proceed from one year to the next, and may require a student to withdraw from the course at any time, if it considers the student's progress to be unsatisfactory. The Department may also impose certain constraints upon option choices to ensure that a student undertakes a well-balanced and appropriate programme.

MSci Physics

The MSci Physics programme is an integrated Master's Honours degree programme of four years' duration intended to provide a firm base for professional work in physics and research. In the third year students attend three core physics courses, one 0.5-unit of laboratory work and select five 0.5-unit option courses at level three. The fourth year of the MSci course contains a major project and students select five physics option courses at level four. They also attend a course on research interfaces. MSci candidates normally complete a total of 16 course units and have to satisfy the examiners in at least 13 (including two in the fourth year).

BSc Physics

The BSc Physics course is designed to give students a thorough grounding in basic principles of theoretical and experimental physics in preparation for further study at postgraduate level or for careers in research and industry. BSc Physics candidates take 12 units at the rate of four each year. To qualify for an Honours degree students must satisfy the examiners in at least nine course units.

MSci/BSc Physics with Theoretical Physics

Students who opt for these programmes are expected to concentrate on the more theoretical options. In the first year they attend a course in mathematical analysis in place of the first year laboratory project. In the second year they take the mathematical methods option, whilst their final year contains a major theoretical project.

MSci Physics with a Year in Europe

This programmes is of four years' duration and is based on the four-year MSci programme. The third academic year of study is spent at a university in continental Europe and includes a substantial individual research project. Entry to the year abroad depends on satisfactory progress in the first two years.

In preparation for four units of study in the host university, students on the MSci Physics with a Year in Europe programme are required to attend 0.5-unit language courses in the first and second years, unless already fluent in the language of the country to be visited. In their first year, they attend a 0.5-unit course of laboratory and project work, and in their second year, they take the option in mathematical methods. Project work abroad (2.5 units) is assessed by a project report written in English and an oral presentation in the language of the host university. In addition, students attend and are examined in 1.5 units of taught physics courses at the host university. In their fourth year, they take core courses and select a range of standard or laboratory options at level four and sit the comprehensive papers. They must satisfy the examiners in at least 13 units.

BSc Physics with Studies in Musical Performance

This four-year joint course with the nearby Royal College of Music was established for students of physics who have a high ability in musical performance and are able to reach the RCM's stringent admission standards. It provides students with a BSc Honours degree in Physics as well as musical training in one instrument to the highest international standards. The music component also includes musical theory and history.

In the first year students replace the first year laboratory project with a 0.5-unit of musical studies. In the second year they take 1.75 units of musical studies instead of electromagnetism, optics, laboratory and an option course. In the third year they take 1.75 units of music, a 0.75-unit of laboratory including a project, and 1.5 units of core physics. In the fourth year they can take two or 2.5 units of music and a range of physics options. Students are expected to complete 16 units and to satisfy the examiners in at least 13.

Course structure

FIRST YEAR

All programmes			**Course unit value**
P.1.1a	Mechanics		(P.1.1a and b
P.1.1b	Relativity		make up 0.5 unit)
P.1.2a	Electricity and magnetism		(P.1.2a and b
P.1.2b	Electronics		make up 0.5 unit)
P.1.3a	Structure of matter		(P.1.3a, b, c
P.1.3b	Vibrations and waves		and P.1.4
P.1.3c	Quantum physics		make up
P.1.4	Professional skills I		one unit)
MPh.1	Mathematics I		1
PL.1	Laboratory I		0.5
MSci Physics/BSc Physics			
PP.1	Physics short experiments and project I		0.5
or			
P.1.5	Mathematical analysis		0.5
BSc/MSci Physics with Theoretical Physics			
P.1.5	Mathematical analysis		0.5
MSci Physics with a Year in Europe			
Either PLP.1	Physics laboratory and project I (instead of PL.1)		0.5
and			
Lang 1	Language I		0.5
or (if fluent in host language)			
PP.1	Physics short experiments and project I		0.5
or			
P.1.5	Mathematical analysis		0.5
BSc Physics with Studies in Musical Performance			
PMus.1	Music I	Principal instrument	0.5

SECOND YEAR

All programmes (except MSci Physics with a Year in Europe and BSc Physics with Studies in Musical Performance)		**Course unit value**
P.2.1	Quantum mechanics	0.5
P.2.2a	Thermodynamics	(P.2.2a and b
P.2.2b	Statistical physics	make up 0.5 unit)
P.2.3a	Applications of quantum mechanics	(P.2.3a and b
P.2.3b	Electrons in solids	make up 0.5 unit)
P.2.4a	Electromagnetism	(P.2.4a and b
P.2.4b	Optics	make up 0.6 unit)
P.2.5a	Statistics of measurement	(P.2.5a, b and
P.2.5b	Mathematics	P.2.6 make up
P.2.6	Professional skills II	0.7 unit)
PL.2	Laboratory II	0.7

MSci/BSc Physics

MPh.2	Mathematical methods	0.5
or		
PO.2.1	Sun, stars and planets	0.5
or		
PO.2.3	Environmental Physics	0.5
or		
Lang.2	Language II	0.5

MSci/BSc Physics with Theoretical Physics

MPh.2	Mathematical methods	0.5

MSci Physics with a Year in Europe

Lang.2	Language II	0.5
and either		
PL.2	Laboratory II	0.7
or		
PLM.2	Laboratory and mathematical methods	0.7

(unless fluent, when standard MSci options are followed)

BSc Physics with Studies in Musical Performance

P.2.1	Quantum mechanics	0.5
P.2.2a	Thermodynamics	(P.2.2a and b
P.2.2b	Statistical physics	make up 0.5 unit)
P.2.3a	Applications of quantum mechanics	(P.2.3a and b
P.2.3b	Electrons in solids	make up 0.5 unit)
P.2.5a	Statistics of measurement	(P2.5a, b and
P.2.5b	Mathematics	P2.6 make up
P.2.6	Professional skills II	0.75 unit)
PMus.2.1	Music 2.1 Principal instrument	1

PMus.2.2	Music 2.2	Aural training	0.25
PMus.2.3	Music 2.3	Stylistic studies	0.5
or			
PMus.2.4	Music 2.4	Historical studies	0.5

THIRD YEAR

All programmes (except MSci Physics with a Year in Europe)		**Course unit value**
P.3.1	Nuclear and particle physics	0.5
P.3.2	Solid state physics	(P3.2, P3.3
P.3.3	Atomic and molecular physics	and P3.4 make
P.3.4	Professional skills	0.5 unit)
plus	Comprehensive papers I and II	

MSci Physics

PL.3	Laboratory III	0.5
plus	Five level three options*	2.5

BSc Physics

PP.3.3	Project	0.5
PL.3	Laboratory III	0.5
plus	Four level three options*	2

MSci Physics with Theoretical Physics

PO.3.5	Advanced classical physics	0.5
plus	Five level three options*	2.5

BSc Physics with Theoretical Physics

PTP	Theory project	0.5
PO.3.5	Advanced classical physics	0.5
plus	Four level three options*	2

A total of at least three theory options must be chosen in the third year.

BSc Physics with Studies in Musical Performance

P.2.4a	Electromagnetism		(P.2.4a and b
P.2.4b	Optics		make 0.5 unit)
PPL	Project and laboratory		0.75
PMus.3.1	Music 3.1	Principal instrument	1.0
PMus.3.2	Music 3.2	Practical studies	0.25
plus			
PMus.2.3	Music 2.3	Stylistic studies	0.5
or			
PMus.2.4	Music 2.4	Historical studies	0.5

Students choose Music 2.3 or Music 2.4, whichever is not taken in the second year.

MSci Physics with a Year in Europe

PYP	Year in Europe major research project	2.5
PY.1	MSci Year in Europe Physics I	0.75
PY.2	MSci Year in Europe Physics II	0.75

* May include up to one option each at level two and four

FOURTH YEAR

MSci Physics

		Course unit value
P.MP	MSci project and Research interfaces	1.5
plus	Five level four options**	2.5

MSci Physics with Theoretical Physics

P.MP	MSci project (theoretical) and Research interfaces	1.5
plus	Five level four options**	2.5

A total of at least six theory options must be chosen in the third and fourth years.

All MSci students must take at least five level four options in the third and fourth years.

BSc Physics with Studies in Musical Performance

PMus.4.1	Music 4.1	Principal instrument	2
plus	Four level three options*		2

Students may replace one physics option with one 0.5-unit Royal College of Music option.

MSci Physics with a Year in Europe

P.3.1	Nuclear and particle physics	0.5
P.3.2	Solid state physics	(P.3.2 and P.3.3
P.3.3	Atomic and molecular physics	make 0.5 unit)
PL.4	Laboratory IV	0.5
plus	Five options, at least four at level four	2.5
plus	Comprehensive papers I and II	

If the syllabus of P.3.1 is covered during the third year in Europe, students may choose one further option. Similarly, if both P.3.2 and P.3.3 syllabuses are covered in the third year in Europe, students may choose one further option. If at least three theory options are chosen, students may choose a further option instead of PL.4.

* May include up to one option each at level two and four.
** May include one option at level three, if a level four option is taken in the third year.

THIRD AND FOURTH YEARS

Standard options

PO.2.1	Sun, stars and planets	0.5
PO.2.3	Environmental physics	0.5
PO.3.2	Plasma physics	0.5
PO.3.3	Lasers, optics and holography	0.5
PO.3.4	Advanced classical physics	0.5
PO.3.5	Instrumentation	0.5
PO.3.6	Astrophysics	0.5
PO.3.7	Physics applied to medicine	0.5
PO.4.1	Atmospheric physics	0.5
PO.4.2	Biophysics of nerve cells and networks	0.5
PO.4.3	Space physics	0.5
PO.4.4	Optical communications physics	0.5
PO.4.5	Cosmology	0.5
PO.4.6	Quantum optics	0.5
PO.4.7	Device physics	0.5
PO.4.8	Laser technology	0.5
MPh.2	Mathematical methods	0.5
PL.3	Laboratory III	0.5
PL.4	Laboratory IV	0.5
P.RI	Research interfaces	0.5

Theory options

PT.3.1	Foundations of quantum mechanics	0.5
PT.3.2	Group theory	0.5
PT.3.3	Dynamical systems and chaos	0.5
PT.3.4	Statistical mechanics	0.5
PT.3.5	Computational physics	0.5
PT.4.1	Advanced particle physics	0.5
PT.4.2	General relativity	0.5
PT.4.4	Quantum field theory	0.5
PT.4.5	Quantum theory of matter	0.5
PT.4.6	Unification	0.5

Humanities options

H.1	Philosophy	0.5
H.2	Controversies and ethical dilemmas in science and technology	0.5
H.5	European history 1870–1989	0.5
H.6	Politics	0.5
H.7	Science and technology in western civilisation	0.5
H.8	Global history of twentieth century things	0.5
H.9	History of medicine	0.5
H.10	Modern literature and drama	0.5
H.11	Art of the twentieth century	0.5
H.12	Music and western civilisation	0.5
H.13	Communicating science: the public and the media	0.5
H.17	The Roman Empire	0.5
H.19	Creative writing	0.5
H.21	Music technology	0.5
H.22	Saying true things: how science invents and persuades	0.5

Tanaka Business School options

BS.0806	Entrepreneurship	0.5
BS.0808	Finance and financial management	0.5
BS.0515	Managerial economics	0.5

Syllabuses

FIRST YEAR

P.1.1a Mechanics

DR M. MCCALL
About 22 lectures.
Newton's laws, inertial frames, one-dimensional forces, constant acceleration, one-dimensional forces dependent on speed, one-dimensional forces dependent on position, inertia versus gravitational mass. Conservation of energy, potential energy function, motion near a potential minimum. Two-body dynamics, centre-of-mass frame, two body collisions, rocket motion. Three-dimensional motion, central forces, angular momentum and torque, central force orbits. Rigid body motion, moment of inertia.

P.1.1b Relativity

PROFESSOR D. WEBSDALE
About 8 lectures.
Mechanics and electromagnetism in inertial frames of reference. Invariance of the speed of light. Postulates of special relativity. Light clocks, time dilation, and length contradiction. Lorentz transformations and space-time diagrams. Velocity addition. Relativistic momentum and energy. Mass-energy equivalence. Relativistic mechanics of nuclear and high-energy particle interactions.

P.1.2a Electricity and magnetism

PROFESSOR S. SCHWARTZ
About 20 lectures.
Electric charge. Coulomb's law. Electric field and potential. Electric flux and Gauss's law. Charges on conductors. Field calculations and the method of images. Capacitance and stored electrical energy. Properties of dielectrics. D and P vectors. Current electricity and Ohm's law. Magnetism and the Lorentz force. The Hall effect. Force on a current element and the motor principle. The Biot-Savart law. Ampère's law. Solenoids and magnetic dipoles. Magnetic materials. EMF. Faraday's law and the dynamo principle. Inductance and transformers.

P.1.2b Electronics

DR M. NEIL
About 12 lectures.
Charge, current, potential difference, power and electromotive force. Forces on charges in simple electric and magnetic fields, the relationship between electric field and voltage or potential. Joules and electron Volts, energy of a visible photon in eV.
Electrical resistance and Ohm's law. Kirchoff's laws, Norton or Thevenin equivalents, superposition and the analysis of simple passive DC electrical circuits. Combining resistances and impedance matching. Capacitors and inductors. Principles of operation and construction. Differential and integral relationships between voltage and current. Combining capacitors and inductors in series and parallel.
Arbitrary sinusoidal signals in terms of complex numbers, the nature of phase, phase lead, lag and delay. Complex vector representations of sinusoidal signals and their time domain amplitude, P-P amplitude or RMS equivalent conversions.
Complex impedences and the analysis of AC circuits with capacitors and inductors as well as resistors. Circuit properties, such as the time domain current, voltage and power dissipated in an impedance. Simple high, low, notch and band pass filters. Centre frequency and Q value of LCR resonant circuits, examples of uses for such a circuit.

Transient operation of DC circuits containing switches to zero, first and second order differential equations. Equivalence of electrical circuits to other physical systems described by the same differential equations, such as damped spring balances.

P.1.3a Structure of matter

DR M. COPPINS
About 12 lectures.
Microscopic and macroscopic; qualitative differences between solids, liquids and gases at microscopic level; basic kinetic theory; ideal gas equation of state; equipartition of energy; first law of thermodynamics; heat capacities; isothermal atmosphere; Boltzmann law; velocity component distribution function; Maxwell speed distribution function; moments of distribution functions; Lennard-Jones 6-12 potential; van der Waals equation of state; mean free path; Archimedes' principle; continuity equation; inter-particle forces; phase changes.

P.1.3b Vibrations and waves

DR A. CAMPBELL
About 12 lectures.
How simple harmonic motion (SHM) occurs: SHM in simple physical systems such as a mass on a spring, the small amplitude simple pendulum and a parallel inductor-capacitor circuit.
The general complex solution to SHM: the phasor diagram in the complex components. Angular frequency, frequency, period, amplitude, phase in SHM. Acceleration, velocity, kinetic energy, potential energy and the total energy for a simple mechanical system undergoing SHM.
Linearity and non-linearity in SHM: general solution to damped SHM. The three limiting cases: under or lightly damped; over or heavily damped; exponential decay and the quality factor Q in lightly damped SHM. General solution to forced or driven SHM. Resonance, resonant frequency, phase shift, power-transfer and quality factor, bandwidth, in-phase and out-of-phase components. Absorption and transmission of a driving oscillation or wave. Lightly and strongly-coupled oscillators. Resonant frequency splitting.
Waves—transverse and longitudinal: wavelength, wavevector, phase velocity. The wave equation and its general solutions. Wave on a string, sound waves, water waves. Combining waves: beats, wave packets. Group velocity. Dispersion, anomalous and normal. Refractive index. Changing phase velocity at a boundary. Refraction, internal reflection, Snell's law.
The Doppler effect: standing waves—longitudinal and transverse. Interference. Waves from two point sources overlapping in space. Constructive and destructive interference. Double-slits, Young's experiment. Diffraction. Single slits, multiple slits.

P.1.3c Quantum physics

PROFESSOR W.M. FOULKES
About 15 lectures.
Wave- and particle-like properties of light. Planck and de Broglie hypotheses. Wave-like properties of particles. Standing waves and the Bohr atom. The two-slit diffraction experiment. Probability amplitudes and densities. The wave function and its interpretation. Wave packets and the uncertainty principle. Standing waves in a square well. Atomic energy levels and bound states. Probabilistic results of subatomic experiments. Calculating quantum mechanical probabilities. The wave function immediately after a measurement. The time-dependent Schrödinger equation. Evanescent waves and tunnelling.

P.1.4 Professional skills I

PROFESSOR J. DREW AND SEMINAR GROUP LEADERS
One lecture, about 20 seminar meetings.
This course teaches transferable and problem-solving skills. The main elements of the course are (i) group library research projects leading to an oral presentation, (ii) writing summaries of articles from a popular science journal, (iii) problem-solving exercises, (iv) the preparation and delivery of a short talk. The course is centred around seminar groups of 16–18 students which subdivide into groups of five to six for group work. There are about 10 seminar meetings during terms 1 and 2, and an opportunity for every student to give an individual short talk within academic tutorials in term 3. Assessment is by a combination of coursework, oral presentation and a test.

P1.5 Mathematical analysis

PROFESSOR J. HALLIWELL
27 lectures and seven classworks.
The aim of the course is to show students how to turn vague arguments into rigorous mathematical proofs. Topics likely to be covered are: Sets and numbers. Sequences and series. Convergence. Speed of convergence. Functions of real variables. Continuity. Convexity. Differentiation. Newton's method. Riemann integration. Interchanging limits. Vectors and matrices. Operations on vectors. Eigenvalues and eigenvectors. Functions of matrices.

MPh.1 Mathematics I

DR M. COPPINS, PROFESSOR A. PARRY, PROFESSOR G.H.C. NEW, DR P. TÖRÖK
About 70 lectures.
Differentiation and integration of functions of one variable; hyperbolic functions; partial differentiation; total differential; Taylor's series for functions of one or more variables; maxima and minima; limits; indeterminate forms; multiple integrals; transformation of variables; Jacobians; orthogonal systems of curves, differentiation under the integral sign. Fourier transforms; delta function, superposition of simple harmonic vibrations, convergence of series. Complex numbers; the Argand diagram, determinants; matrices; solution of simultaneous algebraic equations, matrix eigenvalue equations. Solution of standard types of first order differential equations. Vector algebra; scalar and vector products; scalar differentiation of vectors; three-dimensional geometry; equations of line and plane; scalar and vector fields; line, surface and volume integrals; gradient, divergence, curl; theorems of Gauss, Stokes and Green.

PL.1 Physics laboratory I

DR B. SAUER AND DEMONSTRATORS
Approximately six hours per week during the first and second terms.
Electronics: use of meters and oscilloscopes, diodes and transistors, amplifiers, phase and AC circuits, filters. The principles of logic circuits.
Optics: geometrical optics, interference and diffraction, sources, polarisation, Michelson interferometer.
Computing: an introduction to computing techniques.
The course also includes lectures on and training in the treatment of errors of measurement.

PP.1 Physics short experiments and project I

DR B. SAUER AND DEMONSTRATORS
Approximately six hours per week during second and third terms.
Four weeks are spent on a choice of six-hour short experiments. In the third term students work in pairs on a practical project either in the first year laboratory or in a research group supervised by research personnel. Some projects are of a computational nature. Students prepare a written report and make a poster presentation of their work.

PLP.1 Physics laboratory and project I (MSci Year in Europe only)

DR B. SAUER AND DEMONSTRATORS
Approximately six hours per week.
During the first 13 weeks of the session students undergo training and perform experiments successively in several different sections of the laboratory in which they are introduced to the basic ideas and techniques of experimental physics. These sections are:
Electronics: use of meters and oscilloscopes, diodes and transistors, amplifiers, phase and AC circuits, filters. The principles of logic circuits.
Optics: geometrical optics, interference and diffraction, sources, polarisation, Michelson interferometer.
Computing: an introduction to computing techniques.
The course also includes lectures on and training in the treatment of errors of measurement. During the third term students work in pairs on a practical project either in the first year laboratory or in a research group supervised by research personnel. Some projects are of a computational nature. Students prepare a written report and make a poster presentation of their work.

SECOND YEAR

P.2.1 Quantum mechanics I

DR D. SEGAL
About 30 lectures.
Review of quantum phenomena, Planck and de Broglie relations, Wave-particle duality, Schrödinger equation.
Observables and operators, eigenvalues and eigenfunctions, measurement in quantum mechanics, compatibility and complementarity, expectation values and uncertainties, postulates of quantum mechanics.
One-dimensional systems, potential steps, wells and barriers, tunnelling, quantum harmonic oscillator, ladder operators.
Three-dimensional systems, angular momentum, central potentials.
Magnetic effects in quantum systems, Stern-Gerlach experiments, spin, Pauli spin formalism.
Time development of quantum systems, conserved quantities.

P.2.2a Thermodynamics

DR M. COPPINS
About 18 lectures.
Thermodynamic variables, equation of state, thermodynamic equilibrium. Zeroth law.
Temperature, absolute zero and perfect gases. First law of thermodynamics.
Work, internal energy, heat capacities and enthalpy. Adiabatic change and adiabats.
Reversible and irreversible changes. Heat engines, thermal efficiencies and Carnot cycles.
Second law of thermodynamics. Clausius' theorem.
Combined first and second law. Phase changes and latent heat. Maxwell relations. Reciprocity theorem.
Helmholtz and Gibbs functions. Free energy. Third law of thermodynamics.

P.2.2b Statistical physics

PROFESSOR J. HARRIES
About 12 lectures.
Microstates and degeneracy, distinguishable and indistinguishable particles. Thermodynamic functions of state, distribution functions. Entropy, disorder and the probability of system configuration occurring. Information theory. Arrow of time. Equilibrium confirguration, Boltzmann distribution. Temperature. Partition function. One-dimensional harmonic oscillator. Planck distribution, black body radiation. Fermi-Dirac and Bose-Einstein distributions.

P.2.3a Applications of quantum mechanics

PROFESSOR J. MARANGOS
About 12 lectures.
Bohr model of the hydrogen atom—successes and deficiencies. The energy level structure of hydrogen derived from the Schrödinger equation. The structure of helium ground state energy in the independent particle approximation. Introduction to time independent perturbation theory. Improved helium ground state using perturbation theory. Excited states of helium. Identical particles. Perturbation theory for excited states of helium, the inclusion of spin. Molecules, Born-Oppenheimer approximation, vibrational and rotational structure.

P.2.3b Electrons in solids

PROFESSOR D.D. VVEDENSKY
About 18 lectures.
Electrons in square wells, free electron model of solids, density of states, the Fermi function, thermal properties of the Fermi gas; the Kronig-Penney model, Bloch functions, energy bands and band gaps, effective mass; Brillouin zones and band filling, metals, insulators and semiconductors; electrons and holes in semiconductors, donor and acceptor states.

P.2.4a Electromagnetism

PROFESSOR A. MACKINNON
About 24 lectures.
Maxwell equations. Relativistic invariance. Magnetic and electric energy densities, Poynting flux. Momentum flux. Electromagnetic wave equation. Electromagnetic waves. Electromagnetic spectrum. Radiation pressure and polarisation. Dielectric media and phase velocity. Boundary conditions, reflection and transmission coefficients. Brewster angle. Anti-reflective coatings. Conducting media and wave attenuation. Electron dipoles, origin of refractive indices and absorption. Collisionless plasma, cut-off at the plasma frequency.

P.2.4b Optics

PROFESSOR R.C. THOMPSON
About 12 lectures.
Rays, Fermat's principle. Reflection and refraction, Snell's law. Curved mirrors and thin lenses, virtual image. F-number. Thin lens and mirror equation. Magnification, microscopes and telescopes. Polarisation, filters, birefringent crystals, polarised light and Malus' law. Brewster's angle. Constructive and destructive interference. Theory of secondary sources, diffraction grating, circular aperture and resolution of optical instruments, Fabry-Perot interferometer. Application of Fourier theory to diffraction and Young's slits. Use of the convolution theorem, frequency filters. Holography.

P.2.5a Statistics of measurement

DR R. FORSYTH
About 9 lectures.
Laws for adding probabilities and calculating a conditional probability. Independent events. Permutations and combinations. Binomial distribution and random walks. Continuous probability distribution. Differential and integral distributions. Mean (expectation), variance and standard deviation. Poisson distribution. Stirling's formula and Gaussian distribution. Central limit theorem. Error calculations and rules for combining errors. Applications to experimental measurements.

P.2.5b Mathematical physics

DR J. ZHANG, PROFESSOR W.M. FOULKES
About 27 lectures.
Differential equations.
Ordinary differential equations: classification, separable equations, integrating factors, constant coefficients, homogeneous equations, complementary functions and particular integrals, finite differencing, general solutions and boundary conditions, linearly dependent/independent functions, series expansion methods.
Partial differential equations: wave equation, diffusion equation, Poisson's equation, Schroedinger's equation, general solutions and boundary conditions, separation of variables, Fourier methods, polar coordinates.
Eigenvalues and eigenfunctions: normal modes, Sturm-Liouville theory, Hermitian operators, completeness and orthogonality.
Special functions: Bessel functions, Legendre polynomials, spherical harmonics.
Fourier analysis. Orthogonality and orthornormal basis set of functions. Fourier series, Dirichlet's condition for Fourier series, Gibb's phenomena in Fourier series. Parseval's theorem for Fourier series. Odd and even functions. Half range Fourier series. Fourier series in complex exponentials. Parseval's theorem for Fourier series in complex exponentials. Fourier transform in one dimension.
Linearity, shift theorem, scaling theorem, correlation theorem and convolution theorem.
Fourier transform of delta function, rectangular function and application of Fourier transform in study of diffraction from transmission grating.
Fourier transform in two and higher dimensions.

P.2.6 Professional skills II

PROFESSOR L. COHEN
Further development of professional skills introduced in the first year, particularly those associated with producing a précis and writing an extended 2,000-word essay. Introduction to the basic concepts associated with writing a usable CV.

PO.2.1 Sun, stars and planets

DR J. PICKERING
About 26 lectures.
The sun, stellar structure, the nuclear generation, energy transport to surface. Hydrostatic equilibrium, Schwarzschild convective stability criterion. Outer layers of the sun, solar electromagnetic spectrum, solar wind. Life-cycle of stars, Hertzsprung-Russell diagram. Magnitude, parallax and proper motion. Galaxy, distribution of stars in type and position. Kepler's laws, planets in the solar system. Detecting extra-solar planets. Recent discoveries, planet formation, life in the universe.

PO.2.3 Environmental physics

DR J. HASSARD, DR A. CZAJA, DR J. NELSON
About 26 lectures.
Energy for human use: Energy sources, supply conversion and use. Historical and future needs. Costs of power, historical and future. How energy should be costed. Electrical power, demand, generation, distribution. Fossil fuels for power generation and transport. Nuclear energy, fission and fusion. Energy conservation and storage. Fuel cells and hydrogen technology. Cost analysis of these technologies.
Renewable sources of energy: Solar radiation and thermodynamics of solar energy transfer. Solar thermal energy conversion. Photovoltaic solar energy conversion. Photosynthesis and biomass. Wind, wave, tidal and hydroelectric power. Cost analysis of these technologies.
Environmental monitoring: Role of monitoring. Environmental spectroscopy. Spectroscopic methods in the atmosphere and water. Ground based techniques. Satellite observations.
Climate modelling: The global climate. Role of modeling. Numerical weather and climate prediction. Chaos and the predictability problem.

MPh.2 Mathematical methods

PROFESSOR H.J. JENSEN (DEPARTMENT OF MATHEMATICS)
About 29 lectures and 13 classworks.
Basic linear algebra and introduction to vector space theory, Hilbert space (and quantum mechanics). Rotational and transformation properties of vectors and tensors. Kronecker delta, Levi-Civita symbols. Pseudo-vectors and pseudo-tensors.
Numerical methods, Runge-Kutta, Newton-Raphson, Gaussian elimination techniques.
Complex function theory. Standard functions, trig, hyperbolic logarithm, differentiability, analytic functions, Taylor and Laurent series. Cauchy-Riemann formulae. Cauchy's theorems, calculus of residues. Jordan's lemma. Evaluation of integrals in the complex plane.
Fourier transform theory. Transform of a derivative. Sine and cosine transforms, Dirac-delta function. Convolution theory. Applications to solutions of linear PDEs on infinite and semi-infinite line. Green's functions for PDEs. Variational methods.

PL.2 Physics laboratory II

DR S. LEBEDEV AND DEMONSTRATORS
Students complete the computing section and three other experiments form the list below:
Computing: use of object-oriented programming to solve physics problems. Classes and objects. Operator overloading and inheritance. Computational solution of charged particle moving in a magnetic field. Pion decay processes: use of random number generators, Lorentz transformations and simple detector physics.
Diffraction and holography: use of Fourier transforms in explaining diffraction patterns. Spatial filtering.

Construction of holograms. Holographic lens.
Interferometry: use of Fabry-Perot interferometer to measure wavelengths of spectral lines and refractive index. Use of Michelson interferometry to carry out Fourier transform spectroscopy and to measure coherence length.
Nuclear physics: training in the safe use of low-level radioactive sources. Investigation of the interaction of beta rays and gamma rays with matter. Study of random processes. Use of solid state detectors and computer-aided data acquisition.
Solid state physics: X-ray crystallography. Study of the three-dimensional parameters of a cubic crystal. Design and construction of electronic circuit to examine light emission, absorption and band structure in semiconductors. Computer modelling of energy levels and wavefunctions for coupled quantum wells to study nature of energy bands and covalent bonds in solids.
Spectroscopy: generation, recording and analysis of metal spectra. Investigation of light absorption and fluorescence in organic dyes. Concept of optical depth. Analysis of Skylab ultraviolet spectrum of the Sun to determine conditions in solar atmosphere.
Transmission lines and thermal waves: propagation of voltage waves along lumped-impedance transmission line. Concepts of characteristic impedance, phase and group velocities, matching, resonance. Propagation of temperature waves through a solid. Fourier-Bessel techniques. Diffusion equation. Low-pass filter.

PLM.2 Laboratory II plus mathematical methods (MSci with a Year in Europe only)

Mathematical methods (MPh.2) plus half (two experiments) of Physics laboratory II (PL.2)

THIRD AND FOURTH YEAR

Core courses

P.3.1 Nuclear and particle physics

PROFESSOR D. WARK
About 26 lectures.
Particle physics: relativistic kinematics, energy-momentum four-vectors, virtual particles, anti-particles. Fundamental fermions; quarks, leptons and neutrinos. Fundamental bosons; electromagnetic, weak and strong interactions. Feynman diagrams, Coupling constants, cross-sections and decay rates. Hadron physics; strange and charmed particles, meson and baryon resonances, Quark model and basic ideas of QCD. Weak interactions; beta decay, weak decays of quarks, parity and CP non-conservation. Production and decay of Z boson, unification of weak and electromagnetic interactions.
Nuclear physics: the deuteron and the two-nucleon potential, nuclear radii and binding energies, the semi-empirical mass formula and its uses, main properties of stable nuclei. Nuclear structure; indicators of nuclear structure, the nuclear shell model, other models. Alpha, beta and gamma decay, radioactive decay chains, natural radioactivity, nuclear fission. Nuclear reactions, chain reactions, nuclear reactors, nuclear reactions in stars.

P.3.2 Solid state physics

PROFESSOR C. PHILLIPS
About 15 lectures.
Introduction and overview: history and how old the subject is. What solid state physics can achieve and what it can't (yet); success stories. Reading list. Scope of course.
Crystals and lattices: crystal symmetries and shapes—the lattice; lattice vectors; basis; primitive unit cells; conventional unit cells. Examples: Miller notation; plane separations; Bragg diffraction; planar spacings. Periodocities.
Reciprocal space: Braggs' laws in reciprocal space; k-space ideas; constructing and working with the three-dimensional reciprocal lattice mathematically.
Electrons in crystals: atoms and atomic core levels; origins of electron bands; bands in molecules; bands in a solid; bonding/antibonding states; square well analogies of bonding and anti-bonding. Bloch's

theorem; consequences of Bloch's theorem; k as suitable quantum number in crystals; crystal momentum; limitatations to applicability of Bloch's theorem. Effective mass.
Electrical transport and conductivity: carrier mobility and diffusion; momentum relaxation mechanisms; diffusion currents. Einstein relation between D and μ; carrier recombination times. Success stories—the p-n junction in thermal equilibrium; sketching band-edge diagrams; electrostatics of the built-in potential step; the p-n junction as a rectifier; analysis of current characteristics; injection, diffusion lengths and the Shockley equation. Magnetism; E+M basics; diamagnetism; paramagnetism; ferromagnetism; magnetic data storage technologies.
Optical properties: optical properties and the classical dipole model; E+M basics, frequency dependent dielectric function; complex refractive index; absorption coefficients; atomic polarisability; frequency dependencies. Birefringence and dichroism. Ensemble of oscillators models of the optical properties of a solid; examples of dipoles; bulk absorption in an insulator/semiconductor; optical fibres and dispersion away from resonance; optical anisotropies. The quantum view of optical properties. Optical devices; the p-n junction as an optical detector; the p-n junction as a light emitter; heterostructure diode lasers: quantum well lasers.
Phonons and thermal properties: phonons, the quanta of sound; linear chain model; phonon dispersion curves. Uses of Phonon dispersion curves: phonons in electron scattering; intraband relaxation processes; carrier recombination; speed of sound; IR optical properties; crystal specific heats.

P.3.3 Atomic and molecular physics

DR B. SAUER
About 15 lectures.
Many electron atoms, spin and degeneracy, spin-orbit coupling and its effect on energy states, Zeeman effect, Stak effect, Lamb shift, superpositions of two states, dipole radiation, overlap integral, perturbation theory, transition lifetimes, line broadening, selection rules, spontaneous and stimulated emission. Einstein A and B coefficients, populations in thermal equilibrium, population inversion, coherent radiation, laser action, three-level atomic laser, many electron atoms as a collection of electrons interacting separately with a shielded nucleus, periodic table, chemical and physical properties, covalent and ionic bonding of molecules.

PL.3 Physics laboratory III

PROFESSOR R. TOUMI AND DEMONSTRATORS
About 100 hours.
Students take three advanced experiments (or equivalent). The experiments are chosen from a list of about 40, including such topics as: Compton effect, lasers and diffraction, holography, squids, bubble chamber track analysis, photoelectric effect and Planck's constant, magneto-phonon effect, solid state diode characteristics, Millikan's method for the electronic charge, black body radiation and Planck's constant, electron density in solids by plasma frequency measurement, Zeeman effect, polarisation of light, measurement of the gravitational constant, analysis of star survey data, digital image processing, transformers, transmission lines, waveguides, analogue and digital electronics, electronic noise, Hall effect, analogue computers, spin resonance in ferrites, nuclear magnetic resonance, optical pumping, decay of metastable states, Michelson interferometer applied to the study of solids, X-ray diffraction, cosmic rays and the muon lifetime, light scattering and turbulence in the atmosphere. There is also a taught course with associated practical work on programming of microprocessors in assembler language.

PP.3 Project

PROFESSOR K. KRUSHELNICK AND SUPERVISORS
About 100 hours.
Projects last one term and may be built around existing standard experiments, or they may be based on project proposals (approximately 100–120 available) from demonstrators or members of academic staff, or they may be proposed by students themselves. Some projects are located in the third year laboratory and others are located in the research groups of the Blackett Laboratory.

PMP MSci project

DR K. CHRISTENSEN AND SUPERVISORS
About 300 hours.
Students undertake project work either in a research group in the Department, in the College, in a research establishment or hospital, a teaching laboratory or perhaps linked with industry. The project may be experimental, theoretical, computational or most likely a combination of these. Students produce a literature review, a final written report and are required to give an oral presentation of their work.

PYP MSci Year in Europe major research project

About 600 hours.
A major research project carried out in the research laboratories of a continental European university under the direction of a local supervisor. Projects are monitored by Imperial College academic staff and the final written report is assessed by them. Students also give an assessed presentation in the language of the host university.

PY.1 MSci Year in Europe physics I

About 60 hours of lectures or equivalent.

PY.2 MSci Year in Europe physics II

About 60 hours of lectures or equivalent.
Students attend lectures and examinations in the foreign language at the host university in continental Europe; the package of courses selected by the student to be agreed by the Department.

P.RI Research interfaces (optional for MSci Year in Europe

PROFESSOR D. BRADLEY, PROFESSOR J. DREW, DR J. HASSARD, STAFF FROM TANAKA BUSINESS SCHOOL AND HUMANITIES PROGRAMME
The course addresses five aspects of the interface between the professional physicist and non-physicists and aims to improve understanding and communication in the areas of: a) instrument design and engineering; b) the written word for communication both within and outside the physics environment; c) the management of research; d) financial management at local and strategic levels: e) spoken communication; f) entrepreneurship and business start-ups.
Extensive use is made of group work and practical exercises.

Standard options

PO.3.2 Plasma physics

DR J. CHITTENDEN
About 26 lectures.
Basic properties of plasmas: quasi-neutrality, Debye shielding, plasma oscillations, electromagnetic waves in plasmas.
Magnetohydrodynamics: MHD equations, magnetic tension/pressure, field line freezing and reconnection, MHD equilibria, Alfvén waves, instabilities.
Particle motion: guiding centre drifts, magnetisation, adiabatic invariants, magnetic mirrors.
Collisions: nature of inter-particle collisions in plasmas, resistivity, Bremsstrahlung.
Fusion: background physics, break-even and ignition, the fusion power station.

PO.3.3 Lasers, optics and holography

DR R.A. SMITH
About 26 lectures.
Introduction: Wave representation of light and the wave equation.
Interference: division of amplitude and division of wave front; dual and multiple beam interference, diffraction gratings; temporal coherence.
Diffraction: Huygen-Fresnel principle; Kirchoff’s diffraction theory; applications to near and far field

diffraction; Fraunhofer approximation and Fourier transforms; implications in imaging, Airy disc and resolution; diffraction gratings revisited. Optical information processing: lens as a Fourier transforming element; optical processing-spatial filtering and spatial light modulators; phase contrast imaging.
Laser action: Einstein A and B coefficients, three and four level systems; resonators, modes and stability; laser threshold; common laser systems-HeNe; semiconductor lasers.
Holography: in line holography (Gabor); recording and reconstruction of an off-axis hologram; recording materials (thick and thin holograms); white light holograms; holographic interferometry. Generation and measurement of ultra-short light pulses.

PO.3.4 Advanced classical physics

DR M. McCALL
About 26 lectures
Rotation: rotating frames, centrifugal and Coriolis forces, inertia tensor, principal axes of inertia, gyroscopes.
Lagrangian and Hamiltonian mechanics: calculus of variations, action integral principle of least action, generalised co-ordinates and momenta, normal modes, Lagrangian for charged particle motion in electromagnetic field, Hamiltonian, Hamiltonian's equations, canonical transformations, poisson brackets, continuous symmetries.
Electrodynamics and relativity: four vectors, Lorentz transformations for electromagnetic fields, magnetic field required by relativity, four-vector potential, Maxwell's equations in four-vector form, Lienard-Wiechart potentials, radiation by an accelerated charge, Bremsstrahlung, dipole radiation, antennas, Rayleigh scattering, Thomson scattering.

PO.3.5 Instrumentation

DR J. POZIMSKI
About 26 lectures.
Introduction: what is instrumentation?
Detectors: transducers, basic principles, temperature sensors, traditional mercury thermometer, thermocouples, thermistors, integrated circuits, platinum resistance. Diode light level sensors, semiconductor sensors, radiation detectors, interaction of radiation with matter, photons, particle counters, spectrometers, imaging.
Conditioning electronics: types of signals, continuous analogue, pulses, Fourier transforms, digital, buffers, amplifiers, filters, transfer functions, laplace transforms, types of filters.
Processing electronics: transient recorder, digitisation, sampling, frequency analysis, phase sensitive detection and phase lock loops, spectrum analysis, pulse height analysis, pulse shaping, multi-channel analysers.
Noise and sensitivity: fundamental limitations, electronic noise, noise in electronic components, thermal noise, shot noise, 1/f noise, interference, power supplies, capacitive coupling, magnetic induction, electromagnetic pick-up, ground currents.

PO.3.6 Astrophysics

DR Y. UNRUH
About 26 lectures.
Astrophysical end states-compact objects. Introductory overview. The degenerate equation of state (starting from F-D statistics and phase space considerations). The mass-radius relation for degenerate objects; Chandrasekhar mass. Brown dwarfs, evolved stellar cores, white dwarfs and neutron stars Stellar and supermassive black holes (microquasars and quasars). Steady-state accretion onto compact objects. Supernovae: explosion via (i) TNR on degenerate objects, (ii) core collapse in massive stars (including basic nucleosynthetic considerations). Gamma ray bursters: hypernovae and merging neutron-star binaries.
Interstellar medium and gaseous nebulae. Introduction: diagnosing the physical state and chemical abundances of diffuse matter in space
Diffuse interstellar clouds and the formation of absorption lines (simple line-broadening mechanisms and

COG; results depletion of heavy elements). HI 21cm observations and the structure of the galaxy. The properties of dust (interstellar extinction; nature of dust grains, condensation temperatures and implication for IR/sub-mm observations). Ionised nebulae: overview of HII regions and PNe. Ionised nebulae: formation of emission lines (to include discussion of physical processes involved, low density simplification statistical equilibrium, critical density and emission line diagnostics). Ionised nebulae: cosmic abundance determinations.
Dark matter. Evidence for dark matter. Galaxy rotation curves. X-ray observations of galaxy clusters. The virial theorem. The collisionless Boltzmann equation and Jeans equations. Gravitational lensing.

PO.3.9 Physics applied to medicine

DR C. GUY, DR V. MOORE, DR D. LARKMAN (FACULTY OF MEDICINE)
About 26 lectures.
Tomography: Fourier method—the central slice theorem. Aliasing. Transfer equation. Beer's law. Attenuation. Attenuation mechanisms. Scattering and absorption processes.
Diagnostic X-rays and CT imaging: image contrasts, radiation dose. Ionising radiation. Production and detection of kilovolt photons. Image quality.
Gamma imaging: metabolic uptake. Radioactive decay. Suitable isotopes and carriers. Gamma camera. Scattering mechanisms. SPECT and PET.
Diagnostic ultrasound: production and detection. A, B and M modes. Doppler ultrasound: blood flow.
Magnetic resonance imaging: The MR signal and relaxation processes. Spatial encoding and image contrast. Pulse sequence design. Image reconstruction. Structural imaging. Functional imaging. Parallel imaging.

PO.4.1 Atmospheric physics

PROFESSOR J. HAIGH
About 26 lectures.
Basic properties of the atmosphere: composition, temperature and wind structure. Hydrostatic equilibrium, entropy and potential temperature; adiabatic lapse rates and vertical stability.
Earth radiation balance: radiative transfer and Schwarzchild's equation; the spectral properties of gases; absorption and scattering of solar radiation, including the role of ozone; absorption and emission of thermal radiation by water vapour and carbon dioxide; the "greenhouse effect." Radiative forcing of climate change.
Cloud formation; radiative properties of cloud; cloud-climate feedbacks.
Remote sensing of the atmosphere using satellite instruments.
Geophysical fluid dynamics; Navier-Stokes equations of momentum and continuity; the effects of a rotating planet; geostrophic and cyclostrophic motion; thermal wind. Isobaric and isentropic coordinates. Barotropic and baroclinic instability. Waves in the atmosphere: acoustic, gravity, planetary (Rossby). Weather charts.
Global scale atmospheric circulation. Climate modelling.

PO.4.2 Biophysics of nerve cells and networks

PROFESSOR N.P. FRANKS AND DR S. BRICKLEY (DEPARTMENT OF BIOLOGICAL SCIENCES)
About 26 lectures.
Introduction: overall anatomy of nervous system; localisation for function and parallel processing. Cells in the nervous system: neuronal classifications; different types of potentials. Molecular structure of nerve membranes: lipid and protein structure; functions of membrane proteins. Diffusion across membranes: Gibb's free energy; Fick's law and passive diffusion across membranes; channels and pumps; active and passive transport. Basic experimental techniques for studying nerve activity. Passive properties of nerve membranes. Nernst-Planck equation; Nernst equation; Donnan effect; origin of resting potential; constant field equation. Observation and ionic basis of action potentials: sodium and potassium channels; refractory period; action potential propagation; myelin. Voltage-clamping the squid axon; Hodgkin/Huxley equations; voltage-gain of ion channels; modifications of the Hodgkin/Huxley action potentials. Synapses: electrical and chemical; pre synaptic mechanisms and quantal release; post-synaptic mechanisms and receptor types; classes of chemical neurotransmitters. Noise analysis: power

spectral density and the auto-correlation function; determination of channel conductance and mean open time. Patch-clamping technique: direct determination of single-channel kinetics. Genetic approaches to neurobiology: obtaining the cDNA library and cloning channels; expression in oocytes; genetic engineering. Actions of drugs on nerve membranes: agonists and antagonists of neurotransmitters; general and local anaesthetics; tranquillisers. The visual system: general anatomy; rods and cones; light transduction at the photoreceptor membrane; second messenger cascade. Retinal and cortical neuronal networks: colour vision; higher order visual processing. Cerebellum: anatomical structure, electrophysiological activity; models of cerebellar function; mutations and abnormal functions.

PO.4.3 Space physics

DR T. HORBURY
About 26 lectures.
Introduction and review of relevant physics (three lectures plus handouts). The solar wind. The thermally driven wind (Parker analysis). What works and what does not. Modifications to resolve discrepancies. The three-dimensional wind structure. Winds driven by waves. The extension to stellar corona. Radiation-driven winds. Inverse winds (accretion processes) (seven lectures). Coronae and atmospheres. Solar and stellar magnetic fields. Conditions needed for equilibrium. Why is the corona hot? An introduction to the magnetic reconnection process. Radiation from atmospheres: emission processes and the difficulty in interpretation. Highly energetic charged particles: their existence and possible cause (eight lectures). Magnetospheres. Why does a magnetosphere form? An overview of the Earth’s magnetosphere. The linkage between the solar and terrestrial magnetic fields. Global magnetospheric convection. Planetary magnetic fields and magnetosphere: a comparative survey. The role of rotation. Pulsar magnetospheres (eight lectures).

PO.4.4 Optical communications physics

DR R. MURRAY
About 26 lectures.
Information content and encoding: quantifying information; Shannon’s formula for channel capacity; digital encoding of analogue signals; sampling theorem; Nyquist rate; quantisation; analogue and digital signalling; multilevel signalling; information theory; redundancy; data compression; error detection and correction.
Transmission of information: principles of communication systems; system limitations: bandwidth, attenuation, noise, dispersion. Baseband and modulated carrier transmission; multiplexing (time-division, wavelength division, space division, statistical).
Transmission media: free-space, twisted pair cable, coaxial cable, optical fibre.
Signals: time and frequency representation; Fourier transforms; convolution; system frequency and time response, low, high amd bandpass filters, transmission line model of electrical communication channels (twisted pair and coax), impedance matching, reflections and time-domain response (TDR).
Noise: theory of random processes, physical origins of noise: thermal, photon (shot) noise, amplifier. Implication for analogue and digital systems: signal to noise ratio, error rates, eye diagrams. Link power budget calculations, bandwidth specification, error rate calculations including decision theory.
Modulation, multiplexing and coding transmission: classical analogue modulation theory, digital, binary amplitude shift keying (BASK), phase shift keying (BPSK), frequency shift keying (BFSK), coherent and differential coding, optical context: practical IM-DD, coherent detection in optics, practical issues in optical modulation, e.g. chirp, data rates.
Multiplexing—multiple user access: time division (SONET, SDH) wavelength division (DWDM, CWDM), code division multiple access (CDMA).
Optical fibres: geometrical picture, multimode and single-mode fibre; EM wave modelling for full modal (evanescent wave) description, attenuation, dispersion, non-linear processes—uses and limitations.
Modern communication systems: communication networks (local, metropolitan, wide area network); packet and circuit switched networks; network protocols. Mobile communications network. Optical telecommunications systems: 1.3micron, 1.55micron; laser sources; modulators; photodetectors; optical components; repeaters and optical amplifiers.

PO.4.5 Cosmology

PROFESSOR K. NANDRA
About 26 lectures.
Introduction: the visible universe, our galaxy and other galaxies; empirical basis for cosmology.
Newtonian cosmology: brief introduction to special and general relativity; the Robertson-Walker metric; Friedmann models and their classification.
Cosmological parameters: redshift, Hubble law, age of universe, horizon.
Early stages of the universe: evolution of universe from 10^{-6} seconds to 300,000 years, origin of light elements, evolution of density fluctuations, epoch of recombination and microwave background radiation. Very early universe: GUTs and inflation, the Planck era, origin of density fluctuations. From the fireball to the present: formation of galaxies and clusters of galaxies, masses of galaxies, density of matter in the universe, dark matter, intergalactic gas. Cosmological tests: luminosity distance, diameter distance, source counts, integrated background radiation from galaxies, values of the cosmological parameters. Other cosmological theories: effects of non-zero cosmological constant, steady-state theory, variable G theories, anisotropic and inhomogeneous universes, Eddington's large numbers, anthropic principle. Some controversies in cosmology today.

PO4.6 Quantum optics

PROFESSOR E. HINDS
About 26 lectures.
Quantum optics is concerned with the interaction of atoms and photons, and the manipulation of quantum states and information. Black body spectrum, Einstein rate equations, stimulated emission. Origin of laser gain, thresholds, mode-locking and ultra-short pulse generation.
Introduction to non-linear optics: susceptibility expansion, parametric processes, basic idea of phase matching and example of up-conversion, non-linear refractive index.
Interaction of radiation with atoms: dressed states, Rabi oscillations, spectrum of resonance fluorescence, high harmonics and above threshold ionisation. Field quantisation: photons, states of the field, interaction of quantised light with atoms, spontaneous emission.
Laser cooling: Doppler cooling, dipole forces, dipole trap, optical molasses, magneto-optical traps, dark states and ultimate limits of cooling, evaporative cooling.
Cavity QED: modified lifetimes, Casimir forces. Non-classical light and quantum information processing, squeezing.

PO4.7 Device physics

PROFESSOR G. PARRY, DR A. CAMPBELL
About 26 lectures.
Review and expansion of relevant electrons in solids/solid state physics material (real band structures, localised states, band and hopping transport, carrier mobilities; occupation statistics, doping, carrier densities, traps; electrical transport: drift, diffusion, scattering, generation and recombination).
p-n junction diodes (as used in rectifier diodes, light emitting diodes (LEDs), lasers): full treatment, DC characteristics. Bipolar junction transistors: DC and AC characteristics. Device fabrication (wafer growth, MBE, doping, lithography, organic deposition).
Schottky diodes and Ohmic contacts (optical detectors, diodes, device contacts): full treatment, CV characteristics, thermionic emission, tunnelling. Metal oxide semiconductor (MOS) capacitors (computer memory, optical imaging): full treatment, CV characteristics, effect of traps and interface states. MOS field effect transistors (MOSFETs) (computer processors, flat-screen displays): full treatment, DC and AC characteristics. MOS optical devices (charge-coupled-devices). Advanced silicon technologies (poly-Si, amorphous-Si, large-area displays)
Optical properties of semiconductors. The III-V family of semiconductors. Recombination processes in semiconductors. Theory of heterojunctions based on GaAs/AlGaAs material system. Use of heterostructures in semiconductor lasers, LEDs, detectors and heterojunction bipolar transistors. Optical waveguiding in heterostructures.

The concept of low-dimensional structures: quantum wells, wires and dots. Carrier confinement in quantum wells. Excitons in quantum wells. The quantum confined Stark effect and its application to optical modulation.
Principles of operation of semiconductor quantum well lasers. Examples of applications of semiconductor quantum well lasers in optical communications and optical data storage.
Advanced organic semiconductor technologies (organic LEDs, solar cells, FETs).

PO.4.8 Laser technology

PROFESSOR M. DAMZEN, DR J. TISCH
About 20 lectures plus classworks.
Part 1: Laser device technology
Overview of laser fundamentals. Survey of commercial laser market. Performance of key industrial lasers: CO_2, Nd:YAG and excimer. Laser amplifiers: saturable gain coefficient and gain extraction. Laser oscillators. Power efficiency, slope efficiency, optimising efficiency. Thermal issues in solid state lasers. Thermally induced lensing, stress induced birefringence, depolarisation. Rod, slab and disc geometries. Spatial characteristics: single mode selection; multimode operation. Defining M^2 beam propagation parameter. Diode lasers: edge-emitting; single-mode narrow stripe; broad stripe; diode arrays; diode stacks; fibre-coupled. Operational characteristics of AlGaAs; red diodes; blue diodes; telecom diodes; vertical cavity surface emitting lasers (VCSELs). Case study: single mode AlGaAs diode laser. Diode-pumped solid-state lasers. Cavity design for TEM_{00} operation. Case study: diode end-pumped Nd:YAG/Nd:YVO_4. Survey of solid-state laser media. Tunable solid-state lasers. Fibre lasers. Spectral tuning; line-narrowing; ultrashort pulse techniques. Frequency converted lasers. Laser applications. Focusing laser radiation, spot size, depth of focus. Industrial material processing: cutting, welding, surface marking. Optical storage. Optical telecommunications. Medical laser therapeutics.
Part 2: Non-linear optics
Overview: history, context, importance, goals of course.
Review of linear optics: electromagnetic force on moving charges, Lorentz oscillator model, linear polarisation and susceptibility, inhomogeneous wave equation, complex refractive index, absorption/gain and dispersion.
Foundation concepts of non-linear optics: origin of the non-linear response, susceptibility expansion for non-linear polarisation, divergence of susceptibility expansion, catalogue of non-linear processes, introduction to phase-matching.
Second harmonic generation: description of process and introduction to important applications, photon picture, solution of wave equation for second harmonic field, interpretation of solution, phase-matching factor, parameter scalings, phase-matching in birefringent crystals, properties of non-linear crystals, second harmonic generation with real laser sources, application in measuring ultra-short laser pulses.
The electro-optic eeffect: origin and applications.
The optical Kerr effect: the non-linear refractive index, self-focusing and self phase-modulation, applications.
Frequency mixing processes: sum/difference frequency mixing, optical parametric amplification and oscillation, four wave-mixing and optical phase conjugation, applications.

Theory options

PT.3.1 Foundations of quantum mechanics

DR F. DOWKER
About 26 lectures.
Definition of vector spaces, linear maps, subspaces, basis vectors. Scalar products and norms on vector spaces, Hilbert spaces, Dirac notation. Linear operators. Adjoint and hermitian operators, projection operators. Eigenvectors, eigenvalues and the spectral theorem.
Properties in classical physics: the state space of classical physics; classical realism; the logical structure of classical physics.
The general formalism of quantum theory. Functions of an operator. Density matrices and mixed states. Compatible quantities. Time and conserved quantities.

Unitary operators. Stones's theorem; Wigner's theorem. Derivation of the canonical commutation relations using displacement operators. The uncertainty relations; the Schwarz lemma.
Conceptual issues in quantum theory: the role of measurement; probability; entanglement; state-vector reduction.
The Kochen-Specher theorem. Quantum logic. The Bell inequalities.

PT.3.2 Group theory

DR T. EVANS
About 26 lectures.
Mathematical background: basic definitions, subgroups, cosets, conjugacy classes, maps, homorphisms and isomorphisms, product groups.
Representation theory: irreducible representations, character tables, Schur's lemmas and the orthogonality theorem.
Lie groups and Lie algebras: rotation groups, continuous groups, representations of Lie algebras.
Physical applications: matrix representation of classical differential equation problems and their symmetry, matrix representation of quantum mechanical problems and their symmetries, symmetry definition and implications for eigenstates and eigenvalues of matrices.

PT.3.3 Dynamical systems and chaos

DR F.H. BERKSHIRE (DEPARTMENT OF MATHEMATICS)
About 26 lectures.
Phase plane dynamics: critical points in the phase plane and their character. Examples: free and damped oscillators, non-linear pendula, prey-predator models of competing species, models of disease. Richardson's theory of war. Simple extensions to three-dimensional phase space and beyond—rotation of rigid bodies, the Lorenz system.
Discrete dynamics: deterministic systems modelled by one-dimensional and two-dimensional maps. Fixed points and stability; period doubling; fractal dimension. Chaos, strange attractors and the breakdown of predictability. Examples: from population dynamics (e.g. the logistic map), the Ikeda map from optics, the Hénon map.
Mechanics: calculus of variations (brief). Hamilton's principle leading to Lagrange's equations. Normal modes. Hamiltonian formulation and equations; constants of the motion and symmetries; Noether's theorem. Integrable and non-integrable systems. Canonical transformations. Liouville's theorem. Action/angle variables. Poincaré return maps; breakdown of order leading to chaos (brief).
Examples: Kepler problem, Hénon-Heiles system (from astronomy), accelerator dynamics, billiards, dice and tops.

PT.3.4 Statistical mechanics

DR K. CHRISTENSEN
About 26 lectures.
Cooperative phenomena in disordered and equilibrium systems. Fractals. Phase transitions, scaling and universality. Scaling arguments as applied to systems at phase transition. Derivation of scaling relations. Real space renormalisation transformation and relationship with scale invariance. Implementation of Landau theory to equilibrium systems at, or close to, a critical point. Self-organisation in non-equilibrium systems. Self-organised criticality. Scaling in disordered and equilibrium systems at a phase transition and in non-equilibrium systems displaying self-organised criticality.

PT.3.5 Computational physics

DR U. EGEDE
About 33 hours' lectures, practicals and projects.
Numerical solutions to ordinary and partial differential equations applied to physics problems (e.g. in mechanics, electromagnetism, quantum mechanics). Accuracy and stability of the relevant numerical methods; matrix methods for solving systems of differential equations.
Random number generation: Optimisation of parameters from experimental data (high energy physics); Monte Carlo for simulating particle dynamics; time series analysis using Fourier transforms.

Two projects that use the theoretically developed methods have to be completed. For the long project there is the possibility to choose between several projects or you can propose your own.

PT.4.1 Advanced particle physics

DR C. FOUDAS
About 26 lectures.
Basic concepts: quarks, leptons and boson propagators, Feynman diagrams, quantum numbers, charge, colour. weak charge, flavour, symmetries and conservation laws. Dirac equation. Gauge theories; local U(1) invariance, QED Lagrangian; non-Abelian gauge theories. QCD; Lagrangian, gluons, hadron jets.
Electroweak interactions: parity violation, charged and neutral weak currents, Weinberg angle, spontaneous symmetry breaking, Higgs bosons, standard model Lagrangian; radiative corrections and the top quark; particle oscillations. CP violation.
Beyond the standard model: neutrino oscillations, SUSY, dark matter, GUT.
Typical topics for advanced study: radiative corrections and tests of the standard model. Present and future attempts to discover the Higgs. Measuring CP violation in the B system. Neutrino mass and oscillations. Searches for dark matter.

PT.4.2 General relativity

PROFESSOR R. RIVERS
About 26 lectures.
Introduction: what is general relativity? Gravitational and inertial mass. Eötvös experiment. The equivalence principle. Bending of light rays by massive bodies. Gravitational redshift. Cartesian tensors: index and summation conventions. Vectors and tensors. Alternating tensor. Div, grad and curl. Special relativity: Lorentz transformations. Tensor analysis in Minkowski spacetime. Relativistic particle mechanics.
Curved surfaces: general ideas. Manifolds as the correct expression of the equivalence principle. Tensor analysis on general manifolds. Vectors. Covectors. Tensors. Metric tensor. Raising and lowering operations. General operations on tensors. Geodesics. Christoffel connection. Geodesic equation and its Newtonian limit.
The Schwarzschild spacetime: geodesics of the Schwarzschild metric. Comparison with Newtonian orbits. Perihelion precession. Bending of light rays. Gravitational time dilation. Black holes. Curvature tensors, Einstein equations: covariant derivatives of vectors, tensors. Curvature tensors. Riemann tensor and its properties. Absolute derivative and parallel transport. Ricci tensor. The vacuum Einstein equations. Recovery of Newtonian gravity in the weak field limit. Einstein equations with matter, cosmology: energy momentum tensor. Ricci scalar, Einstein tensor. Basic observational facts about cosmology. Robertson-Walker metric. Friedmann equation. Time-dependence of the cosmic scale parameter. Cosmological constant.

PT4.4 Quantum field theory

PROFESSOR J. GAUNTLETT
About 26 lectures.
The need for relativistic quantum mechanics. Lagrangian and Hamiltonian classical mechanics. The Klein-Gordon equation and its action principle formulation. Second quantisation. The Dirac equation and the concept of spin and antiparticle. Second quantisation of the Dirac field. The electromagnetic field. Interactions and Feynman diagrams.

PT.4.5 Quantum theory of matter

DR D. LEE
About 26 lectures.
Superfluids and superconductors
Overview: broken symmetry in condensed matter physics; examples—BEC, superfluids, superconductors, magnetism; macroscopic quantum effects—SQUIDs; new materials—cuprate superconductors.
Second quantisation: quantisation of normal modes—from waves to particles; creation and annihilation operators.
Bose-Einstein condensation: ideal Bose gas; condensate fraction; ideal Bose gas in harmonic trap—ultracold atoms.

Quantum Bose fluids: liquid helium (^4He); Hamiltonian for interacting bosons (field operators; number-phase representation for the Hamiltonian; connection to hydrodynamics—Bernouilli, incompressible flow; topological excitations—vortex quantisation; vortex lattice.
Excitations in a Bose fluid: phonons in a quantum fluid—derivation from number-phase representation (Bogoliubov); superfluidity—Landau criterion, critical velocity, Goldstone's theorem; quantum fluctuations—number-phase uncertainty.
Superconductors—macroscopic quantum effects: phenomenology of condensate phase—London equations and Ginzburg-Landau theory; Meissner effect—penetration depth (Higgs mechanism); hidden order—phase coherence and the Josephson effect; type II superconductors—flux quantisation; Abrikosov flux lattice—flux flow and dissipation.
Superconductors—microscopics: fermions—creation and annihilation operators; Cooper pairing—Fermi sea on the edge of an instability; Bardeen-Cooper-Schrieffer (BCS) trial wavefunction; BCS Hamiltonian—energy gap, excitations
Pairing symmetry and condensate spin

PT.4.6 Unification

DR T EVANS
About 26 lectures.
Review of relevant aspects of group theory and particle physics.
Outline of relevants parts of field theory.
Global symmetries, how a typical QFT (quantum field theory) Lagrangian behaves under transformation, and derivation of the form of the conserved Noether's current.
Symmetry breaking of a global symmetry in QFT, proving Goldstone's theorem.
Local or gauge symmetry and link to massless gauge boson particles.
Symmetry breaking of gauge theories, use of unitary guage to show gauge bosons acquire mass in this context.
Fermions: review of some aspects covered in more depth in the QFT course. Existence and properties of chiral fermions, writing down a Lagrangian for them.
Standard model of particle physics using all the tools developed so far.
The gauge boson, Higgs and lepton sectors of the electro-weak mode and their contributions to the electro-weak Lagrangian, related to the fundamental observed properties of weak and electromagnetic forces.
Quarks in both QCD theory and in the electro-weak model.
How to deduce a suitable action given the mass spectrum and charges of some particles, and vice versa.
Examples from models with the following symmetries: SO(2), SO(3), U(1), SU(2) and simple products of these groups, using their one, two or three-dimensional matrix representations; SO(N) or SU(N) using their trivial or fundamental representations.

BSc Physics with Studies in Musical Performance—music courses

Assessed by Royal College of Music staff and based on the BMus degree programme. The repertoire experience of students is monitored by Imperial's Director of Music and the RCM to ensure that the experience gained is appropriate to the course.

FIRST YEAR

P.Mus.1	Music 1	Principal instrument

SECOND YEAR

P.Mus.2.1	Music 2.1	Principal instrument
P.Mus.2.2	Music 2.2	Aural training
P.Mus.2.3	Music 2.3	Stylistic studies
P.Mus.2.4	Music 2.4	Historical studies

THIRD YEAR

P.Mus.3.1	Music 2.1	Principal instrument
P.Mus.3.2	Music 2.2	Practical studies
P.Mus.2.3	Music 2.3	Stylistic studies
P.Mus.2.4	Music 2.4	Historical studies

FOURTH YEAR

PMus.4.1		Principal instrument

Examinations

	Date
FIRST YEAR	
Mechanics and relativity	April
Mathematics I	"
Electricity and magnetism	June
Vibrations and waves and quantum physics	"
Mathematical analysis	"
SECOND YEAR	
Quantum mechanics	June
Electromagnetism, optics	"
Mathematics, statistics of measurement	"
Thermodynamics, statistical physics	"
Electrons in solids, applications of quantum mechanics	"
Optional courses	"
THIRD AND FOURTH YEARS	
Comprehensive paper I	May
Comprehensive paper II	"
Core, theory, and standard option courses	"

Courses for students in other departments

Vibrations and waves

DR I. LIUBARSKY
About 20 lectures.
Simple harmonic motion. Oscillatory motion with resistive forces. Forced oscillations resonance. One dimensional treatment of waves. Differential form of the wave equation. Velocity of waves in strings, rods and gases. Group velocity. Standing waves. Optical interference and diffraction. Elementary consideration of diffraction of X-rays and electrons by crystalline materials.

Electricity and magnetism

DR Z. NAJMUDIN
About 20 lectures.
Electrostatics: electric charge, Coulomb’s law; electric field, Gauss’ law; electric potential; capacitors; dipoles; dielectrics.
Currents: electric currents; conductors; charge dissipation; DC circuit analysis.
Magnetism: magnetic fields; Biot-Savart’s law; Ampère’s law; motion of charge in a magnetic field; magnetic dipole moment; magnetic materials.
Electromagnetism: displacement current; electromagnetic induction.

Nuclear physics

DR Y. UCHIDA
About 10 lectures.
The nucleus: elementary particles; composition of nuclei; size; binding energy; the semi-empirical mass formula; mass; the N-Z chart; the shell model.
Radiative decays: nuclear stability; radiation types, detection and measurement; half lives; decay chains; dosimetry.
Nuclear reactions: fission, fusion, reactors, the sun
Applications: medical; analysis; diagnostics; tracework; age measurements.