

**IOP** Institute of Physics

# The Physics Degree

**Graduate Skills Base and the Core of Physics**

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## THE PHYSICS DEGREE

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This document details the skills and achievements that graduates of accredited degree programmes should have. The Institute appreciates that there is a wide range of honours degrees including single, dual and joint degrees; this document only relates to the physics component of each degree. This document should be read in conjunction with the QAA benchmark statement for Physics, astronomy and astrophysics<sup>1</sup>, aspects of which have been adapted for this document. The Institute considers the benchmark statement as definitive and expects that all accredited degree programmes will comply with it.

- 1 Degree programmes should provide a positive experience of physics and should encourage the student to foster and maintain an intellectual curiosity in the discipline.
- 2 All degree programmes including joint and combined honours must impart a secure knowledge of the fundamental elements of physics as expressed by the **Core of Physics**. However, the Institute expects that programmes will be taught to a considerably richer curriculum than the *Core of Physics* and will include advanced material reflecting the specialist interests of the department.
- 3 All programmes should enable students to acquire the skills listed in the **Graduate Skills Base**. These skills consist of both physics skills and transferable skills.
- 4 BSc degree programmes must incorporate either project work or a dissertation; integrated Masters programmes must incorporate extended project work. Project objectives are discussed in the section **Project Work**.

<sup>1</sup> <http://www.qaa.ac.uk/en/Publications/documents/Subject-benchmark-statement-Physics-astronomy-and-astrophysics.pdf>

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## GRADUATE SKILLS BASE

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### A. PHYSICS SKILLS

Students should learn:

***How to tackle problems in physics and formulate an appropriate solution.***

For example, they should learn how to identify the appropriate physical principles; how to use special and limiting cases, dimensional analysis and order-of-magnitude estimates to guide their thinking about a problem; and how to present the solution making their assumptions explicit.

***How to use mathematics to describe the physical world.***

They should know how to turn a physics problem into a mathematical form and have an understanding of mathematical modelling and of the role of approximation.

***How to plan, execute and report the results of an experiment or investigation.***

All graduates of an accredited degree programme should have some appreciation of physics as an experimental science. They should have an understanding of the elements of experiment and observation and should therefore be able to

- plan an experimental investigation;
- use apparatus to acquire experimental data;
- analyse data using appropriate techniques;
- determine and interpret the measurement uncertainties (both systematic and random) in a measurement or observation;
- report the results of an investigation and
- understand how regulatory issues such as health and safety influence scientific experimentation and observation.

As guidance, the Institute recommends a minimum of 30 CATS or 15 ETCS credits of experimental work be contained within a non-theoretical physics degree. This does not include final year project work.

For many degree programmes, experimental work in a conventional laboratory course will be a vital and challenging part and will provide students with the skills necessary to plan an investigation and collect and analyse data. However, for some theoretical or mathematical physics programmes, these required skills could be acquired through computer simulation, paper exercises with appropriate data, or case studies using real experimental data from a published source. Other methods may be used provided they meet the above objectives.

***How to compare results critically with predictions from theory.***

Students should understand the concept of using data to test a hypothesis and be able to assess the reliability of data, to understand the significance of results, and to relate results from numerical modelling or experiment to the relevant theory.

## **B. TRANSFERABLE SKILLS**

A Physics degree should enhance:

### *Problem-solving skills*

Physics degree programmes involve students in solving physics problems with well-defined solutions. They should also gain experience in tackling open-ended problems. Students should develop their ability to formulate problems in precise terms and to identify key issues. They should develop the confidence to try different approaches in order to make progress on challenging problems.

### *Investigative Skills*

Students should have opportunities to develop their skills of independent investigation. They should develop the ability to find information by using textbooks and other available literature, by searching databases and the Internet, and through discussions with colleagues.

### *Communications skills*

A physics degree should develop students' ability to communicate complex information effectively and concisely by means of written documents, presentations or discussion. Students should be able to use technical language appropriately.

### *Analytical skills*

Students should develop their ability to grasp complex concepts, to understand and interpret data precisely and to construct logical arguments. They should be able to distil a problem to its basic elements.

### *IT skills*

Students should become familiar with appropriate software such as programming languages and packages. They should develop their computing and IT skills in a variety of areas including the preparation of documents, information searches, numerical calculations, and the manipulation and presentation of data.

### *Personal skills*

Students should develop their ability to work independently, to use their initiative and to organise themselves to meet deadlines. They should gain experience of group work and be able to interact constructively with other people.

### *Ethical behaviour*

Students should gain an appreciation of what constitutes unethical scientific behaviour. They should be required to demonstrate high ethical standards throughout their degree programme.

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## PROJECT WORK

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- 1 BSc degree programmes must incorporate either a project or dissertation in the final year. Students should not be able to graduate without having carried out a project or dissertation. Integrated Masters programmes must incorporate extended project work as a substantial part of the final year. Additional requirements for integrated Masters degrees are detailed on the next page.
- 2 Final year project work may be undertaken individually, in pairs or in groups but degree programmes should allow students to experience both individual and group project work.
- 3 Projects may be experimental, observational, computational or theoretical depending on the topic and the available facilities.
- 4 The objectives of such project work will include most of the following:
  - investigation of a physics-based or physics-related problem
  - planning, management and operation of an investigation to test a hypothesis
  - development of information retrieval skills
  - carrying out a health and safety assessment
  - establishment of co-operative working practices with colleagues
  - design, assembly and testing of equipment or software
  - generation and informed analysis of data and a critical assessment of experimental (or other) uncertainties
  - formulation of appropriate conclusions and a critical comparison with relevant theory
  - production of a final written report
  - presentation and defence of the results of the project

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## INTEGRATED MASTERS

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All integrated Masters degrees submitted for accreditation are expected to meet the requirements detailed below.

- 1 Integrated Masters degree programmes must comply with the benchmark statement and therefore the standards detailed in section 6 of the benchmark statement.
- 2 Mathematical requirements must go beyond the minimum detailed in *the Core of Physics*.
- 3 Integrated Masters programmes should ideally contain the equivalent of one full academic year's work (120 CATS or 60 ECTS credits) at M-level in accordance with qualifications frameworks<sup>2,3</sup> a bare minimum would be 90 CATS or 45 ECTS credits
- 4 At least 60 CATS or 30 ECTS M-level credits should be demonstrably physics or physics-based.
- 5 The project component must be at M-Level and should be at least 30 CATS or 15 ECTS credits and must be passed.

Credit levels given assume that a full academic year constitutes 120 CATS or 60 ECTS credits and equivalent volumes of learning should be demonstrated if a different credit system is used.

<sup>2</sup> <http://www.qaa.ac.uk/en/Publications/Documents/Framework-Higher-Education-Qualifications-08.pdf>

<sup>3</sup> <http://www.qaa.ac.uk/en/Publications/Documents/FQHEIS-June-2014.pdf>

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## CORE OF PHYSICS

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- 1 All accredited physics degree programmes, including joint and combined honours, must impart a secure knowledge of the fundamental elements of physics as expressed by the **Core of Physics**. However, the Institute expects that programmes will be taught to a considerably richer curriculum than that indicated here and will include advanced material reflecting the specialist interests of the department.
- 2 The *Core of Physics* contains a set of headings under which appear topics that should be covered in an accredited physics degree. As such, it should not be read as a syllabus and a traditional arrangement of the curriculum is not a requirement, nor is a traditional teaching approach. It is more appropriate to read the *Core of Physics* as a set of key concepts that should be familiar to a graduate of an accredited degree programme. This particular arrangement of the material is given as one possible example.
- 3 The content of the "Core of Physics" is intended to represent the crucial physics knowledge and techniques that every graduate is expected to have understood by the end of their course. As such, it is generally expected that every listed topic is covered at some point. Exceptionally, there may be a small number of topics that are absent from the curriculum in some institutions for sound educational reasons. In these cases, departments should identify the missing topics in the accreditation application and state where in the curriculum other topics are introduced that present equivalent examples or applications of the same physical principles.
- 4 Physics is a quantitative discipline and requires proficiency in mathematics in order to understand and apply key physical principles. The *Core of Physics* therefore starts with a statement of the mathematical knowledge and techniques with which students must be familiar in order to master the physics at an appropriate level. This does not imply that the mathematics must be taught in dedicated modules, but the physics topics should be taught at a mathematical level indicated by the content of this section.
- 5 A degree eligible for accreditation should have engendered a familiarity with the *Core of Physics*, to include an appreciation of the limitation of the physical theories, to be able to apply the fundamental principles to particular areas and to include some awareness of how they have developed over time.
- 6 Physics is a hierarchical discipline, therefore, before some of the topics identified below can be treated in adequate depth certain prerequisite material must also be covered. The phrase "to the level of" should therefore be taken to imply that additional intermediate topics are required in order to reach the level of the listed topics.

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## CORE OF PHYSICS

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### Mathematics for Physicists

- Trigonometric and hyperbolic functions; complex numbers
- Series expansions, limits and convergence
- Calculus to the level of multiple integrals; solution of linear ordinary and partial differential equations
- Three-dimensional trigonometry
- Vectors to the level of div, grad and curl; divergence theorem and Stokes' theorem
- Matrices to the level of eigenvalues and eigenvectors
- Fourier series and transforms including the convolution theorem
- Probability distributions

### Mechanics and Relativity

Classical mechanics to include:

- Newton's laws and conservation laws including rotation
- Newtonian gravitation to the level of Kepler's laws

Special relativity to the level of:

- Lorentz transformations and the energy-momentum relationship

### Quantum Physics

Background to quantum mechanics to include:

- Black body radiation
- Photoelectric effect
- Wave-particle duality
- Heisenberg's Uncertainty Principle

Schrödinger wave equation to include:

- Wave function and its interpretation
- Standard solutions and quantum numbers to the level of the hydrogen atom
- Tunnelling
- First order time independent perturbation theory

Atomic, nuclear and particle physics to include:

- Quantum structure and spectra of simple atoms
- Nuclear masses and binding energies
- Radioactive decay, fission and fusion
- Pauli exclusion principle, fermions and bosons and elementary particles
- Fundamental forces and the Standard Model

## Condensed Matter Physics

- Mechanical properties of matter to include elasticity and thermal expansion
- Inter-atomic forces and bonding
- Phonons and heat capacity
- Crystal structure and Bragg scattering
- Electron theory of solids to the level of simple band structure
- Semiconductors and doping
- Magnetic properties of matter

## Oscillations and Waves

- Free, damped, forced and coupled oscillations to include resonance and normal modes
- Waves in linear media to the level of group velocity
- Waves on strings, sound waves and electromagnetic waves
- Doppler effect

## Electromagnetism

- Electrostatics and magnetostatics
- DC and AC circuit analysis to the level of complex impedance, transients and resonance
- Gauss, Faraday, Ampère, Lenz and Lorentz laws to the level of their vector expression
- Maxwell's equations and plane electromagnetic wave solution; Poynting vector
- Electromagnetic spectrum
- Polarisation of waves and behaviour at plane interfaces

## Optics

- Geometrical optics to the level of simple optical systems
- Interference and diffraction at single and multiple apertures
- Dispersion by prisms and diffraction gratings
- Optical cavities and laser action

## Thermodynamics and Statistical Physics

Zeroth, first and second laws of thermodynamics to include:

- Temperature scales, work, internal energy and heat capacity
- Entropy, free energies and the Carnot Cycle
- Changes of state

Statistical mechanics to include:

- Kinetic theory of gases and the gas laws to the level of Van der Waals equation
- Statistical basis of entropy
- Maxwell-Boltzmann distribution
- Bose-Einstein and Fermi-Dirac distributions
- Density of states and partition function

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