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Subject Benchmark Statement

Physics, Astronomy and Astrophysics

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Contents

How can I use this document?

This is the Subject Benchmark Statement for Physics, Astronomy and Astrophysics. It defines the academic standards that can be expected of a graduate, in terms of what they might know, do and understand at the end of their studies, and describes the nature of the subject.

The UK Quality Code for Higher Education (Quality Code) sets out the Expectations and Core practices that all providers of UK higher education are required to meet. Providers in Scotland, Wales and Northern Ireland must also meet the Common practices in the Quality Code.

The Quality Assurance Agency for Higher Education (QAA) has also published a set of Advice and Guidance, divided into 12 themes, and a number of other resources that support the mandatory part of the Quality Code. Subject Benchmark Statements sit alongside these resources to help providers develop courses and refine curricula but are not part of the regulated requirements for higher education providers in the UK.

This Statement is intended to support you if you are:

- involved in the design, delivery and review of courses of study in physics, astronomy and astrophysics or related subjects
- a prospective student thinking about studying this subject, or a current student of the subject, to find out what may be involved
- an employer, to find out about the knowledge and skills generally expected of a graduate in this subject.

Subject Benchmark Statements provide general guidance for articulating the learning outcomes associated with the course but are not intended to represent a national curriculum in a subject or to prescribe set approaches to teaching, learning or assessment. Instead, they allow for flexibility and innovation in course design within a framework agreed by the subject community.

It may be helpful to refer to relevant Advice and Guidance when using this Statement.

Explanations of unfamiliar terms used in this Subject Benchmark Statement can be found in QAA's Glossary.

About the Statement

This Subject Benchmark Statement refers to bachelor's degrees with honours in physics, astronomy and astrophysics and integrated master's degrees in physics, designated Master of Physics (MPhys) and Master of Natural Science (MSci), and Bachelor of Science (BSc) degrees.[1]

It has been produced by a group of subject specialists drawn from, and acting on behalf of, the subject community. The process is facilitated by QAA, as is the full consultation with the wider academic community and stakeholder groups each Statement goes through.

In order to ensure the continuing currency of Subject Benchmark Statements, QAA initiates regular reviews of their content, five years after first publication, and every seven years subsequently, or in response to significant changes in the discipline.

Relationship to legislation

Higher education providers are responsible for meeting the requirements of legislation and any other regulatory requirements placed upon them, for example by funding bodies. This Statement does not interpret legislation, nor does it incorporate statutory or regulatory requirements. The responsibility for academic standards remains with the higher education provider who awards the degree.

Higher education providers may need to consider other reference points in addition to this Statement in designing, delivering and reviewing courses. These may include requirements set out by professional, statutory and regulatory bodies (PSRBs), and industry or employer expectations.

Sources of information about other requirements and examples of guidance and good practice are signposted within the Subject Benchmark Statement where appropriate. Individual higher education providers will decide how they use this information.

Summary of changes from the previous Subject Benchmark Statement (2017)

This version of the Statement forms its fourth edition, following initial publication of the Subject Benchmark Statement in 2002 and review and revision in 2008 and 2017.

This latest version of the Statement is the consequence of the revision to the UK Quality Code for Higher Education which was published in 2018. It has been revised to update references to the Quality Code and other minor changes within the sector. Changes have been made by QAA and confirmed by a member of the most recent review group.

There have been no revisions to the subject-specific content of the statement.

[1] Bachelor's degrees are at level 6 (Master's at level 7) in *The Framework for Higher Education Qualifications in England, Wales and Northern Ireland* and level 10 (Master's at level 11) in *The Framework for Qualifications of Higher Education Institutions in Scotland*, as published in The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies

1 Introduction

1.1 This Subject Benchmark Statement characterises the skills and achievements that graduates of physics-based degrees have. There is a wide range of such degrees, reflecting the varying aspects of the discipline. These include single honours degrees in physics, theoretical physics, applied physics, astrophysics and astronomy. There are also joint and dual honours degrees in physics where it is expected that graduates should meet the standards in this Statement.

1.2 Throughout this Statement references to physics should be considered as encompassing astronomy and astrophysics courses, unless otherwise stated.

1.3 Physics is a major subject in the UK higher education system producing highly employable graduates who play an important role in the UK economy. Physics is, however, not simply a discipline for the training of scientific personnel, but is at the core of our intellectual understanding of all aspects of nature and is the foundation of many of the sciences.

1.4 Degrees designated as Master of Physics (MPhys) and Master of Natural Science or Master in Science (MSci) are included in this Statement. An integrated master's degree is awarded after an extended course of study which allows students to study physics to a greater depth than is possible on a bachelor's course and to extend the opportunities to develop their generic skills and undertake project work. These master's degrees provide a coherent and broad-based education in physics. They are to be distinguished from Master of Science (MSc) courses in physics, which are self-contained courses, normally involving one or two years of postgraduate study in a specialist area. MSc courses are not covered by this Statement.

1.5 Physics is a demanding discipline. A deep understanding of the frontiers of physics often requires advanced knowledge, which cannot necessarily be acquired during a bachelor's or master's degree course. This Statement has taken this into account in interpreting the generic statements of The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies honours and master's level degree courses.

1.6 Physics degrees will continue to evolve in response to developments in the subject and to reflect changes in the school curriculum. This Statement, therefore, concentrates on general graduate outcomes and does not specify a core physics curriculum. The Institute of Physics can be consulted for guidance on possible curriculum content.

2 Nature and extent of physics, astronomy and astrophysics

2.1 Physics is concerned with the observation, understanding and prediction of natural phenomena and the behaviour of fabricated systems. It deals with profound questions about the nature of the universe and with some of the most important practical, environmental and technological issues of our time. Its scope is broad and involves mathematics and theory, experiments and observations, computing and technology. Ideas and techniques from physics also drive developments in related disciplines, including chemistry, computing, engineering, materials science, mathematics, medicine, biophysics and the life sciences, meteorology, environmental science, and statistics.

2.2 Physics is a continually evolving discipline that has theoretical, computational and experimental aspects; many physicists span these categories. It is characterised by the idea that systems can be understood by identifying a few key quantities, such as energy and momentum, and the universal principles that govern them. Part of the appeal of the subject is that there are relatively few such principles and that these apply throughout science and not just in physics. The laws of mechanics are a good example; deduced by Newton after studying observations of planetary motion, they govern systems familiar from everyday life as well as many of the phenomena observed in the movement of stars and galaxies.

2.3 In order to make quantitative predictions, physics uses theoretical models usually expressed in mathematical terms and often involving approximations. The types of approximation used to find satisfactory models of experimental observations turn out to be very similar whether the underlying laws are those of classical physics, statistical mechanics or quantum theory. Typically, an idealised model of some phenomenon is established, the equations for the model are solved (often with further approximations) and the results related back to what is observed experimentally. Sometimes a model turns out to be appropriate in very different circumstances. For example, the degenerate Fermi gas model describes the behaviour of electrons in a metal and in a white dwarf star.

2.4 Physicists use mathematics to formulate theories, to make predictions and to construct models. A computational approach may be valuable where theoretical or experimental approaches are currently impossible or hard to achieve, for example in the study of emergent phenomena or simulation of the microscopic behaviour of systems. It can also be valuable in the analysis of large scale datasets.

2.5 Physics is an empirical science. The skills and methods used to make measurements are an integral part of physics and the final test of the validity of any theory is whether it agrees with experiment. Many important discoveries are made as the result of the development of some new experimental technique. For example, the techniques developed to liquefy helium subsequently led to the totally unexpected discovery of superconductivity, superfluidity and the whole field of low temperature physics. Instruments developed originally in physics can find applications in other branches of science. The synchrotron radiation emitted by electrons in accelerators, which were originally designed to study elementary particles, is now used to study the properties of materials in engineering, biology and medicine.

2.6 Progress in physics requires imagination and creativity. It is often the result of collaboration between physicists with different backgrounds and can involve the exchange of ideas and techniques with people from outside the discipline.

2.7 Studying physics brings benefits that last a lifetime and knowledge and skills that are valuable outside physics. Such benefits include a practical approach to problem-solving, often using mathematical formulation and solution, the ability to reason clearly and to communicate complex ideas, familiarity with information and communication technologies (ICT), ability to judge statistical presentation of results, acquisition of self-study skills, and the pleasure and satisfaction that comes from being able to understand the latest discoveries in science. After graduation, physicists work in a wide variety of employment, including research and development in industry and academia, education, medicine, business and finance, and government and public service, where they are sought for their pragmatic and analytical approaches to the solution of problems.

3 Subject-specific knowledge and understanding

3.1 Bachelor's degrees with honours in physics include the more general and fundamental topics of physics alongside a selection of more advanced topics. They also develop investigative, experimental, mathematical, computational, modelling and other generic skills. Degree courses vary in the emphasis given to different areas of physics. For example, theoretical physics courses generally include more mathematical and computational skills, usually replacing much or possibly all conventional laboratory work. Applied physics courses often have a technological focus. Some degree courses offer placements in schools, higher education provider research groups or industry. Joint and dual honours courses vary in the amount and extent of physics content, depending on the precise definition and title of the course in question, but still cover the fundamental topics of physics. In addition to this, integrated master's degree courses provide a greater depth of knowledge that is informed by current research, further development of subject-specific skills and enhanced project work.

3.2 Honours degree physics courses cater for students planning to move on to research (in industry or academia), as well as for students looking for a broad-based physics education which will make them numerate, articulate and eminently employable. The fundamentals, which all physics degrees cover to some extent, include electromagnetism, quantum and classical mechanics, statistical physics and thermodynamics, wave phenomena and the properties of matter.

3.3 Students also study the application of the fundamental principles to particular areas. These may include (but need not be limited to) atomic physics, environmental physics, fluids, hard and soft condensed matter, materials, medical physics, nuclear and particle physics, optics, and plasmas, as well as the application of physics to other disciplines.

3.4 Astrophysics and astronomy courses generally include (but need not be limited to) the application of physical principles to cosmology; the structure, formation and evolution of stars and galaxies, planetary systems, and high-energy phenomena in the universe.

3.5 All physics-related degrees equip students with skills that will enable them to develop expertise in applying physics to unfamiliar areas that they may encounter post-graduation. In addition, courses expose students to recent research in order to develop some qualitative understanding of current developments at the frontiers of the subject.

3.6 Mathematics is an essential part of a physics degree and students learn that physics is a quantitative subject. Students gain sufficient mathematical skills to enable modelling of the physical world, solving problems and working with probabilities and statistics.

3.7 Physics courses give students experience of the practical nature of physics. They provide students with the skills necessary to plan investigations, analyse data, including estimation of inherent uncertainties and appreciation of limitations. Graduates in physics have some appreciation of natural phenomena in an experimental context. Except for non-experimental physics degrees where the skills identified here are gained in other ways clearly specified by the provider, practical work is thus a vital and challenging part of a physics degree. Students also become proficient in presenting experimental results or theoretical conclusions, and in the communication of complex data and ideas.

3.8 Open-ended project work is used to facilitate and stimulate the development of students' skills in research and planning (for example, by use of databases and published literature) and their ability to assess critically the link between theoretical results and experimental observation.

Subject-based skills, generic skills and attributes

3.9 Bachelor's and integrated master's degrees in physics provide the opportunity for students to acquire and demonstrate a wide range of competences in both subject-specific and generic skills, of which the following are particularly relevant.

Physics skills

3.10 Physics skills include the ability to:

- i formulate and tackle problems in physics. For example, students learn how to identify the appropriate physical principles, how and when to use special and limiting cases and order-of-magnitude estimates to guide their thinking about a problem and how to present the solution, making their assumptions and approximations explicit
- ii use mathematics to describe the physical world. Students gain an appreciation of mathematical modelling, computing, and of the role of approximation
- iii plan, execute and report the results of an experiment or investigation
- iv use appropriate methods to analyse data, to evaluate the level of its uncertainty and to take this into account in the development of work and to relate any conclusion made to current theories of the physics involved
- v use appropriate software such as programming languages and purpose-written packages
- vi compare critically the results of theoretical and computational modelling with those from experiment and observation.

Generic skills

3.11 Generic skills include:

- i problem-solving skills - physics degree courses require students to solve problems with well-defined solutions. They also allow students to gain experience in tackling open-ended problems that may cross subject boundaries. Courses allow students to demonstrate their ability to formulate problems in precise terms and to identify key issues. They enable students to develop the confidence and creativity to try different approaches in order to make progress on challenging problems
- ii investigative skills - physics degrees provide students with the opportunity to develop their skills of independent investigation. Students gain experience of using textbooks, and other available literature, of searching databases and the internet, and of interacting with colleagues to derive important information
- iii communication skills - physics, and the mathematics used in physics, deal with surprising ideas and difficult concepts; good communication is essential. Physics degrees allow students to demonstrate their ability to listen carefully, to read demanding texts, and to present complex information in a clear and concise manner to a range of different audiences
- iv analytical skills - physics degrees help students learn the need to pay attention to detail and to demonstrate their ability to manipulate precise and intricate ideas, to construct logical arguments and to use technical language correctly
- v ICT skills - physics degrees provide the opportunity for students to acquire these skills in a variety of ways
- vi personal skills - physics degrees allow students to demonstrate their ability to work both independently and in a group. Independently they are able to use their initiative, be organised and meet deadlines. In a group they are able to interact constructively as part of a team.

Professional behaviour

3.12 Physics degrees allow students to develop:

i an appreciation that to fabricate, falsify or misrepresent data or to commit plagiarism constitutes unethical scientific behaviour. A professional physicist is objective, unbiased and truthful in all aspects of their work and recognises the limits of their knowledge

ii the ability to identify the potential ethical issues in their work

iii where appropriate, an appreciation of intellectual property, environmental and sustainability issues

iv an understanding of what constitutes a safe working environment.

4 Teaching, learning and assessment

4.1 Physics is a hierarchical discipline that lends itself to systematic exposition and the ordered and structured acquisition of knowledge. It is also an empirical subject. Practical skills, including an appreciation of the link between theory and experiment, are developed. This leads to teaching methods that may include:

- lectures supported by problem classes and group tutorial work
- practical work
- the use of textbooks, electronic resources and other self-study materials
- open-ended project work, some of which may be team-based
- activities devoted to generic and subject-specific skills development
- placements/visits to industrial or other research facilities.

4.2 The balance between these may vary between providers, courses and modules, and will evolve with time due to advances in ICT and pedagogical thinking.

4.3 Approaches to skills development encompass both generic and subject-specific skills. It may well be most appropriate to develop both within the physics context. Development between levels of study may be evident; for example laboratory work may become open-ended with more demanding reporting criteria at the higher levels. Computer skills may include programming and the use of software packages for simulation, for computer algebra and for data analysis. Skills may also be developed in the use of computers for the control of experiments and the acquisition of data.

Assessment

4.4 A variety of assessment methods are appropriate within a physics course, some of which are more suitable to formative assessment. Evidence of the standards achieved could be obtained from many of the following:

- time-constrained examinations
- closed-book and open-book tests
- problem-based assignments
- laboratory books and reports
- observation of practical skills
- individual project reports (including placement or case-study reports)
- team project reports
- oral and/or poster presentations; possibly including seminar presentation
- viva voce interviews
- essays
- project artefacts such as computer programmes or electronic circuits
- electronic media such as videos or websites
- computerised adaptive testing
- peer and self-assessment.

4.5 Examination and test questions are graded to assess a student's understanding of concepts and the ability to develop mathematical models, complete calculations, solve new problems and communicate physical arguments. Time-constrained work has its place in testing the student's capacity to organise work, as well as to think and to communicate under pressure. Such assessments may be augmented by others, such as presentations and project reports, which may be more appropriate for assessing project planning and execution, research skills, application of ICT and report writing. This may also allow students to demonstrate what they can achieve with somewhat less severe time constraints.

4.6 The performance of an individual student may vary significantly between modules and the student's marks on some modules may not be commensurate with their overall performance. This is an inherent feature of the subject and reflects both its conceptual difficulty and the need to solve quantitative problems. In assessments that include significant amounts of problem-solving, frequently requiring extensive use of mathematics, marks often span the entire range (0-100 per cent). Students towards the lower end of the performance range may fail some modules while still meeting the overall learning outcomes of the course. Assessment regulations need to be flexible enough to take account of the variability, and providers need to allow examiners to judge the overall performance against the learning outcomes for the course.

5 Benchmark standards

Introduction

5.1 All graduates with honours degrees in physics have demonstrated that they have acquired knowledge, abilities and skills in the areas identified in the previous sections, but there will inevitably exist significant differences in their level of attainment. In particular, there will be differences between the level of attainment demonstrated by a typical bachelor's graduate and a typical integrated master's graduate.

5.2 This Statement provides threshold and typical standards for both bachelor's and integrated master's degrees. However, providers expect that students demonstrate a higher level of attainment in early years in order to continue onto the later stages of an integrated master's course. Therefore, providers expect all students progressing to the final years of an integrated master's degree to meet the typical level and only rarely will an integrated master's graduate have met the threshold level only.

5.3 In discussing the range of knowledge and levels of attainment in this Section, the topics to be covered are those outlined in Section 3.

Benchmark standards for honours degrees

Threshold level

5.4 A graduate who has reached the bachelor's degree with honours threshold level has demonstrated an ability to:

i comprehend basic physical laws and principles
ii identify and use relevant principles and laws when dealing with simple problems
iii execute and analyse the results of an experiment (if on an experimental course) or investigation. Such analysis will include the evaluation of the level of uncertainty in their results, a comparison of the results with expected outcomes, theoretical and computational models or published data and, hence, an assessment of their significance
iv safely use basic laboratory apparatus in an experimental procedure (if on an experimental course)
v competently use appropriate ICT software packages/systems for the analysis of data, simulation of physical systems and the retrieval of appropriate information
vi undertake numerical manipulation and to present and interpret information graphically
vii communicate scientific information, in particular through scientific reports
viii manage their own learning and to make use of appropriate texts and learning materials.

Typical level

5.5 A graduate who has reached the bachelor's degree with honours typical level has demonstrated the capabilities and skills of the threshold honours degree level in 5.4 and competence in:

i the application of physical principles to diverse areas of physics
ii the solution of problems in physics by selecting and using appropriate mathematical and physical techniques
iii making appropriate approximations when solving problems

iv critical analysis of the results of an experiment or investigation, evaluation of their significance and setting them in context
v the design and execution of effective experiments (if on an experimental course)
vi use of mathematical and computational techniques and analysis to model physical behaviour
vii clear and accurate communication of scientific information
viii management and use of research-based materials.

Benchmark standards for integrated master's degrees

Threshold level

5.6 The level of attainment required to progress on to the latter stages of an integrated master's degree means most graduates will have met the typical level capabilities described in paragraph 5.8, and few will graduate having only met the threshold level described in 5.7.

5.7 A graduate who has reached the integrated master's degree with honours threshold level has demonstrated the capabilities and skills of the typical BSc level and will have:

i a working knowledge of a variety of experimental, mathematical and/or computational techniques applicable to current research or applications in physics
ii undertaken an extended investigation and exhibited the competence to do so
iii encountered research-level material.

Typical level

5.8 A graduate who has reached the integrated master's degree with honours typical level has demonstrated the capabilities and skills of the integrated master's threshold level and an ability to:

i apply fundamental laws and principles to a variety of areas in physics, some of which are at (or are informed by) the forefront of the discipline
ii solve advanced research-informed problems in physics
iii interpret and contextualise mathematical descriptions of physical phenomena
iv demonstrate some originality during an extended investigation
v show the competent use of specialised equipment or research grade software or methods
vi master new techniques in a theoretical, computational or experimental context
vii communicate complex scientific ideas, the conclusions of an experiment, investigation or project concisely, accurately and informatively
viii plan and execute an open-ended extended research project
ix demonstrate an understanding of scientific research and propose realistic suggestions as to how it may progress further.

Appendix: Membership of the benchmarking and review groups for the Subject Benchmark Statement for Physics, Astronomy and Astrophysics

Membership of the review group for the Subject Benchmark Statement for Physics, Astronomy and Astrophysics (2019)

The fourth edition, published in 2019, was revised by QAA to align the content with the revised UK Quality Code for Higher Education, published in 2018. Proposed revisions were checked and verified by the Chair of the Subject Benchmark Statement for Physics, Astronomy and Astrophysics review group from 2017.

Professor Michael Edmunds	Cardiff University
Dr Alison Felce	QAA

Membership of the review group for the Subject Benchmark Statement for Physics, Astronomy and Astrophysics (2016)

Professor Michael Edmunds (Chair)	Cardiff University
Robyn Henriegel	Institute of Physics
Dr Mark Everitt	Loughborough University
Professor Alan Fitzsimmons	Queen's University, Belfast
Professor Robert Lambourne	The Open University
Dr David Sands	University of Hull

Student Reader
Karl Nordström

Employer
Science and Technology Facilities Council

QAA Officer

Simon Bullock	QAA

Membership of the review group for the Subject Benchmark Statement for Physics, Astronomy and Astrophysics (2008)

Details provided below are as published in the second edition of the Subject Benchmark Statement.

Dr Nick d'Ambrumenil	University of Warwick
Dr Richard Bacon	University of Surrey
Professor Susan Cooper	University of Oxford
Professor Michael Edmunds (Chair)	Cardiff University
Robyn Henriegel (Secretary)	Institute of Physics
Professor James Hough	University of Hertfordshire
Dr Robert Lambourne	The Open University
Professor Andrew Long	University of Glasgow
Professor Peter Main	Institute of Physics
Professor Richard Thompson	Imperial College London
Dr Alison Voice	University of Leeds

Membership of the original benchmark statement group for Physics, Astronomy and Astrophysics (2002)

Details below are as published in the original Subject Benchmark Statement for Physics, Astronomy and Astrophysics.

Dr Nick d'Ambrumenil	University of Warwick
Dr Craig Adam	Staffordshire University
Professor Mick Brown	University of Cambridge
Mr Philip Diamond (Secretary)	Institute of Physics
Professor Michael Edmunds	University of Wales, Cardiff
Professor Peter Main	University of Nottingham
Dr Tony Phillips	University of Manchester
Professor David Saxon	University of Glasgow
Dr Edward Slade (Chair)	University of Keele (until July 2001)
Dr Alison Voice	University of Leeds
Dr Robin Walker	University of Bristol
Dr Nicola Wilkin	University of Birmingham
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