Subject benchmark statement

Physics, astronomy and astrophysics

Draft for consultation September 2007

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Preface

Subject benchmark statements provide a means for the academic community to describe the nature and characteristics of programmes in a specific subject or subject area. They also represent general expectations about standards for the award of qualifications at a given level in terms of the attributes and capabilities that those possessing qualifications should have demonstrated.

This subject benchmark statement, together with others published concurrently, refers to the **bachelor's degree with honours**[1]. Standards for the integrated master's awards (MPhys and MSci) are also included in this subject benchmark statement.

Subject benchmark statements are used for a variety of purposes. Primarily, they are an important external source of reference for higher education institutions (HEIs) when new programmes are being designed and developed in a subject area. They provide general guidance for articulating the learning outcomes associated with the programme but are not a specification of a detailed curriculum in the subject.

Subject benchmark statements also provide support to HEIs in pursuit of internal quality assurance. They enable the learning outcomes specified for a particular programme to be reviewed and evaluated against agreed general expectations about standards. Subject benchmark statements allow for flexibility and innovation in programme design and can stimulate academic discussion and debate upon the content of new and existing programmes within an agreed overall framework. Their use in supporting programme design, delivery and review within HEIs is supportive of moves towards an emphasis on institutional responsibility for standards and quality.

Subject benchmark statements may also be of interest to prospective students and employers, seeking information about the nature and standards of awards in a given subject or subject area.

The relationship between the standards set out in this document and those produced by professional, statutory or regulatory bodies for individual disciplines will be a matter for individual HEIs to consider in detail.

This subject benchmark statement represents a revised version of the original published in 2002. The review process was overseen by the Quality Assurance Agency for Higher Education (QAA) as part of a periodic review of all subject benchmark statements published in this year. The review and subsequent revision of the subject benchmark statement was undertaken by a group of subject specialists drawn from and acting on behalf of the subject community. The revised subject benchmark statement went through a full consultation with the wider academic community and stakeholder groups.

QAA publishes and distributes this subject benchmark statement and other subject benchmark statements developed by similar subject-specific groups.

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[1] This is equivalent to the honours degree in the Scottish Credit and Qualifications Framework (level 10) and in the Credit and Qualifications Framework for Wales (level 6).

The Disability Equality Duty (DED) came into force on 4 December 2006[2]. The DED requires public authorities, including HEIs, to act proactively on disability equality issues. The Duty complements the individual rights focus of the *Disability Discrimination Act* (DDA) and is aimed at improving public services and outcomes for disabled people as a whole. Responsibility for making sure that such duty is met lies with HEIs.

The Disability Rights Commission (DRC) has published guidance[3] to help HEIs prepare for the implementation of the Duty and provided illustrative examples on how to take the duty forward. HEIs are encouraged to read this guidance when considering their approach to engaging with components of the Academic Infrastructure[4], of which subject benchmark statements are a part.

Additional information that may assist HEIs when engaging with subject benchmark statements can be found in the DRC revised *Code of Practice: Post-16 Education*[5], and also through the Equality Challenge Unit[6] which is established to promote equality and diversity in higher education.

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[2] In England, Scotland and Wales

[3] Copies of the guidance *Further and higher education institutions and the Disability Equality Duty*, guidance for principals, vice-chancellors, governing boards and senior managers working in further education colleges and HEIs in England, Scotland and Wales, may be obtained from the DRC at www.drc-gb.org/employers_and_service_provider/disability_equality_duty/sectoral_guidance/further_and_higher_education.aspx

[4] An explanation of the Academic Infrastructure, and the roles of subject benchmark statements within it, is available at www.qaa.ac.uk/academicinfrastructure

[5] Copies of the DRC revised *Code of Practice: Post-16 Education* may be obtained from the DRC at www.drc-gb.org/employers_and_service_provider/education/higher_education.aspx

[6] Equality Challenge Unit, www.ecu.ac.uk

Foreword

The subject benchmark statement for physics, astronomy and astrophysics was published by QAA in 2002. In 2007, following a wide consultation with the community, professional societies and The Higher Education Academy Physical Sciences Centre, QAA invited the Institute of Physics to convene a group of specialists to review the benchmark statement.

The initial consultation process indicated that the benchmark statement required only minor revision and this reflects the excellent work undertaken by the original benchmarking group. The review group shared this opinion and after full discussion of the comments received, produced this revised benchmark statement.

The intention of the original benchmarking team had been to produce a statement that was sufficiently descriptive but not prescriptive, and for that reason no core curriculum was included. The review group reconsidered this position but were in agreement that the original intention was sound and that there was no benefit in prescribing a more detailed curriculum. Changes that have been made are in the main to increase clarity and to keep the statement up to date with recent developments in higher education and advances in technology-based learning. One significant addition is in section four and refers to ethical behaviour.

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1 Introduction

1.1 This benchmark statement characterises the skills and achievements that graduates of physics-based degrees should 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. This statement also relates to the physics components of joint and dual honours degrees where physics forms a significant proportion. Throughout this statement references to physics should be considered as encompassing astronomy and astrophysics programmes, unless otherwise stated.

1.2 Physics is a major subject in the United Kingdom (UK) higher education system with over 10,000 full-time equivalent students registered on undergraduate higher education programmes. Physics graduates play a major 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.

1.3 In view of the wide availability and popularity of integrated master's degrees in physics, designated MPhys and MSci, and their close link with the BSc degree, these programmes are included in this benchmark statement. An MPhys or MSci degree is awarded after an extended programme of study, to students who have achieved learning outcomes for a master's degree. MPhys or MSci degree programmes allow students to study physics to a greater depth than is possible on a bachelor's programme and to extend the opportunities to develop their generic skills and undertake project work. These master’s degrees are classified degrees that provide a coherent and broadly-based education in physics. They are to be distinguished from MSc programmes in physics, which are self contained programmes, normally involving one or two years of postgraduate study in a specialist area and which are not covered by this benchmark statement.

1.4 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 programme. This benchmark statement has taken this into account in interpreting the generic statements of *The framework for higher education qualifications in England, Wales and Northern Ireland* honours (H) and master's (M) level degree programmes.

1.5 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 document *The Physics Degree* from the Institute of Physics is widely used as a source of 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 man-made 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, technology, materials, and information theory. 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, and statistics.

2.2 Physics is both a theoretical and a practical discipline that continually evolves. 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 mathematical models. 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 same model describes the behaviour of electrons in metals and in white dwarf stars.

2.4 Physics is an empirical science. The skills and methods used to make measurements are an integral part of physics. 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; for example, the electromagnetic radiation emitted by electron accelerators, which were originally designed to study elementary particles, is now used to study the properties of materials in engineering, biology and medicine.

2.5 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. Within physics, there are three broad categories of activity: experimental (or observational), computational and theoretical, although many physicists span these categories.

2.6 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, information and communication technologies (ICT) and self-study skills, along with 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, development and education, in industry and academia, and increasingly in areas such as business and finance, where they are sought for their pragmatic and analytical approaches to the solution of problems.

3 Subject knowledge and understanding

3.1 Undergraduate BSc (Honours) degree programmes in physics address the more general and fundamental topics of physics, provide a selection of more advanced topics, and develop investigative, experimental, mathematical, computational, modelling and other generic skills. The various programmes will emphasise different areas. For example, theoretical physics programmes will normally include significantly more mathematical and computational skills, usually replacing much or possibly all conventional laboratory work. Applied physics programmes will emphasise experimentation and provide a more industrially applicable focus to the curriculum. Sandwich degree programmes offer placements in relevant industrial or research-based environments. Joint and dual honours programmes will vary in the amount and extent of physics content depending on the precise definition and title of the programme in question. The MPhys and MSci degree programmes bring additional depth of knowledge and further development of subject-specific skills and project work.

3.2 Undergraduate physics curricula need to cater for students planning to move on to research (in industry or academia), as well as for students looking for a broad physics-based education which will make them numerate, articulate and eminently employable. Curricula will usually distinguish between fundamental ideas and the description and modelling of phenomena. The fundamentals, which all students need to cover to some extent, include electromagnetism, quantum and classical mechanics, statistical physics and thermodynamics, wave phenomena and the properties of matter. Students should also study the application of the fundamental principles to particular areas. These may include atomic physics, nuclear and particle physics, condensed matter physics, materials, plasmas, and fluids. Astrophysics and astronomy programmes should normally include 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. In addition, the curricula should help students to develop some qualitative understanding of current developments at the frontiers of the subject.

3.3 Students should learn that physics is a quantitative subject and appreciate the use and power of mathematics for modelling the physical world and solving problems. Mathematics is an essential part of a physics degree.

3.4 Physics curricula should give students experience of the practical nature of physics. They should provide students with the skills necessary to plan investigations and collect and analyse data, including estimation of inherent uncertainties.
All graduates in physics should have some appreciation of natural phenomena in an experimental context. Except perhaps for theoretical physics degrees where the skills identified here are gained in other, clearly specified ways, practical work should thus be a vital and challenging part of a physics degree. Students should also become proficient in presenting experimental results or theoretical conclusions and in the writing of reports.

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

4 Subject-based skills, generic skills and qualities

4.1 Bachelor's and integrated master's degrees in physics will develop a wide range of competence in generic and subject-specific skills of which the following are particularly relevant.

Physics skills

4.2 Students should learn:

- how to formulate and tackle problems in physics. For example, they should learn how to identify the appropriate physical principles, how 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
- how to use mathematics to describe the physical world. They should 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. They should be able to use appropriate methods to analyse their data and to evaluate the level of its uncertainty. They should also be able to relate any conclusions they make to current theories of the physics involved.

4.3 They should be able to compare critically the results of model calculations with those from experiment and observation.

Generic skills

4.4 A physics degree should enhance the following types of skills.

- **Problem-solving skills -** physics degree programmes involve students in solving problems with well-defined solutions. They will 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 will have opportunities to develop their skills of independent investigation. Students will generally have experience of using textbooks, and other available literature, of searching databases and the internet, and of interacting with colleagues to extract important information.
- **Communication skills -** physics and the mathematics used in physics deal with surprising ideas and difficult concepts; good communication is essential. A physics degree should develop a student’s ability to listen carefully, to read demanding texts, and to present complex information in a clear and concise manner.
- **Analytical skills -** physics helps students learn the need to pay attention to detail and to develop their ability to manipulate precise and intricate ideas, to construct logical arguments and to use technical language correctly.
- **ICT skills -** during their studies, students will develop their computing and ICT skills in a variety of ways, including their ability to use appropriate software such as programming languages and packages.
- **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.

Ethical behaviour

4.5 Students should appreciate that to fabricate, falsify or misrepresent data or to commit plagiarism constitutes unethical scientific behaviour. They should be objective, unbiased and truthful in all aspects of their work and recognise the limits of their knowledge.

5 Teaching, learning and assessment

5.1 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, should be developed. This leads to teaching methods that may typically 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.

5.2 The balance between these may vary between institutions, programmes and modules, and will evolve with time due to advances in information technology and pedagogical thinking.

5.3 Approaches to skills development should 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 should be evident; for example laboratory work may become open-ended with more demanding reporting criteria at the higher levels. Computer skills should normally include the basics of programming but it is increasingly the case that the use of programs for simulation, for computer algebra and for data analysis is most appropriate for the physicist. Skills may also be developed in the use of computers for the control of experiments and the acquisition of data.

5.4 A variety of assessment methods are appropriate within a physics programme, 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 programs or electronic circuits
- electronic media
- peer and self-assessment.

5.5 Examination and test questions should be 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 should be augmented by others, such as presentations and project reports, which allow students to demonstrate what they can achieve with less severe time constraints. Skills such as project planning and execution, research skills, application of ICT and report writing, may be best assessed in this way.

5.6 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 discipline 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% to 100%). Students towards the lower end of the performance range may fail some modules while still meeting the overall learning outcomes of the programme. Assessment regulations should be flexible enough to take account of the variability and institutions should allow examiners to judge the overall performance against the learning outcomes for the programme.

6 Benchmark standards

6.1 All students graduating with honours degrees in physics are expected to demonstrate 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 student graduating from the bachelor's programme and a typical student graduating from the master's programme.

6.2 In discussing the range of knowledge and levels of attainment in this section the topics to be covered are those outlined in section three.

6.3 It is the learning outcomes, contained within a programme specification, that are assessed and it is the responsibility of institutions to ensure that their regulations and procedures guarantee the integrity of their awards.

Bachelor's degree

Threshold level

6.4 Honours degrees should be awarded to students who have demonstrated:

- a basic knowledge and understanding of physical laws and principles, and some application of these principles
- an ability to identify relevant principles and laws when dealing with problems
- the ability to execute and analyse the results of an experiment or investigation. Students should be able to evaluate the level of uncertainty in their results and compare these results with expected outcomes, theoretical predictions or published data and hence assess their significance
- a familiarity with basic laboratory apparatus if on an experimental programme

- competent use of appropriate ICT packages/systems for the analysis of data and the retrieval of appropriate information
- an ability in numerical manipulation and the ability to present and interpret information graphically
- an ability to communicate scientific information, in particular through scientific reports
- an ability to manage their own learning and to make use of appropriate texts and learning materials.

Typical level

6.5 Typical holders of honours bachelor's degrees will have demonstrated:

- a knowledge and understanding of most fundamental physical laws and principles, and competence in the application of these principles to diverse areas of physics
- an ability to solve problems in physics using appropriate mathematical tools. Students should be able to identify the relevant physical principles and make approximations necessary to obtain solutions
- the ability to execute and analyse critically the results of an experiment or investigation and draw valid conclusions. Students should be able to evaluate the level of uncertainty in their results and compare these results with expected outcomes, theoretical predictions or with published data. They should be able to evaluate the significance of their results in this context
- a sound familiarity with laboratory apparatus and techniques if on experimental programmes
- effective use of appropriate ICT packages/systems for the analysis of data and the retrieval of appropriate information
- an ability in numerical manipulation and the ability to present and interpret information graphically
- an ability to use mathematical techniques and analysis to model physical behaviour
- an ability to communicate scientific information. In particular students should be able to produce clear and accurate scientific reports
- an ability to manage their own learning and to make use of appropriate texts, research-based materials or other learning resources.

Master's degree (MPhys/MSci)

Threshold level

6.6 Master's degrees are awarded to students who have demonstrated:

- an understanding of most fundamental laws and principles of physics, along with their application to a variety of areas in physics, some of which are at (or are informed by) the forefront of the discipline
- an ability to solve advanced problems in physics using appropriate mathematical tools. Students should be able to identify the relevant physical principles, to translate problems into mathematical statements and apply their knowledge to obtain order-of-magnitude or more precise solutions as appropriate
- the ability to use mathematical techniques and analysis to model physical behaviour and interpret mathematical descriptions of physical phenomena
- the ability to plan and execute under supervision, an experiment or investigation, analyse critically the results and draw valid conclusions. Students

should be able to evaluate the level of uncertainty in their results, understand the significance of error analysis and be able to compare these results with expected outcomes, theoretical predictions or with published data. They should be able to evaluate the significance of their results in this context

- experimental skills showing the competent use of specialised equipment, the ability to identify appropriate pieces of equipment and to master new techniques and equipment (applies to students on experimental programmes)
- effective use of ICT skills at the level needed for project work; for example, a familiarity with a programming language, simulation software, or the use of mathematical packages for manipulation and numerical solution of equations
- a working knowledge of a variety of experimental, mathematical and/or computational techniques applicable to current research within physics
- the ability to communicate complex scientific ideas, the conclusions of an experiment, investigation or project concisely, accurately and informatively
- the ability to manage their own learning and to make use of appropriate texts, research articles and other primary sources.

Appendix A - Membership of the review group for the subject benchmark statement for physics, astronomy and astrophysics

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	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

Appendix B - Membership of the original benchmarking group for physics, astronomy and astrophysics

Details below appear as published in the original subject benchmark statement for physics, astronomy and astrophysics (2002).

Dr Nick d'Ambrumenil	University of Warwick
Dr Craig Adam	Staffordshire University (now at University of Keele)
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
Professor John Young	Sheffield Hallam University