Physics, astronomy and astrophysics

Subject benchmark statements

Subject benchmark statements provide a means for the academic community to describe the nature and characteristics of programmes in a specific subject. They also represent general expectations about the standards for the award of qualifications at a given level and articulate the attributes and capabilities that those possessing such qualifications should be able to demonstrate.

This *Subject benchmark statement*, together with the others published concurrently, refers to the bachelors degree with honours.

Subject benchmark statements are used for a variety of purposes. Primarily, they are an important external source of reference for higher education institutions 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. Benchmark statements provide for variety and flexibility in the design of programmes and encourage innovation within an agreed overall framework.

Subject benchmark statements also provide support to institutions 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.

Finally, *Subject benchmark statements* may be one of a number of external reference points that are drawn upon for the purposes of external review. Reviewers do not use *Subject benchmark statements* as a crude checklist for these purposes however. Rather, they are used in conjunction with the relevant programme specifications, the institution's own internal evaluation documentation, in order to enable reviewers to come to a rounded judgement based on a broad range of evidence.

The benchmarking of academic standards for this subject area has been undertaken by a group of subject specialists drawn from and acting on behalf of the subject community. The group's work was facilitated by the Quality Assurance Agency for Higher Education, which publishes and distributes this *statement* and other *statements* developed by similar subject-specific groups.

In due course, but not before July 2005, the *statement* will be revised to reflect developments in the subject and the experiences of institutions and others who are working with it. The Agency will initiate revision and, in collaboration with the subject community, will make arrangements for any necessary modifications to the *statement*.

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Academic standards - Physics, astronomy and astrophysics

1 Introduction

1.1 This *Subject benchmark statement* (*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 degrees in single honours physics, theoretical physics, applied physics, astrophysics and astronomy as well as joint and dual honours degrees, where physics forms a significant proportion. This statement relates to the physics components of all such degrees.

1.2 Physics is a major subject in the UK higher education system with over 10,000 full-time equivalent students registered on undergraduate HE 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 MPhys and MSci degrees in physics and their close link with the BSc degree, these programmes are included in this *statement*. An MPhys or MSci degree is awarded after an extended programme of integrated study, to students who have achieved learning outcomes for a Masters degree. MPhys or MSci degree programmes allow students to study physics to a greater depth than is possible on a Bachelors course and to extend the opportunities to develop their transferable skills and undertake project work. These Masters 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 courses, normally involving one or two years of postgraduate study in a specialist area and which are not covered by this *statement*.

1.4 Physics is a maturing and demanding discipline. An understanding of the frontiers of physics often requires advanced knowledge, which cannot necessarily be acquired during a Bachelors or Masters degree programme. This *statement* has taken this into account in interpreting the generic statements of the qualification framework for Honours and Masters 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.

2 Nature and extent of the subject

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, experiment 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 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 at university 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, IT 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 transferable 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 courses 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 development in knowledge, 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 courses may 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). These skills may be acquired as part of a course in a laboratory or by a range of alternatives including computer simulations. Practical work should thus be a vital and challenging part of a physics degree, and all graduates in physics should have some appreciation of natural phenomena in an experimental context. Students should also become proficient in presenting experimental results or theoretical conclusions and in the writing of reports. Open-ended project work should be used to facilitate the development of students' skills in research and planning (by use of data bases and published literature) and their ability to assess critically the link between theoretical results and experimental observation.

4 Subject-based skills and other skills

Honours and Masters degrees in physics will develop a wide range of competence in transferable and subject-specific skills of which the following are particularly relevant:

4.1 Physics skills

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 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;
- how to use mathematics to describe the physical world. They should have an understanding of mathematical modelling and of the role of approximation. They should be able to compare critically the results of model calculations with those from experiment and observation.

4.2 Transferable skills

A physics degree should enhance:

- **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 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 students' 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.

- **IT skills**

During their studies, students will develop their computing and IT 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, to organise themselves to meet deadlines, and to interact constructively with other people.

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;
- laboratory work;
- the use of text books and other self-study materials;
- open-ended project work, some of which may be team-based;
- activities devoted to transferable and subject-specific skills development.

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.

5.2 Approaches to skills development should encompass both transferable 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.

5.3 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 sheet assignments;
- laboratory 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;
- peer and self-assessment.

5.4 Examination and test questions should be graded to assess a student's understanding of concepts, and the ability to develop mathematical models, to complete calculations, to solve new problems and to 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 IT and report writing, are best assessed in this way.

6 Academic standards of attainment

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 bachelors course and a typical student graduating from the masters course.

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 3.

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. Compensation is the responsibility of institutions and is therefore not addressed in the *statement*. Where an institution allows compensation or condonement it should ensure that that the procedures guarantee that the threshold standards are met. The elements of the threshold criteria appropriate to a joint or dual honours programme are a matter for the institution to determine, possibly through the programme specification.

Bachelors degree

Threshold attainment

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;
- competent use of appropriate IT 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;
- a familiarity with basic laboratory apparatus if on an experimental programme.

Bachelors degree

Typical attainment

Typical holders of honours bachelors 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;
- effective use of appropriate IT 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;
- a sound familiarity with laboratory apparatus and techniques if on experimental programmes.

Masters degree (MPhys/MSci)

Threshold attainment

Masters 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;
- effective use of IT 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;
- 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).

Appendix 1

Membership of benchmark group

Dr Nick d'Ambrumenil	University of Warwick
Dr Craig Adam	Staffordshire University (now at University of Keele)
Professor Mick Brown	University of Cambridge
Dr 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