Competencies required for undergraduates completing a degree programme in the School of Physics and Astronomy at The University of Manchester

This document describes how competencies are defined and assessed in the School.

"The Purposes of a Manchester Undergraduate Education (The Manchester Matrix)" sets out eight areas which students undertaking undergraduate education at the University of Manchester are expected to achieve by the end of their study. This document can be found at
http://documents.manchester.ac.uk/display.aspx?DocID=9804
and is attached.

The attributes are a set of core competencies which we expect students to achieve through completion of any University of Manchester programme.

Item 2 in the Manchester Matrix is expanded with specific attributes for degree programmes in the School of Physics and Astronomy. These attributes are described in the "Blue Book" which can be found online at http://bluebook.physics.manchester.ac.uk/. These attributes are reviewed by the Institute of Physics every five years. All programmes are accredited by the Institute of Physics. The IOP provides its accreditation document at
https://www.iop.org/education/higher_education/accreditation/file_43311.pdf,
which is also attached.

Moreover, the programmes comply with the subject benchmark for Physics, Astronomy and Astrophysics as stated in the QAA benchmark statement of February 2017,
http://www.qaa.ac.uk/en/Publications/Documents/SBS-Physics-Astronomy-and-Astrophysics-17.pdf.
This document is also attached.

When assessing whether a student has achieved a competency, various methods are used. The method chosen for each course unit are described in the Blue Book and have been deemed appropriate to assess the learning outcomes by the School Teaching & Learning Committee.

Lecture based courses are normally assessed in unseen and time-constrained examinations. The unseen element ensures that the material required for all the learning outcomes has been absorbed and understood by an individual student. The time-constrained element tests the student's capacity to organise work, as well as to think and communicate under pressure.

The School recognises that undue pressure can lead to stress. To quote the Health and Safety Executive, http://www.hse.gov.uk/stress/furtheradvice/whatisstress.htm
"There is a difference between pressure and stress. Pressure can be positive and a motivating factor, and is often essential in a job. It can help us achieve our goals and perform better. Stress occurs when this pressure becomes excessive. Stress is a natural reaction to too much pressure."

Consequently, examinations are carefully written and checked internally and externally, to ensure that the relevant learning outcomes of a course unit can be tested in the appropriate time period. DASS advice is followed if the time period or other examination conditions need to be adjusted for particular students.

THE PURPOSES OF A MANCHESTER UNDERGRADUATE EDUCATION

The Purposes of a Manchester Education	**Graduate Attributes**	**Assessment Criteria**
1. To develop critical thinking and higher order conceptual reasoning and analytical skills	Manchester graduates will have been encouraged to develop their intellectual curiosity, will have learned how to learn, will have a clear grasp of the fundamental differences between fact and opinion, truth and falsity, validity and invalidity, and will have acquired the basic intellectual tools of logical analysis and critical inquiry.	**Logical reasoning** **Analysis** **Synthesis** **Evaluation**
2. To promote mastery of a discipline	Manchester graduates will have mastered the epistemological, methodological and essential knowledge base of at least one discipline or taught in the University, acquiring a basic understanding of the processes of inquiry and research through which existing paradigms are evaluated and new knowledge created in that discipline or disciplines	**Knowledge** **Epistemology** **Methodology** **Comprehension** **Application**
3. To broaden intellectual and cultural interests	Manchester graduates will be encouraged to value knowledge for its own sake, and to appreciate virtuosity and creativity, whether in art, music, science, literature or any other medium through which human discourse and human culture are advanced and enriched.	**Intellectual curiosity** **Cultural awareness** **Understanding of the historical development and cultural context of particular traditions, disciplines or bodies of knowledge**
4. To prepare graduates for professional and vocational work	Manchester graduates in professional disciplines will have the knowledge and advanced technical skills demanded in a an increasingly sophisticated and rapidly changing professional workplace, and will have been provided with opportunities to develop accompanying skills of initiative, teamwork and professional communication.	**Professional knowledge** **Professional Skills** **Professional Qualities** **Communication and Team work**
5. To challenge and equip students to confront personal values and make ethical judgements	Manchester graduates will have been provided with opportunities to develop personal qualities of independence of mind and to take responsibility for the values, norms, assumptions and beliefs that guide their behaviour as individuals and citizens.	**Ethical awareness** **Grasp of ethical principles** **Awareness of relevant professional ethics**

6. To prepare graduates for citizenship and leadership in diverse, global environments	Manchester graduates will have been encouraged and enabled to confront their own civic values and responsibilities as local, regional and global citizens.	**Awareness of social, political and environmental issues** **Sense of social responsibility** **Leadership skills**
7. To develop advanced skills of written and verbal communication	Manchester graduates will be equipped with advanced skills of written and verbal communication.	**Ability to communicate verbally and in writing lucidly, accurately, relevantly, succinctly and engagingly**
8. To promote equality and diversity.	Manchester graduates will have been educated in an environment that embraces and values cultural diversity, and that is fundamentally committed to equality of opportunity regardless of gender, race, disability, religious or other beliefs, sexual orientation or age.	**A key consideration informing the design, development, delivery and assessment of all Manchester curricula**

IOP Institute of Physics

The Physics Degree

Graduate Skills Base and the Core of Physics

Version date: September 2011

THE PHYSICS DEGREE

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[1], 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***.

[1] http://www.qaa.ac.uk/Publications/InformationAndGuidance/Documents/Physics08.pdf

GRADUATE SKILLS BASE

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.

PROJECT WORK

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

Integrated Masters

This section is a new addition to *The Physics Degree*. All integrated Masters submitted for accreditation from academic year 2010/11 onwards will be 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[2,3]; 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.

[2] http://www.qaa.ac.uk/Publications/InformationAndGuidance/Documents/FHEQ08.pdf
[3] http://www.qaa.ac.uk/Publications/InformationAndGuidance/Documents/SCQF.pdf

CORE OF PHYSICS

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.

CORE OF PHYSICS

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

The Institute of Physics is a scientific charity devoted to increasing the practice, understanding and application of physics.
It has a worldwide membership of around 40 000 and is a leading communicator of physics-related science to all audiences, from specialists through to government and the general public. Its publishing company, IOP Publishing, is a world leader in scientific publishing and the electronic dissemination of physics.

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Subject Benchmark Statement

Physics, Astronomy and Astrophysics

February 2017

UK Quality Code for Higher Education
Part A: Setting and maintaining academic standards

Contents

How can I use this document?

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

You may want to read this document if you are:

- involved in the design, delivery and review of programmes of study in Physics, Astronomy and Astrophysics or related subjects
- a prospective student thinking about studying Physics, Astronomy and Astrophysics, 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 Physics, Astronomy and Astrophysics.

Explanations of unfamiliar terms used in this Subject Benchmark Statement can be found in the Quality Assurance Agency for Higher Education's (QAA's) glossary.[1]

[1] The QAA glossary is available at: www.qaa.ac.uk/about-us/glossary.

About Subject Benchmark Statements

Subject Benchmark Statements form part of the UK Quality Code for Higher Education (Quality Code) which sets out the Expectations that all providers of UK higher education reviewed by QAA are required to meet.[2] They are a component of Part A: Setting and Maintaining Academic Standards, which includes the Expectation that higher education providers 'consider and take account of relevant Subject Benchmark Statements' in order to secure threshold academic standards.[3]

Subject Benchmark Statements describe the nature of study and the academic standards expected of graduates in specific subject areas, and in respect of particular qualifications. They provide a picture of what graduates in a particular subject might reasonably be expected to know, do and understand at the end of their programme of study.

Subject Benchmark Statements are used as reference points in the design, delivery and review of academic programmes. They provide general guidance for articulating the learning outcomes associated with the programme 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 programme design within a framework agreed by the subject community. Further guidance about programme design, development and approval, learning and teaching, assessment of students, and programme monitoring and review is available in Part B: Assuring and Enhancing Academic Quality of the Quality Code in the following chapters:[4]

- *Chapter B1: Programme Design, Development and Approval*
- *Chapter B3: Learning and Teaching*
- *Chapter B6: Assessment of Students and the Recognition of Prior Learning*
- *Chapter B8: Programme Monitoring and Review*.

For some subject areas, higher education providers may need to consider other reference points in addition to the Subject Benchmark Statement in designing, delivering and reviewing programmes. These may include requirements set out by professional, statutory and regulatory bodies, national occupational standards and industry or employer expectations. In such cases, the Subject Benchmark Statement may provide additional guidance around academic standards not covered by these requirements.[5] The relationship between academic and professional or regulatory requirements is made clear within individual statements, but it is the responsibility of individual higher education providers to decide how they use this information. The responsibility for academic standards remains with the higher education provider who awards the degree.

Subject Benchmark Statements are written and maintained by subject specialists drawn from and acting on behalf of the subject community. The process is facilitated by QAA. 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.

[2] The Quality Code, available at www.qaa.ac.uk/assuring-standards-and-quality/the-quality-code, aligns with the *Standards and Guidelines for Quality Assurance in the European Higher Education Area*, available at: www.enqa.eu/wp-content/uploads/2015/05/ESG_endorsed-with-changed-foreword.pdf.
[3] Part A: Setting and Maintaining Academic Standards, available at: www.qaa.ac.uk/assuring-standards-and-quality/the-quality-code/quality-code-part-a.
[4] Individual chapters are available at: www.qaa.ac.uk/assuring-standards-and-quality/the-quality-code/quality-code-part-b.
[5] See further Part A: Setting and Maintaining Academic Standards, available at: www.qaa.ac.uk/assuring-standards-and-quality/the-quality-code/quality-code-part-a.

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. The Quality Code does not interpret legislation nor does it incorporate statutory or regulatory requirements. Sources of information about other requirements and examples of guidance and good practice are signposted within the Subject Benchmark Statement where appropriate. Higher education providers are responsible for how they use these resources.[6]

Equality and diversity

The Quality Code embeds consideration of equality and diversity matters throughout. Promoting equality involves treating everyone with equal dignity and worth, while also raising aspirations and supporting achievement for people with diverse requirements, entitlements and backgrounds. An inclusive environment for learning anticipates the varied requirements of learners, and aims to ensure that all students have equal access to educational opportunities. Higher education providers, staff and students all have a role in, and a responsibility for, promoting equality.

Equality of opportunity involves enabling access for people who have differing individual requirements as well as eliminating arbitrary and unnecessary barriers to learning. In addition, disabled students and non-disabled students are offered learning opportunities that are equally accessible to them, by means of inclusive design wherever possible and by means of reasonable individual adjustments wherever necessary.

[6] See further the *UK Quality Code for Higher Education: General Introduction*, available at: www.qaa.ac.uk/publications/information-and-guidance/publication?PubID=181.

About this Subject Benchmark Statement

This Subject Benchmark Statement refers to bachelor's degrees 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.[7]

This version of the Statement forms its third edition, following initial publication of the Subject Benchmark Statement in 2002 and review and revision in 2008.[8]

Note on alignment with higher education sector coding systems

Programmes of study which use this Subject Benchmark Statement as a reference point are generally classified under the following codes in the Joint Academic Coding System (JACS):[9]

F300 (Physics)
F310 (Applied physics)
F311 (Engineering physics)
F320 (Chemical physics)
F321 (Solid-state physics)
F330 (Environmental physics)
F331 (Atmospheric physics)
F332 (Marine physics)
F340 (Mathematical & theoretical physics)
F341 (Electromagnetism)
F342 (Quantum mechanics)
F343 (Computational physics)
F350 (Medical physics)
F351 (Radiation physics)
F360 (Optical physics)
F361 (Laser physics)
F370 (Nuclear & particle physics)
F390 (Physics not elsewhere classified)
F500 (Astronomy)
F510 (Astrophysics)
F520 (Space & planetary sciences)
F521 (Space science)
F522 (Planetary science)
F530 (Solar & solar terrestrial physics)
F540 (Astronomy observation)
F550 (Astronomy theory)
F590 (Astronomy not elsewhere classified).

Some programmes may have codes which did not appear on the JACS list at the time this statement was written, so this should be taken as an indicative rather than a complete list.

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[7] Bachelor's degrees are at level 6 in *The Framework for Higher Education Qualifications in England, Wales and Northern Ireland* and level 10 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*, available at: www.qaa.ac.uk/assuring-standards-and-quality/the-quality-code/qualifications.
[8] Further information is available in the *Recognition scheme for Subject Benchmark Statements*, available at: www.qaa.ac.uk/publications/information-and-guidance/publication?PubID=190.
[9] Further information about JACS is available at: www.hesa.ac.uk/content/view/1776/649.

Summary of changes from the previous Subject Benchmark Statement (2008)

This Statement has seen a number of minor revisions since the 2008 version.

The review group agreed that wholesale changes to the Statement were not needed, and concentrated on updating terminology and clarifying certain points. The importance of Mathematics has been made clearer. The description of ethical behaviour has been changed to professional behaviour and expanded to include matters such as an understanding of a safe working environment.

The Statement retains a description of the typical and threshold standards for bachelor's degrees and integrated master's degrees in the subject. For integrated master's degrees, they have been simplified to remove duplication and concentrate on the additional capabilities and skills needed beyond the bachelor's level.

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. 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 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.

1.3 Degrees designated as Master's of Physics (MPhys) and Master's of Natural Science or Master's in Science (MSci) are included in this Statement. An integrated master's degree is awarded after an extended programme of study which allows 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 provide a coherent and broad-based education in Physics. They are to be distinguished from Master of Science (MSc) programmes in Physics, which are self-contained programmes, normally involving one or two years of postgraduate study in a specialist area. MSc programmes are not covered by this 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 Statement has taken this into account in interpreting the generic statements of *The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies*[10] honours and master's 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.

[10] Available at: www.qaa.ac.uk/assuring-standards-and-quality/the-quality-code/qualifications.

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 programmes vary in the emphasis given to different areas of Physics. For example, theoretical Physics programmes generally include more mathematical and computational skills, usually replacing much or possibly all conventional laboratory work. Applied Physics programmes often have a technological focus. Some degree programmes offer placements in schools, higher education provider research groups or industry. Joint and dual honours programmes vary in the amount and extent of Physics content, depending on the precise definition and title of the programme in question, but still cover the fundamental topics of Physics. In addition to this, integrated master's degree programmes 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 degrees Physics programmes 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 programmes 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, programmes 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 programmes 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 programmes 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. Programmes 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 for students 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 facitlities.

4.2 The balance between these may vary between providers, programmes and modules, and will evolve with time due to advances in information technology 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 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 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 programme. Assessment regulations need to be flexible enough to take account of the variability, and providers allow examiners to judge the overall performance against the learning outcomes for the programme.

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 programme. 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 programme) 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 programme)
- 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 programme)
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 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 within 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 (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	Quality Assurance Agency for Higher Education

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 (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

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