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A EUROPEAN SPECIFICATION FOR PHYSICS MASTER STUDIES

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A EUROPEAN SPECIFICATION FOR PHYSICS MASTER STUDIES

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PREFACE

The **European Physical Society** (EPS) is a European-wide professional association with 41 national member societies. The EPS supports the Bologna Process and provides with a series of *specifications* a means to describe the characteristics of the physics study programmes in a European dimension. This series of brochures covers the bachelor or first-cycle or EQF level 6, master or second-cycle or EQF level 7 and doctorate or third-cycle level or EQF level 8, as one of the three priorities in the *Bologna Process* [EC09a]. The brochures also represent general expectations about the standards for the award of qualifications at the given level and articulate the attributes and capabilities – i.e. the learning outcomes - that those possessing such qualifications should be able to demonstrate. These qualifications are in agreement with the *European Qualifications Framework* (EQF) [EC09b]. National statements and guidelines [MS04, KF05, IM07, LM07 and QA08] have already been established in some countries, and have been very influential in designing these specifications. The European master level or EQF level 7 corresponds to the UNESCO level ISCED 5B [UN06]

The present EPS *specification* refers to the physics master degree in a European perspective. **Specifications 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. They provide general guidance for articulating the learning outcomes associated with the programme but are not detailed descriptions of a core or model curriculum. Specifications provide for variety and flexibility in the design of programmes and encourage innovation within an agreed overall national, regional or institutional framework.

Specifications 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.

Finally, specifications are among a variety of **external reference points** that may be drawn upon for the purpose of external review. Reviewers should not use specifications as a crude checklist for these purposes however. Rather, they should consider them in conjunction with the relevant programme descriptions, the institutions' own internal evaluation documentation, in order to arrive at a rounded judgment based on a broad range of evidence.

The present physics master specification has been undertaken by a **European group of physics higher education specialists** (see Annex 1). The group's work has been funded with support from the European Commission [EC07] and was facilitated by the European Physical Society, which publishes and distributes these documents. The present document went through a full consultation and validation process with the wider European academic community and the stakeholder groups.

In due course the specification will be **revised** to reflect developments in physics (and astronomy) and the experiences of institutions and others who are working with it. The EPS will initiate revision and will make arrangements for any necessary modifications to the description in collaboration with the European physics community.

A **Glossary** of key terms in higher education can be found in [EU09a] [Vl07].

PHYSICS MASTER STUDIES

1- Introduction

1.1 The present *specification* for *physics master programmes* characterises a European-wide view of the competences and achievements that graduates of physics master degrees should have acquired through their studies and training. There exists a wide range of programmes delivering such degrees reflecting the varying aspects of physics and different national perspectives, traditions and educational policy imperatives. However, there is wide agreement across Europe of what constitutes the basics of physics and the essentials of what should be included in a second degree in physics. This specification relates to the physics components of programmes delivering degrees where **physics (including astronomy) and mathematics represents a significant proportion - at least 70% - of the programme.** In a large number of European countries master degrees are a fairly recent development inspired by the Bologna Process. Physics departments and national physical societies might welcome some guidance on what such degrees should try to achieve and the topics they should aim to cover. This document builds on extensive work carried out over recent years by the physics group in the *TUNING* project [TU09a] and over a longer period by the *EUPEN* group of physics departments [Fe05] both of which have done a great deal to establish European-wide consensus on the essentials of physics degree programmes. While this work has been vital in order to establish a European wide consensus, several parts of the present text rely very much on the Physics Benchmark produced by the QAA in the UK [QA08] from which they have been directly taken.

1.2 Physics is a *major discipline* in the European Higher Education Area (EHEA) with over 100 000 full-time equivalent students registered on undergraduate HE programmes. Physics graduates play a major role in the EU economy. However, the importance of physics is not restricted to the provision of professional scientists and technologists. It is also an essential part of our understanding of all aspects of nature and the principles and methods which allow us to understand the universe. As such it has wide and deep cultural dimensions and its study is of universal value. It forms the foundation of many of the sciences and their applications. Physics is also an important backbone for new advances in technology, which constitutes an important factor in the development and economy of our society.

1.3 Physics is a mature and demanding discipline. An understanding of the frontiers of physics often requires advanced *knowledge*, which cannot necessarily be acquired during a master degree programme. The present specification has taken this into account in interpreting the generic competences of the qualification framework for master or second-cycle level physics degree programmes.

1.4 Physics degrees will continue to evolve in response to developments in the discipline and changes in the (secondary) school curriculum. Hence the present specification concentrates on general learning outcomes and does *not specify a model or a core physics curriculum.*

2 - Programme structure and delivery

2.1 Physics is a *hierarchical* discipline that requires systematic exposure and ordered as well as structured acquisition of knowledge. It is a subject which relies on experiment and observation as the source of our knowledge of the physical universe but which complements this with theoretical constructs based on a fairly small number of all embracing principles and laws often expressed and developed using mathematics. Practical skills have to be developed as also does an appreciation of the link between theory and experiment. 'This leads to teaching methods that may typically include:

- lectures supported by problem classes and group tutorial work;
- laboratory work;
- the use of textbooks and other self-study materials;
- open-ended project work, some of which may be team-based;
- activities devoted to physics-specific and generic competence development'. [QA08]

In the *TUNING* methodology [TU09a], the use of learning outcomes and competences is necessary in order to make programmes and their course units or modules student-centred and output-oriented. This approach requires that the key knowledge and skills that a student needs to achieve during the learning process determine the content of the study programme. *Modularisation* of the study programmes is explained in [We09, Ke09].The balance between the above teaching methods may vary between institutions, programmes and modules, and will evolve with time due to advances in information technology and pedagogical thinking [Fe05, Ke09].

2.2 'Approaches to skills development should encompass both *physics-specific and generic competences*, developed 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 include the basics of programming. Acquiring familiarity with programs for simulation, computer algebra and data analysis has gained increasing relevance for the physicist. Skills may also be developed in the use of computers for the control of experiments and the acquisition of data'. [TU09b]

2.3 'A variety of *assessment methods* are appropriate within a physics programme, some of which are more suitable for formative assessment. Evidence of the standards achieved could be obtained from some or all of the following:

- time-constrained examinations;
- closed-book and open-book tests;
- problem based assignments;
- laboratory reports;
- observation of practical skills;
- individual project reports (including placement or case-study reports);
- team project reports;
- and/or poster presentations, including seminar presentation;
- oral examinations & *viva voce* interviews;
- essays;
- project outcomes such as computer programs or electronic circuits;
- electronic media;
- peer and self assessment'. [QA08]

2.4 'Examination and test questions should be graded to assess a *student's understanding of concepts* and ability to develop, apply and test mathematical models, to complete calculations, to solve new problems and to communicate physical arguments and to assess critically results in their context. 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 under less severe time constraints. Skills such as project-planning and execution, research competences, application of IT and report writing, are best assessed in this way' [QA08].

2.5 In 2004 the *Joint Quality Initiative* [JQ04] developed the following descriptors, known as the *Dublin Descriptors* (based on Bloom's [Bl56] Taxonomy), to determine when students in their learning process would have attained the master level:
'Qualifications that signify completion of the second cycle are awarded to students who:

- have demonstrated knowledge and understanding that is founded upon and extends and/or enhances that typically associated with bachelor's level, and that provides a basis or opportunity for originality in developing and/or applying ideas, often within a research context;

- can apply their knowledge and understanding, and problem solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study;
- have the ability to integrate knowledge and handle complexity, and formulate judgements with incomplete or limited information, but that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgements;
- can communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously;
- have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous'.

In their 2007 London Summit the 'Bologna' ministers insisted on the use of learning outcomes in curriculum design and student-centred pedagogy (see also [TU09a]).

2.6 Institutions which apply the *European Credit Transfer and Accumulation System* (ECTS) [EC09c] publish their course catalogues on the web, including detailed descriptions of study programmes, units of learning, university regulations and student services [Ke09 & Ke10]. Course descriptions contain learning outcomes (what students are expected to know, understand and be able to do) and workload (the time students typically need to achieve the learning outcomes), expressed in terms of credits. In most cases, student workload ranges from 1,500 to 1,800 hours for *an academic year of 60 ECTS*, and one credit corresponds to 25-30 hours of work. Credit transfer and accumulation are helped by the use of the ECTS key documents (course catalogue, learning agreement, and transcript of records) as well as the *Diploma Supplement* [DS09].

2.7 A recent study [Ke10] showed that the **vast majority** of the 155 investigated physics master programmes from 24 countries have a duration of *two years or 120 ECTS* credits in continental Europe and in the Nordic countries. Only in an exceptional case [e.g. Ph09] is the duration condensed to one year. However in the data from the UK, almost one half were integrated master programmes either of 4 years (38 %) or 5 years (8 %) duration, the latter being the norm in Scotland. The rest are stand alone master programmes and have a duration of one year (47%) or two years (7%). In Ireland most master programmes have a duration of one year.

2.8 *Physics master degree programmes* address a broad selection of advanced fundamental topics of physics, and encourage further the development of investigative, experimental, mathematical, computational, modelling and other generic competences. The various programmes will emphasise different areas. Technical/applied physics courses might emphasise experimentation and simulation and provide a focus to the curriculum that is more geared towards industrial applications and the design of physics-based devices.

2.9 *Physics master curricula* need to cater both for students planning to move on to research in industry or academia - and obtain a subsequent physics or physics-related doctorate degree - as well as for students looking for a broad physics-based education which will provide them with a firm base of generic skills and make them eminently employable.

3 - Physics

3.1 'Physics is concerned with the quantitative observation, understanding and prediction of *natural phenomena* and the *behaviour of human-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, measurement, *i.e.* quantitative experimentation 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' [QA08].

3.2 'Physics is both *an experimental and a theoretical* discipline that is continuously evolving. It is deeply rooted in the idea that even complex 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 physics 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' [QA08].

3.3 Physics as *an experimental 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 a 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 frequently find applications in other branches of science; for example, 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' [QA08]. Moreover, devices such as transistors and lasers, which were developed within basic physics research programmes, have revolutionised technology.

3.4 '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 compared with what is observed experimentally. Sometimes a model is applicable to very different circumstances. For example, the same statistical model that describes the behaviour of electrons in metals is equally valid for white dwarf stars'. [QA08]

3.5 'Progress in physics requires *imagination and creativity*. It is often the result of collaboration between physicists with different backgrounds and increasingly involves the exchange of ideas and techniques with people from other disciplines. Within physics, there are three broad categories of activity: experimental (or observational), computational and theoretical, although many physicists span these categories'. [QA08]

3.6 'Studying physics at a university brings *benefits that last a lifetime* and knowledge and skills that are valuable outside the field of 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 physics or natural 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 analytical and synthetical approaches to the solution of problems'. [QA08]

4 - Physics master discipline competences

4.1 Physics master students should gain a thorough understanding with the application of fundamental principles to particular areas by building further on their introductory bachelor knowledge of some or all of these sub-fields:

- atomic physics
- nuclear and particle physics
- condensed matter physics
- physics of materials
- plasma physics
- physics of fluids
- mathematical and numerical methods in physics.

Alternatively, they should learn to apply their knowledge and skills acquired in their physics bachelor programme in interdisciplinary areas, such as:

- biophysics
- medical physics
- geophysics and/or meteorology
- physics of nanostructures
- econophysics
- atmospheric and/or environmental physics.

In case *astrophysics and astronomy* courses are part of the programme, these may include the application of physical principles to:

- cosmology
- the structure, formation and evolution of stars and galaxies
- planetary systems
- high-energy phenomena in the universe.

In addition, the curricula should help master students to achieve a more qualitative understanding of current developments at the frontiers of the physics discipline within broader (or multidisciplinary) contexts.

4.2 Master students should learn that physics is a quantitative field of study and appreciate the use and power of mathematics for *modelling* the physical world and *solving problems*. Advanced mathematical and theoretical methods are essential parts of a physics master degree.

4.3 Physics master curricula should give students experience of the practical nature of physics [IU08]. 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; these experimental competences could also be acquired by providing opportunities for student internship in national or multinational laboratories or industrial research and development centres, hence stimulating transnational mobility while improving foreign language skills. Practical work should thus be a vital and challenging part of a physics master degree. Master students should also improve their capabilities in presenting experimental results or theoretical conclusions to professional and lay audiences and in the writing of scientific reports. Independent 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 to enhance their ability to assess critically the link between theoretical results and experimental observation.

4.4 Physics master students should extend and/or enhance their learning skills on:

- how to formulate and tackle *problems* in physics. For example, they should learn how to identify the appropriate physical principles in new and unfamiliar environments, how to use special and limiting cases and order-of-magnitude estimates to guide their thinking about a complex problem and how to present a solution making their assumptions and approximations explicit;
- how to plan and execute an *experiment* or investigation and to report the results. They should be able to select and 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 be able to manage 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. They should also be trained to do error and statistical analysis of acquired data to insure the validity and significance of results.

4.5 Master students should become familiar with the 'culture' of physics research, should acquire some detailed knowledge of at least one frontier physics speciality, *via* their *research/master project work/thesis*, hence developing an awareness of the highest scientific standards.

4.6 Some master students should be able to publish the results of their research project leading to the master degree *in an international, peer-reviewed journal*.

5 - Physics master generic competences

A physics master degree should enhance the following generic competences [TU09b & Fe05] (most of the following text is taken directly from [QA08]):

▶ Problem-solving

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 or non-standard problems.

▶ Analytical

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.

▶ Investigative

Students will have opportunities to develop their skills of independent investigation. Generally students will gain experience in gathering relevant information by using textbooks, and other literature, by searching databases and by interacting with colleagues.

▶ Communication

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 difficult ideas and complex information in a clear and concise manner.

▶ Information Technology

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 software packages and to design and carry out numerical simulations.

▶ Personal

Students should develop their ability to work with a high degree of autonomy accepting responsibility in planning and managing projects, to use their initiative, to organise their activities to meet deadlines, to aim for the highest quality standards and to interact constructively with other people in a team that may include people with different academic backgrounds.

▶ Language

Since a mobile labour force with language competences is crucial for economic growth and better jobs, enabling European enterprises to compete effectively in the global marketplace, multilingualism contributes to personal development and reinforces social cohesion. Students should **at least** develop an oral and written knowledge of English, the *lingua franca* of physics.

Ethical behaviour

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, behave with professional integrity and recognise the limits of their knowledge.

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ANNEX

Membership of the master specification group

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The **European Physical Society** (EPS) is a not-for-profit representative organization whose purpose is to promote physics and physicists in Europe. Created in 1968, the EPS provides an international forum to discuss science and policy issues of interest to its members.

NOTES

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