European Benchmark for Physics Bachelor Degree

1. Summary

This is a proposal to produce a common European Benchmark framework for Bachelor degrees in Physics. The purpose is to help implement the common European Higher Education area and to facilitate cooperation and student exchange between European Universities. It is aimed at the level of an indicative listing, which broadly specifies the common programme which can be found in most physics degrees across Europe. It also aims to represent the level of physics knowledge and skills physics departments across Europe generally consider sufficient to admit graduates of other universities to their master programmes without supplementary requirements. It is not intended to either provide a fixed and detailed physics syllabus or to replace the national quality assurance systems in force in various countries.

2. Introduction

Most European countries have introduced a Bachelor degree in response to the Bologna agreement and have introduced, or are in the process of introducing Masters programmes. In parallel to this countries are either introducing or strengthening national (in some cases cross-border or regional) quality assurance mechanisms which are external to the university.

Major changes to the structure of Physics degrees are associated with

- The Bologna agreement
- The introduction of the bachelor/master system
- External quality assurance mechanisms on a national or regional level
- National degree benchmarks for subject areas

Quality agencies are mainly concerned with generic competences (e.g. teamwork, communication skills) and the general organisation of university studies. They are not usually prescriptive at the level of detailed curricula. Indeed most national frameworks for physics degrees only provide a very general idea of the content and are not sufficiently detailed for our purpose. Examples of this are the German[1] (English version) and UK[2] national frameworks for Physics degrees.

There have been extensive studies of physics curricula by the EUPEN[3] (EUropean Physics EDucation) network, and its continuation the STEPS[4] project. In addition the TUNING project has also looked in detail at physics degrees and produced *Reference Points for the Design and Delivery of Degree Programmes in Physics*.[5] Similar publications have been produced by the German conference of Physics Departments[6] (in German) and the IOP (Institute of Physics) in the UK[7]. While there are many similar documents, the German and UK documents span the full spectrum of approaches to physics, from the more rigorously mathematical "*Continental European*" approach to the more empirical "*Anglo-Saxon*" one.

This is an attempt to provide a more detailed common physics syllabus but without specifying the content in too much detail as many different approaches are possible to teach the same content and skills. The level of detail involved lies between the general learning outcomes for a degree course and those for particular modules/course units.

3. Rationale

The rationale for this project is to provide a general reference point for Physics degrees, to aid the implementation of the Bologna changes and facilitate co-operation and student exchange between physics departments across Europe. The aims are as follows:

- Provide a Europe wide reference set of benchmarks
- Not to be overly prescriptive, allowing for variations in teaching approaches
- Concentrating on physics content, not general competences, which are well covered in other documents
- Specify the physics knowledge required for a masters level course in physics
- Provide a “quality mark” for Physics degrees
- Help mobility both within Bachelor degrees (Socrates/ Erasmus type mobility) and between Bachelor and Master degrees (Bologna type mobility).
- Provide a useful reference point especially for smaller countries and less well known universities, or for bachelor students planning to enrol in a master programme elsewhere.

Clearly if this is going to be a useful document it needs to be sufficiently detailed to be useful without imposing a rigid curriculum. All the following detailed structure needs to be approached from a flexible perspective and not applied in an inflexible manner. General competences should also be addressed explicitly in the programme, either as an integrated part of some of the content oriented courses or in separate courses:

4. Overall structure

On the basis of the EUPEN and TUNING studies, six broad areas of study or themes have been identified. Five of these are essential for a physics degree and clearly compulsory and the sixth is provided for optional minor specialisations. The sixth theme can be a minor subject (or subjects) either related to Physics or totally unrelated. Examples of this are foreign language skills, Chemistry, Electronics, Medical Physics, Astronomy & Astrophysics and Geophysics; it may also contain courses on general or teaching skills. Another alternative is a placement period in an outside organisation. This stream may also be omitted and the credits reassigned to other streams.

This structure is based on a 3 year bachelor degree, but it could equally cover the first 3 years of an integrated degree or even a 4 year bachelor. In the case of a 4 year bachelor degree, it is possible that the credit allocations would be larger in some streams. Credit allocations are indicative not precise values. Most modules/course units on a degree programme should be allocated to one area based on their content, even if they also cover part of another stream. However occasionally they may need to be split between areas.

The streams are indicated in the following table. Overall at least 140 of the normally 180 credits would have to be in physics and maths; that is in the first 5 streams. Notional credit values for each stream are in the range 20-40, with the exception of the optional stream which is 0-40. The tables are not intended to specify a temporal order of the subjects or a grouping in modules or other units.

Physics Bachelor degree

At least 140/180 credits in physics & maths

- **Mechanics & Thermodynamics** (20-40 credits)
  Classical mechanics, Thermodynamics and kinetic theory, Special relativity, Advanced classical mechanics, Background to quantum mechanics.

- **Optics & Electromagnetism** (20-40 credits)
  Oscillations & waves, Basic optics, Electromagnetism, Advanced Electrodynamics and Optics

- **Quantum Physics** (20-40 credits)
  Quantum mechanics, Statistical mechanics, Solid state physics, Atomic, nuclear and particle physics,

- **Experimental/laboratory** (20-40 credits)
  Laboratory work, Project work

- **Mathematics & computing** (20-40 credits)
  Mathematics, IT skills & Modelling

- **Optional subjects** (0-40 credits)
  A minor subject (or subjects) either related to Physics or totally unrelated.

A more detailed structure for the benchmark is given in the table on the following 2 pages. In order to keep this table to a reasonable size the topics have been given as headings which should be understandable to physicists. It has become usual to specify learning outcomes for particular modules, this is not done in this case to save space and avoid repetition. Each of the items contained in this listing will refer to several learning outcomes.

In addition to general physics bachelor programmes, departments may offer interdisciplinary or specialised bachelor programmes (e.g. aimed at future physics teachers or to other professional fields). Such programmes are not primarily designed to prepare for a Physics Master and may not contain all the subjects listed in this document, or treat them in the breadth envisaged here. In general, there will be arrangements to grant graduates of such programmes access to physics master programmes as well, but such arrangements may involve restrictions on the electives chosen, or "bridging courses" to be covered before or during the master programme.

5. Detailed structure

Mechanics and Thermodynamics	**Optics & Electromagnetism**	**Quantum Physics**
20-40 ECTS credits	20-40 ECTS credits	20-40 ECTS credits
Classical mechanics • Newton's laws and conservation laws including rotation • Newtonian gravitation to the level of Kepler's laws **Thermodynamics and kinetic theory of gases** Zeroth, first and second laws of thermodynamics to include: • Temperature scales, work, internal energy and heat capacity • Entropy, free energies and the Carnot Cycle • Kinetic theory of gases and the gas laws to the level of the van der Waals equation • The Maxwell-Boltzmann distribution • Statistical basis of entropy • Changes of state **Special relativity** • to the level of Lorentz transformations and the energy-momentum relationship **Advanced classical mechanics** Elements of Lagrangian and Hamiltonian mechanics. **Background to quantum mechanics** • Black body radiation • Photoelectric effect • Wave-particle duality • Heisenberg's Uncertainty Principle	**Oscillations & 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 **Basic optics** • Geometrical optics to the level of simple optical systems • The Electromagnetic spectrum • Interference and diffraction at single and multiple apertures • Dispersion by prisms and diffraction gratings • Optical cavities and laser action **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 **Advanced Electrodynamics and Optics** • Maxwell's equations and plane electromagnetic wave solution; Poynting vector Polarisation of waves and behaviour at plane interfaces	**Quantum mechanics** 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 **Statistical mechanics** • Bose-Einstein and Fermi-Dirac distributions • Density of states and partition function **Atomic, nuclear and particle physics** • 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 **Solid state 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

Experimental & laboratory work	**Mathematics & computing**	**Optional subjects**
20-40 ECTS credits	20-40 ECTS credits	0-40 ECTS credits
Laboratory work • 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. **Project work** 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	**Mathematics** • 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 **IT skills & Modelling** • Wordprocessing packages • Data analysis and manipulation packages • Data calculation & presentation • Information searching • (A) Programming language(s) • Modelling of physical systems	A minor subject (or subjects) either related to Physics or totally unrelated. This stream may also be omitted and the credits reassigned to other streams. **Examples include:** • Foreign language skills • Chemistry • Electronics • Astronomy & Astrophysics • Medical Physics • Geophysics • Biophysics • Meteorology This theme may also include courses on generic and/ or teaching skills **Industrial Placement** Some degree programmes may include a placement in industry or other external organisation for up to one semester.

6. Implementation

The present scheme has some analogies with the Eurobachelor[8] model of the European Association of Chemical and Molecular Sciences. However, we do not propose to follow their procedure in all particulars. We suggest physics departments self-certify their programmes as being consistent with these benchmarks or not, and if not give their reasons. These statements could be monitored in the course of existing quality assurance procedures.

The next step involves finalising the document and getting approval for this document, first from a broad majority of STEPS TWO partners and then from a wider group,. After final validation by STEPS TWO we aim to get approval by the EPS and national Physical societies.

7. References

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[1] http://www.asiin.de/english/download/crit_tc13.pdf

[2] http://www.qaa.ac.uk/academicinfrastructure/benchmark/statements/Physics08.pdf

[3] http://www.eupen.ugent.be/

[4] http://www.stepstwo.eu/

[5]http://www.tuning.unideusto.org/tuningeu/index.php?option=com_docman&Itemid=59&task=view_category&catid=19&order=dmdate_published&ascdesc=DESC

[6] http://www.kfp-physik.de/dokument/Empfehlungen_Ba_Ma_Studium.pdf

[7] http://www.iop.org/activity/policy/Degree_Accreditation/file_26578.pdf

[8] http://ectn-assoc.cpe.fr/eurobachelor/