COURSE OUTLINE

(1) GENERAL

SCHOOL	School of Science		
ACADEMIC UNIT	Physics		
LEVEL OF STUDIES	Undergraduate (Postgraduate course offered to undergraduate students)		
COURSE CODE	**10EK412**	**SEMESTER**	**8**
COURSE TITLE	**ELEMENTARY PARTICLES**		
INDEPENDENT TEACHING ACTIVITIES *if credits are awarded for separate components of the course, e.g. lectures, laboratory exercises, etc. If the credits are awarded for the whole of the course, give the weekly teaching hours and the total credits*		**WEEKLY TEACHING HOURS**	**CREDITS**
Lectures		4	6
COURSE TYPE *general background, special background, specialised, general knowledge, skills development*	Specialised Knowledge		
PREREQUISITE COURSES:	No		
LANGUAGE OF INSTRUCTION and EXAMINATIONS:	Greek		
IS THE COURSE OFFERED TO ERASMUS STUDENTS	Yes (in the English language for Erasmus students)		
COURSE WEBSITE (URL)	https://eclass.uoa.gr/courses/PHYS236/		

(2) LEARNING OUTCOMES

Learning outcomes

The course learning outcomes, specific knowledge, skills and competences of an appropriate level, which the students will acquire with the successful completion of the course are described.

Consult Appendix A

- *Description of the level of learning outcomes for each qualifications cycle, according to the Qualifications Framework of the European Higher Education Area*
- *Descriptors for Levels 6, 7 & 8 of the European Qualifications Framework for Lifelong Learning and Appendix B*
- *Guidelines for writing Learning Outcomes*

The course offers to the student the necessary knowledge for the understanding of basic concepts and methods of particle physics, starting from the phenomenology of particle interactions and closing with the completion of the modern picture for the nature of matter and its fundamental interactions, the Standard Model. Upon completion of the course the student is able to:

- To handle easily the tools for computing cross sections, decay rates, and phase space of elementary particles (fermion and boson basis states in cartesian and polar coordinates, algebra of Dirac matrices, trace theorems and techniques, multidimensional phase space integrals).
- To apply the Feynman rules of fundamental interactions in "tree-level" Feynman diagrams (without loops of virtual particles) and using them to extract the fundamental observables of elementary particle reactions (cross sections or decay rates) at the lowest perturbative order.
- To know the effect of higher-order corrections (with loops of virtual particles) on the physical characteristics of elementary particles and on the observables of particle reactions.
- To interpret qualitatively the results of advanced calculations of observables and how are these compared to corresponding experimental results.
- To understand the purpose, conceptual design, requirements and results of elementary particle physics experiments.
- To understand in depth the symmetries characterising the elementary particles of matter and their interactions (space-time discrete and continuous symmetries, global and local gauge symmetries, flavour symmetries), the breaking mechanism of continuous symmetries and their consequences.
- To understand in depth the questions left unanswered by the Standard Model.

General Competences

Taking into consideration the general competences that the degree-holder must acquire (as these appear in the Diploma Supplement and appear below), at which of the following does the course aim?

Search for, analysis and synthesis of data and information, with the use of the necessary technology
Adapting to new situations
Decision-making
Working independently
Team work
Working in an international environment
Working in an interdisciplinary environment
Production of new research ideas

Project planning and management
Respect for difference and multiculturalism
Respect for the natural environment
Showing social, professional and ethical responsibility and sensitivity to gender issues
Criticism and self-criticism
Production of free, creative and inductive thinking
……
Others…
…….

The course aims at the following general competences:

- Search for, analysis and synthesis of data and information, with the use of the necessary technology.
- Working independently.
- Analytical and synthetic thinking.
- Critical thinking.
- Problem solving.

(3) SYLLABUS

1. Review (4 hours)

- Klein-Gordon equation, Dirac equation. Antiparticles and spin. Algebra of Dirac matrices.
- Feynman diagrams and invariant amplitude of a physical process. Decays, scattering, cross section. Phase space and its integration.

2. Leptons and Quantum Electrodynamics (10 hours)

- Interactions, gauge theories, "discovery" of electromagnetism.
- Electrodynamics of spinless particles: interaction of a pion with the electromagnetic field. Feynman diagrams and rules, photon propagator.
- The scattering processes $\pi^+K^+ \rightarrow \pi^+K^+$, $\pi^+\pi^+ \rightarrow \pi^+\pi^+$, $\pi^+\pi^- \rightarrow \pi^+\pi^-$.
- Electrodynamics of particles with spin: interaction of an electron with the electromagnetic field. Feynman diagrams and rules.
- The processes $e^+e^- \rightarrow \mu^+\mu^-$, $e^+e^- \rightarrow e^+e^-$, $e^-\mu^+ \rightarrow e^-\mu^+$. Compton scattering.

3. Higher order corrections (4 hours)

- Qualitative analysis of charge and mass renormalisation. The "running" coupling constant.

4. Hadrons and Quantum Chromodynamics (10 hours)

- Nucleon and meson phenomenology. Electron-proton scattering.
- Deep inelastic scattering. Parton model and structure functions. Scale evolution equations and fragmentation functions.
- Colour and SU(3). Feynman diagrams and rules. Parton scattering, the processes $qq \rightarrow qq$, $qg \rightarrow qg$, $gg \rightarrow gg$. Drell-Yan process.
- Qualitative description of hadronic reactions.

5. Weak interactions (10 hours)

- Parity violation and V−A form of the weak current. Fermi model and weak decays of leptons and hadrons.
- Modern picture via W boson exchange. Lepton flavour universality. β decay. Partially conserved axial currents.
- Neutrino-quark scattering. Neutrino deep inelastic scattering. Weak currents. Elastic neutrino-electron scattering.

6. The Standard Model (8 hours)

- Electroweak theory: $SU(2)\times U(1)$, $W^\pm$, Z and γ bosons.
- Spontaneous symmetry breaking, Nambu-Goldstone and Brout-Englert-Higgs mechanisms.
- The complete Standard Model, physics of W and Z bosons. Production and decay of b and t quarks. Discovery of the Higgs boson.

7. CP and CPT symmetries (4 hours)

- Heavy neutral meson mixing.
- Discovery of CP violation in neutral kaons. CP violation in other neutral mesons.

8. Masses of neutrinos (2 hours)

- Neutrino oscillations. Nature of neutrinos (Dirac/Majorana) and masses.

(4) TEACHING and LEARNING METHODS - EVALUATION

<table>
<tr><td>DELIVERY
Face-to-face, Distance learning, etc.</td><td>Face-to-face</td></tr>
<tr><td>USE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY
Use of ICT in teaching, laboratory education, communication with students</td><td>Yes

Electronic communication with the students using ICT.
Computer-aided lectures, eclass platform</td></tr>
<tr><td>TEACHING METHODS
The manner and methods of teaching are described in detail.
Lectures, seminars, laboratory practice, fieldwork, study and analysis of bibliography, tutorials, placements, clinical practice, art workshop, interactive teaching, educational visits, project, essay writing, artistic creativity, etc.

The student's study hours for each learning activity are given as well as the hours of non-directed study according to the principles of the ECTS</td><td>
<table>
<tr><th>Activity</th><th>Semester workload</th></tr>
<tr><td>Lectures</td><td>52</td></tr>
<tr><td>Individual Study / Study and Analysis of bibliography / Preparation</td><td>48</td></tr>
<tr><td>Projects</td><td>50</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Course Total</td><td>150</td></tr>
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<tr><td>STUDENT PERFORMANCE EVALUATION
Description of the evaluation procedure

Language of evaluation, methods of evaluation, summative or conclusive, multiple choice questionnaires, short-answer questions, open-ended questions, problem solving, written work, essay/report, oral examination, public presentation, laboratory work, clinical examination of patient, art interpretation, other

Specifically-defined evaluation criteria are given, and if and where they are accessible to students.</td><td>4 individual projects written in greek or english on 4 topics of the course (Quantum Electrodynamics, Quantum Chromodynamics, weak interaction and discrete symmetries, gauge theories and Standard Model)</td></tr>
</table>

(5) ATTACHED BIBLIOGRAPHY

- Suggested bibliography:

- André Rubbia, *Phenomenology of Particle Physics*, Cambridge 2022
- Mark Thomson, *Modern Particle Physics*, Cambridge 2014
- Brian R. Martin and Graham Shaw, *Particle Physics*, Wiley 2017
- David Griffiths, *Introduction to Elementary Particle Physics*, Wiley 2016
- Francis Halzen & Alan D. Martin, *Quarks and Leptons: An Introductory Course in Modern Particle Physics*, Wiley 2008
- Ian J. R. Aitchison & Anthony J. G. Hey, *Gauge Theories in Particle Physics: A Practical Introduction*, Vol. 1 & 2, CRC Press 2013
- Ta-Pei Cheng & Ling-Fong Li, *Gauge Theory of Elementary Particle Physics*, Oxford 2000
- Peter Renton, *Electroweak Interactions: An Introduction to the Physics of Quarks and Leptons*, Cambridge 1990
- Sidney Coleman, *Aspects of Symmetry*, Cambridge 1988

- Related academic journals:

- Physical Review D, Physical Review Letters (APS)
- Physics Letters B (Elsevier)
- Journal of High Energy Physics (Springer)
- European Physics Journal C (Springer)