UNIVERSITY OF SARAJEVO

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

CURRICULUM FOR THE ACADEMIC YEAR 2023/2024

PHYSICS

THIRD CYCLE

GENERAL INFORMATION ABOUT THE STUDY PROGRAM

NAME OF THE STUDY PROGRAM:	Physics
TYPE OF THE STUDY PROGRAM:	University Study Program
LEVEL OF THE STUDY PROGRAM:	Third Cycle of Higher Education
GOALS OF THE STUDY PROGRAM:	• Acquiring essential knowledge and skills which qualify students for independent scientific research in one of the following fields: condensed matter physics, atomic, molecular and optical physics, high energy physics, applied physics • Acquiring abilities to recognize and define research topics, abilities to choose and exploit appropriate research methodology, as well as the abilities to draw conclusions on the basis of the research results • Developing abilities for systematic solving of various problems in the relevant fields. • Developing communication, social, mathematical, computer and research skills.
PROVIDER OF THE STUDY PROGRAM:	University of Sarajevo – Faculty of Science, Department of Physics
SCIENTIFIC AREA OF THE STUDY PROGRAM:	Physics
STRUCTURE OF THE STUDY PROGRAM:	Doctoral study is organized in the following fields: condensed matter physics, atomic, molecular and optical physics, high energy physics and applied physics. Teaching and scientific research process is organized through lectures, seminars and exercises as well as through the preparation and defense of the draft version and the final version of the doctoral dissertation. During the first year of studies, students attend one obligatory and five elective courses, out of which at least three courses are from the field of the envisaged doctoral dissertation. Remaining two courses can be chosen from any other field, in accordance with the topic of the doctoral dissertation and personal preferences of the student. At the beginning of the studies, students together with their supervisors, choose elective courses that will help them to prepare and defend their doctoral dissertation in the best way possible. During the second and the third year of studies, students conduct activities related to preparation and defense of their doctoral dissertation.
DURATION OF THE STUDY PROGRAM:	The duration of the study program is three (3) years (six semesters).
LANGUAGE OF THE STUDY PROGRAM:	Bosnian/Croatian/Serbian and/or English language
ENROLMENT REQUIREMENTS AND SELECTION PROCEDURE:	The doctoral study can be enrolled by the applicants that hold the appropriate 1st and 2nd cycle degree of studies or integrated studies with at least 300 ECTS credits, as well as the holders of master of science degree. Furthermore, to be eligible for enrolment prospective applicant must have minimum 7,5 average grade in the first and second cycle of studies. When applying, applicants must also enclose a written consent of the potential supervisor/mentor.
INFORMATION ON QUALIFICATION:	Title of qualification: Doctorate in Physics Level of qualification: Third cycle of higher education; Level 8 in National qualifications framework
EMPLOYMENT POSSIBILITIES:	Degree of doctorate of science in physics qualifies the holder to

	independently teach courses from the appropriate filed of physics and conduct scientific research at the university level and at scientific institutes. Besides that, the holder of the degree is qualified to work in other institutions, firms, and companies that require adequate theoretical and applied knowledge.
EVALUATION OF STUDENT'S WORK:	During the first year of studies, the work of the candidate is evaluated through the assessment of the required obligations, that is through the examinations in obligatory and elective courses. During the third semester, the candidate prepares a proposal of the doctoral dissertation project which is evaluated through defense in front of the appointed committee. During the fourth and fifth semester, the candidate prepares a draft version of the doctoral dissertation to be evaluated in front of the previously appointed committee. Finally, in the last semester, the candidate defends the final version of the doctoral dissertation.
STUDY PROGRAM LEARNING OUTCOMES:	**Learning outcomes specific to physics** The degree holders are capable of: • Competently using terms and formalisms of the given area of physics in order to analyze appropriate physical phenomena and processes, • Defining topics from the given area of physics that will be used for conducting research in accordance with methodology of that area, • Conducting original research and providing personal scientific contribution aimed at broadening of current knowledge in the given area of physics. **Generic learning outcomes** The degree holder is expected to: • Perform critical analysis, evaluation and synthesis of new and complex ideas, • Independently conduct research and present research results in scientific publications and at scientific meetings, • Competently communicate with colleagues, wider scientific community and society in general in the area of their expertise, • Apply recognized ethical codex in his/her research, • Promote technological, social and cultural advancement within academic and professional community in a society based on knowledge.
ELECTIVE COURSES:	Every academic year, Doctoral Studies Council accepts the list of possible elective courses and decides on their implementation in accordance with the current staff and material resources as well as the needs and the interest of the students.
COMPLETION OF THE STUDY:	Students complete the doctoral study upon passing all the exams specified in teaching curriculum and successfully defending the final version of the doctoral dissertation.

LIST OF COMPULSORY AND ELECTIVE COURSES

SEMESTER	I		II	ECTS CREDITS
COURSES	CODE	HOURS	HOURS	
Methodology of scientific research in physics	**PTH7001**	**30**		**10**
Elective course		**30**		**10**
Elective course		**30**		**10**
Total ECTS credits				**30**
Elective course			**30**	**10**
Elective course			**30**	**10**
Elective course			**30**	**10**
Total ECTS credits				**30**

SEMESTER	III	IV	V	VI	ECTS CREDITS
COURSES	CODE	CODE	CODE	CODE	
PhD research I	PHY9011				**30**
PhD research II		PHY9021			**30**
PhD research III			PHY9031		**30**
PhD research IV				PHY9041	**20**
PhD thesis defense				PHY9051	**10**
Total ECTS credits for the complete study					**180**

LIST OF POSSIBLE ELECTIVE COURSES

CONDENSED MATTER PHYSICS		
COURSES	**CODE**	**ECTS CREDITS**
Surface analysis of materials	PCM7011	**10**
Superfluidity and superconductivity	PCM7021	**10**
Thermal and structural analysis of materials	PCM7031	**10**
Percolation Theory	PCM7041	**10**
Data acquisition	PCM7051	**10**
Electrochemistry for materials science	POT7061	**10**

ATOMIC, MOLECULAR AND OPTICAL PHYSICS		
COURSES	**CODE**	**ECTS CREDITS**
Advanced quantum mechanics	PTH7011	**10**
Physics of atoms and ions	PTH7021	**10**
Computational physics	PTH7031	**10**
Path integrals and semiclassical physics	PTH7041	**10**
Advanced statistical physics	PTH7051	**10**
Molecules in the laser field	PTH7061	**10**
Quantum collision theory	PTH7071	**10**
Theory of multiphoton processes	PTH7081	**10**
Advanced course in electrodynamics	PTH7091	**10**
Machine learning and artificial neural networks in physics	PCS8011	**10**

HIGH ENERGY PHYSICS		
COURSES	**CODE**	**ECTS CREDITS**
Advanced quantum field theory	PTH8011	**10**
Advanced elementary particle physics	PTH8021	**10**
Symmetries in elementary particle physics	PTH8031	**10**
Medium energy particle physics	PTH8041	**10**

APPLIED PHYSICS		
COURSES	**CODE**	**ECTS CREDITS**
Advanced radiological imaging	PAP7011	**10**
Advanced medical physics	PAP7021	**10**
Optical fiber sensors	PAP7031	**10**
Microcontrollers in physics	PAP7041	**10**
Accelerator physics I	PAP7051	**10**
Advanced experimental techniques in nuclear physics	PAP7061	**10**
Monte Carlo simulations in radiations physics	PAP7071	**10**
Applications of radiation and nuclear physics	PAP7081	**10**

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**METHODOLOGY OF SCIENTIFIC RESEARCH IN PHYSICS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH7001	**I**	**Mandatory**	**10**	**30**

Course aims and expected learning outcomes	Students become familiar with the basis of methodology in scientific research work and statistics in physics research. Students master basis of scientific writing.

COURSE CONTENT

Why and how to perform the research in physics.

Scientific procedure, difficulties in engaging in scientific research work in physics.

Preparations before research, research design, sample, hypothesis.

Types of scientific research by level and purpose, research projects, preliminary research.

Statistics in physics research, summarizing and presentation of the results, and choice of statistical methods.

Basic information on scientific writing.

Categorization of publications.

Authorship and co-authorship.

Preparing to write a publication, write a review, write a professional article, send a manuscript to a journal, respond to an editor's decision.

<table>
<tr><th>LITERATURE</th><th colspan="2">ASSESSMENT OF LEARNING</th></tr>
<tr><td rowspan="6">Mandatory literature:
- Vlatko Silobrčić, Kako sastaviti, objaviti i ocijeniti znanstveno djelo, HAZU, Zagreb, 2010.

- Zoran V. Popović, Kako napisati i objaviti naučno delo, drugo izdanje, Akademska misao, Beograd i Institut za fiziku, Zemun, 2004.

Broader literature:
- Midhat Šamić, Kako nastaje naučno djelo, Uvođenje u metodologiju i tehniku naučnoistraživačkog

rada – opći pristup, IX izdanje, IP „Svjetlost“ Sarajevo, 2003.

- Herbert L. Hirsch, Essential communication strategies for scientists, engineers, and tehnology professionals, John Wiley & Sons, New Jersey, 2003.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Homework</td><td>20</td></tr>
<tr><td>Seminar papers</td><td>40</td></tr>
<tr><td>Final exam</td><td>40</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
</table>

Remarks

LIST OF POSSIBLE ELECTIVE COURSES

CONDENSED MATTER PHYSICS

Study program	Type of study (cycle)		**Third Cycle**	
	Study program title		**Doctoral Study in Physics**	
Course title	**SURFACE ANALYSIS OF MATERIALS**			
Course code	Semester	Course status	ECTS credits	Teaching hours
	I /II	**ELECTIVE**	**10**	**30**
Course objectives and outcomes	**The aim of this course is to familiarize students with modern experimental techniques used to characterize advanced materials through active usage of analytical instruments.** **Learning outcomes:** - **to understand theoretical background of scanning electron microscopy (SEM) and atomic force microscopy (AFM).** - **to apply theoretical knowledge in experimental work.**			

Course content
Surface analysis. Basics of scanning electron microscopy (SEM). Characteristics of the JEOL-JSM IT 200L microscope. Practical examples. **Basics of atomic force microscopy (AFM). Characteristics of Nanosurf CoreAFM. Practical examples.** **When required, access to UV-vis spectrophotometer will be enabled to students.**

LITERATURE	EVALUATION OF STUDENT'S WORK	
[1] Peter Eaton, Paul West, Atomic Force Microscopy, Oxford University Press, USA, Year: 2010, eBook, ISBN: 0199570450,9780199570454 [2] Joseph Goldstein, Dale E. Newbury, David C. Joy, Charles E. Lyman, Patrick Echlin, Eric Lifshin, Linda Sawyer, J.R. Michael, Scanning Electron Microscopy and X-ray Microanalysis, Springer, Year: 2003, eBook, ISBN: 0306472929,9780306472923	Type of evaluation	Points
	Seminar paper	100
	Total	100

Remark
Students propose a subject of their investigation for the seminar paper in accordance with their interests and available materials. The proposal needs to be accepted by the course professor. The research includes obligatory experimental work in the area of surface characterization methods. The research results are to be written in the form of scientific paper and presented orally.

Study program	Level of studies	Third cycle		
	Title of the study program	Doctoral studies in physics		
Course title	SUPERFLUIDITY AND SUPERCONDUCTIVITY			
Course ID	Semester	Course status	ECTS credits	Teaching hours
ŠIFRA	**I /II**	**Elective**	**10**	**30**
Course aims and expected learning outcomes	**The aim of the course is to get acquainted with the phenomena of superfluidity and superconductivity.** **Learning outcomes:** **- understands the theoretical basics of superfluidity,** **- understands the theoretical basics of superconductivity,** **-applies theoretical knowledge in the experimental work.**			

COURSE CONTENT

Superfluidity: historical and physical introduction to superfluidity; Helium; Superfluids and Condensates.

Superconductivity: Historical and physical introduction to superconductivity; Supercondacting materials, Model of two fluids; Thermodynamics of superconducting state; London equations; Pippards theory/equation; Ginzburg – Landau theory; Bardeen – Cooper – Schrieffer theory; Josephson effect; Applications of superconductivity.

LITERATURE	ASSESSMENT OF LEARNING	
[1]Prof. dr. sc. Amir Hamzić, Suprafluidnost i supravodljivost, PMF Zagreb (2010); [2] James F. Annett, Superconductivity, Superfluids and Condensates, Oxford University press (2005); [3] P. Kapitza, Nature 141, 74, (1938); [4] J. F. Allen, A. D. Misener, Nature 141, 75, (1938); [5] C. Pethcik, H. Smith, Bose-Einstein Condensation in Dilute Gases, New York: Cambridge University Press (2008); [6] C. Kittel, Quantum Theory of Solids, John Wiley&sons, (2005); [7] J. Solyom, Fundamentals of the Physics of Solids, I, II, III, Springer (2007 – 2010);	Assessment Method	Points
	Seminar paper	30
	Final (oral)exam	70
	Total	100
	Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">THERMAL AND STRUCTURAL ANALYSIS OF MATERIALS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>ŠIFRA</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The aim of the course is to get acquainted with the experimental techniques for thermal and structural analysis.

Learning outcomes:

- understands the theoretical basics of thermal analysis,

- understands the theoretical basics of structural analysis,

-applies theoretical knowledge in the experimental work.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Thermal analyzes in general, Differential scanning calorimetry, annealing furnaces in inert and room atmospheres;

Structural analysis in general, X-ray diffraction;

If necessary, as a complementary technique, a device for measuring the microhardness of materials will be available to the students.</td></tr>
</table>

<table>
<tr><td rowspan="2">LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td>Assessment Method</td><td>Points</td></tr>
<tr><td rowspan="5">[1] Michael E. Brown, Introduction to Thermal Anaysis (Techniques and Applications), Kluwe Academic Publisher, 2004, eBook ISBN 0-306-48404-8

[2] <u>Mark Ladd</u>, <u>Rex Palmer</u>, Structure Determination by X-ray Crystallography, Springer, 2014, eBook ISBN 978-1-4614-3954-7</td><td>Seminar paper</td><td>100</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="3">Remarks</td></tr>
<tr><td colspan="3">According to interest and available materials for analysis, the student proposes a research topic, which is confirmed by the instructor. Research must include experimental work in the field of thermal or structural analysis. Research results are written in the form of a scientific paper and presented orally.</td></tr>
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<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">PERCOLATION THEORY</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PCM7041</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The course aims to acquire knowledge and competencies in the percolation theory; introduce basic percolation models; determine the percolation threshold; introduce the random sequential adsorption model and its connection with percolation.

Learning outcomes:

* qualitatively and quantitatively explain percolation theory and explain different percolation models;

* determine the percolation threshold in the classic percolation model;

* explain and apply the random sequential adsorption model.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Introduction to Percolation Theory. Types of percolation models - classical, explosive, invasion, bootstrap and correlated percolation. Exact solution for a 1D Bethe lattice. Cluster structure. Finite-size scaling. Application of percolation. The random sequential adsorption (RSA) model and its relation to percolation.</td></tr>
</table>

<table>
<tr><td>LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td rowspan="6">1. D. Stauffer, A. Aharony, Introduction to Percolation Theory, Taylor& Francis, London, 1992.
2. N.E. Cusak, The Physics of Structurally Disordered Matter, Adam Higler, Bristol, 1988.
3. A. Bunde, S.Havlin , Eds., Fractala and Disordered Systems, Springer, Berlin, 1996.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Seminar paper</td><td>100</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="3">Remarks</td></tr>
<tr><td colspan="3">In the seminar paper, theoretical knowledge from percolation theory will be applied to concrete results of Monte-Carlo simulations.</td></tr>
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<table>
<tr><td rowspan="2">Study program</td><td>Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td>Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">DATA ACQUISITION</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PCM7051</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The goal of this course is to introduce students to the real-time data acquisition using PC and different platforms for mesuring sensor signals and communication with the measuring devices.

It is expected that after finishing the course, student will be able to write source code and implement data acquisition protocols needed for experiments.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Sensor types and implementation – temperature sensors, optical sensors, force and pressure sensors, magnetic field sensors, position senzors, etc. Analog to digital and digitial to analog converters. Communication with measuring devices. Platforms for interaction with sensors. PC hardware for communication with sensors and measuring devices. Software for data acquisition.

Introduction to Python. Communication with sensors and measuring devices using Python.

Practical implementation – communication between PC and measuing devices using serial and parallel ports.</td></tr>
<tr><td colspan="3">LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td colspan="3" rowspan="4">1. Lecture notes.
2. M. Di Paolo Emilio, Data Acquisition System: From Fundamentals to Applied Design (Springer New York, 2013).
3. Pyvisa: Control your instruments with Python (https://pyvisa.readthedocs.io/en/latest/).
4. NI-VISA: Programmer Reference Manual.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Final exam</td><td>40</td></tr>
<tr><td>Practical work</td><td>60</td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="5">Remarks</td></tr>
<tr><td colspan="5">Practical work will require from students to implement thereotical knowledge in real-world experiment and to write a report which will be presented and defended.</td></tr>
</table>

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**ELECTROCHEMISTRY FOR MATERIALS SCIENCE**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
POT7061	**I /II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	**In the frame of the course student acquire basic knowledge in electrochemistry necessary for understanding of energy conversion and storage, corrosion and protection of materials and research and development of smart materials. After succesful completion of the course student is familiar with electrochemical fundamentals and methods necessary for research, development and production of photovoltaics, lithium ion and other battery materials, active materials for electrocehmical supercapacitors and catalytic and memvrane materials for fuel cells and water electrolysers. Furthermore, students will be familiar with electrochemical aspects of hydrogen technologies, electrochemical sensors and development of smart materials, and will gain fundamental competence in corrosion research and engineering.**

COURSE CONTENT

Thermodynamics of electrode processes; Kinetics of electrochemical cell processes; Mass transport, diffusion and migration; Buttler-Volmer equation; Electrocatalysis – role of the material and crystalographic orientation; Electrochemical aspect of corrosion; Kinetics of new phase formation; Models of electrical double layer; Supercapacitor, capacitance and pseudocapacitance; Materials for supercapacitors; Electrochemical systems for energy storage; Materials for electrochemical systems for energy storage; Electrochemical systems for energy conversion; Materials for electrochemical systems for energy conversion; Electrochemical sensors and smart materials; Voltametric techniques; Electrochemical impedance spectroscopy; Electrochemical quartz microbalance; Scanning electrochemical microscopy; Electrochemical instruments, potenciostats/galvanostats, amplifiers.

LITERATURE

1. S. Mentus, Elektrohemija, Univerzitet u Beogradu – Fakultet za fizičku hemiju, Beograd
2. A.J. Bard, L.R. Faulkner, Electrochemical methods. Fundamentals and Applications, 2nd ed. Wiley, 2001.

ASSESSMENT OF LEARNING

Assessment Method	Points
Seminar paper	60
Final exam	40
Final exam	
Total	100

Remarks

LIST OF POSSIBLE ELECTIVE COURSES

ATOMIC, MOLECULAR AND OPTICAL PHYSICS

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**ADVANCED QUANTUM MECHANICS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH7011	**I/II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	The aim of the course is to familiarize students with the concepts and mathematical apparatus of quantum mechanics. Unlike quantum mechanics, which is studied in lower cycles, this advanced quantum mechanics course uses a deductive approach that is more suitable for researchers in theoretical physics.

COURSE CONTENT

Fundamentals of quantum mechanics.

Postulates of quantum mechanics. Dynamics of quantum mechanics.

The uncertainty relation.

The two-particle problem.

Galileo's transformations. Angular momentum theory.

Discrete, dynamical and internal symmetries.

Identical particles.

Approximations in quantum mechanics. Second quantization. Scattering theory.

Path-integral method.

Relativistic quantum mechanics.

LITERATURE	ASSESSMENT OF LEARNING	
F. Herbut, *Kvantna mehanika za istraživače*, Fizički fakultet, Univerzitet u Beogradu, 1999. Broader literature: D. Milošević, *Relativistička kvantna mehanika*, Univerzitetski udžbenik, bosniaARS, Tuzla, 2005 B. H. Bransden, C. J. Joachain, *Quantum mechanics*, Prentice Hall, Harlow, 2000. A. Messiah, *Quantum mechanics*, North-Holland, Amsterdam, 1968. C. Cohen-Tannoudji, B. Diu, F. Laloe, *Quantum mechanics*, Wiley, New York, 1977. E. Merzbacher, *Quantum mechanics*, Wiley, New York, 1997. L. I. Šif, *Kvantna mehanika*, Vuk Karadžić, Beograd, 1968. I. Supek, *Teorijska fizika i struktura materije*, II dio, Školska knjiga, Zagreb, 1977. A. S. Davidov, *Kvantovaja mehanika*, Nauka, Moskva, 1973. F. Schwabl, *Advanced quantum mechanics*, Springer, Berlin, 1999.	Assessment Method	Points
	Homework	20
	Seminar papers	40
	Final exam	40
	Total	100

Remarks

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**PHYSICS OF ATOMS AND IONS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH7021	**I /II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	**The aim of the course is for students to deepen their knowledge of the physics of atoms and ions, quantum mechanical description of the states of hydrogen-like atoms and multi-electron atoms and ions. The student will master the concepts, phenomena and quantum mechanical apparatus of the physics of atoms and ions, and distinguish the models used for the quantum mechanical description of neutral atoms and ions. The student will also be familiar with the description of atoms in external fields.**

COURSE CONTENT

Hydrogen atom. Fine level splitting. Lamb shift. Grotrian diagram.
Photoionization of a one-electron atom. Hydrogen-like atoms.
Two-electron atoms and ions. Pauli's principle and symmetry of the wave function. Self-consistent field for two-electron and multi-electron atoms and ions.
Light atoms. Scale model. Asymptotic wave function. Fine splitting of light atom levels. Atoms and ions with valence s-electrons.
Atoms and ions with valence p-electrons. Structure of heavy atoms. Atoms with valence d and f electrons.
Thomas-Fermi model of the atom. Exchange effects. Schemes of summation of electronic moments in atoms. Correlation and collective effects.
Excited atoms. Meta-stable and resonantly excited atoms.
Generation and detection of meta-stable atoms. Generation and detection of highly excited atoms.
Positive and negative ions. Multiple ions. Electronic wave function of negative ions. Photodetachment.

LITERATURE	ASSESSMENT OF LEARNING	
- Boris M. Smirnov, *Physics of Atoms and Ions*, Springer, New York, 2003.	Assessment Method	Points
- I. Supek, *Teorijska fizika i struktura materije*, II dio, Školska knjiga, Zagreb, 1977.	Homework	30
- L. D. Landau, E. M. Lifšic, *Teoretičeskaja fizika. Tom III: Kvantovaja mehanika. Nereljativistkaja teorija*, Nauka, Moskva, 1989.	Seminar paper	30
- W. Greiner, *Quantum mechanics. Special chapters*, Springer, Berlin, 1998.	Final exam	40
	Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">COMPUTATIONAL PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH7031</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The aim of the course is that student acquire competences in numerical methods and their application in modeling various physical systems. Each project assignment consists of modeling and solving some of the physical problems that are related to students' PhD thesis work. Student will become familiar with available models and modeling techniques and trained to solve specific physical problems in that manner.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Comparison of programming languages Fortran – C/C++ – Pyton.
Special functions. Solving linear algebraic equations. The eigenvalue problem. Laplace equation, heat conduction equation.
Monte Carlo methods. Minimization and maximization of functions.
Fourier transforms and spectral methods.
Nonlinear systems.
Application of higher level software packages - Matlab (Octave), Mathematica. Using the GSL libraries. Parallelization.
Project Jupyter (Jupyter Notebook, JupyterHub, and JupyterLab).</td></tr>
<tr><td colspan="3">LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td colspan="3" rowspan="7">- W.H. Press, S.A. Teukolsky, W.T. Vetterling, B.P. Flannery, Numerical Recipes, Third Edition, Cambridge University Press 2007.

- M. Hjorth-Jensen, Computational Physics, University of Oslo, 2007.

- R.H. Landau, M.J. Páez Mejiá, C. C. Bordeianu, Computational Physics: Problem Solving with Python, 3rd Edition, Wiley- VCH 2015

- D. Landau and K. Binder, Guide to Monte Carlo Simulations in Statistical Physics, Third Edition, Cambridge University Press 2009.

- GSL Reference Manual, https://www.gnu.org/software/gsl/</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Homework</td><td>30</td></tr>
<tr><td>Seminar paper</td><td>30</td></tr>
<tr><td>Final exam</td><td>40</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="5">Remarks</td></tr>
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<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">PATH INTEGRALS AND SEMICLASSICAL PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH7041</td><td>I/II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">Introducing students to the concepts and mathematical apparatus of path integrals and semiclassical physics. Student should be able to apply this method when solving specific problems.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Basics of path integrals and solutions to simple problems. Semiclassical temporal evolution. Semiclassical trace formula. Gutzwiller formula for isolated orbits. Selected problems and applications.</td></tr>
<tr><td colspan="3">LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td colspan="3" rowspan="6">H. Kleinert, Path Integrals in Quantum Mechanics, Statistics, Polimer Physics, and Financial Markets, 5th ed., World Scientific, Singapore, 2009.

M. Brack, R. K. Bhaduri, Semiclassical Physics, Frontiers in Physics, Vol. 96, Addison Wesley, Reading, 1997.

R. P. Feynman, A. R. Hibbs, Quantum Mechanics and Path Integrals, McGraw-Hill, New York, 1965.

L. S. Schulman, Techniques and Applications of Path Integration, Wiley, New York, 1981.

W. Dittrich, M. Reuter, Classical and Quantum Dynamics – from Classical Paths to Path Integrals, 2nd ed., Springer-Verlag, Berlin, 1994.

D. J. Tannor, Introduction to Quantum Mechanics. A Time-Dependent Perspective, University Science Books, Sausalito, California, 2007.

M. C. Gutzwiller, Chaos in Classical and Quantum Mechanics, Springer-Verlag, New York, 1990.

C. Grosche, F. Steiner, Handbook of Feynman Path Integrals, Springer, 1998.

M. S. Child, Molecular Collision Theory, Dover, Mineola, New York, 1996.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Homework</td><td>20</td></tr>
<tr><td>Seminar papers</td><td>40</td></tr>
<tr><td>Final exam</td><td>40</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="5">Remarks</td></tr>
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</table>

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**ADVANCED STATISTICAL PHYSICS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH7051	**I/II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	The aim of the course is to expand the knowledge that students acquired during the statistical physics course. Expected learning outcomes: Mastering the knowledge, methods and mathematical apparatus of quantum statistics. Getting acquainted with various applications of quantum statistics.

COURSE CONTENT

Equilibrium quantum statistics. Formalism of quantum mechanics in Dirac notation. Basic concepts of quantum statistics. Basic results of equilibrium quantum statistics. The ideal gas of quantum particles. Non-equilibrium statistical operator. Linear response of the system and Green's function. The energy and entropy of a non-equilibrium ensemble. The second quantization and Wick's theorem. Phonons and the Debye theory of specific heat. Ferromagnetics at low and high temperatures. Kinematic levels in an optical excitation system. Microtheory of the dielectric constant. Superfluidity. Superconductivity.

LITERATURE

1. B. S. Tošić, *Statistička fizika*, Institut za fiziku Prirodno-matematičkog fakulteta, Novi Sad, 1978.
2. Đ. Mušicki: *Uvod u teorijsku fiziku II - Statistička fizika*, Izdavačko informativni centar studenata (ICS), ŠIP Srbija, Beograd, 1975.
3. I. Supek, *Teorijska fizika i struktura materije*, II dio, Školska knjiga, Zagreb, 1977.
4. L. D. Landau, E. M. Lifšic, *Teoretičeskaja fizika. Tom V (1): Statističeskaja fizika*, Nauka, Moskva, 1976.
5. B. S. Milić, S. M. Milošević, Lj. S. Dobrosavljević, *Zbirka zadataka iz teorijske fizike: Statistička fizika*, Naučna knjiga, Beograd, 1979.

ASSESSMENT OF LEARNING

Assessment Method	Points
Homeworks	20
Seminar paper	40
Final exam	40
Total	100

Remarks

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**MOLECULES IN THE LASER FIELD**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH7061	**I /II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	**Introduction to important concepts in the interaction of molecular systems and a strong laser field. Familiarization with the quantum-mechanical models by which we describe the mentioned interactions. Mastering the concepts and mathematical apparatus of strong-field molecular approximation and molecular low-frequency approximation.**

COURSE CONTENT

Quantum mechanical description of molecules. Electronic, vibrational and rotational energy states.
Symmetry. Basic molecular processes in a strong laser field and their geometry.
Above threshold (higher order) ionization. (Improved) strong-field molecular approximation.
Molecular low-frequency approximation.
Analysis of molecular spectra. Interference effects.
Effects of phase, laser pulse duration and ellipticity on molecular spectra.
Future research perspective.

LITERATURE	ASSESSMENT OF LEARNING	
	Assessment Method	Points
- S. H. Lin, A. A. Villaeys, and Y. Fujimura, *Advances in Multi-Photon Processes and Spectroscopy, Volume 19,* World Scientific, Singapore, 2010.	Homework	30
- P. W. Atkins and R. S. Friedman, *Molecular Quantum Mechanics*, Third Edition, Oxford University Press, Oxford, 1997.	Seminar paper	30
- I. N. Levine, *Quantum Chemistry*, Fifth Edition, Prentice-Hall, Upper Saddle River, New Jersey, 2001.	Final exam	40
- D. B. Milošević, *Strong-field approximation for ionization of a diatomic molecule by a strong laser field,* Phys. Rev. A **74**, 063404 (2006).		
- A. Szabo and N. S. Ostlund, *Modern Quantum Chemsitry-Introdution to Advanced Electronic Structure Theory,* First Edition, Revised, Dover Publications, NewYork, 1996.	Total	100

Remarks

Study program	Level of studies		**Third cycle**	
	Title of the study program		**Doctoral studies in physics**	
Course title	**QUANTUM COLLISION THEORY**			
Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH7071	**I/II**	**Elective**	**10**	**30**
Course aims and expected learning outcomes	The aim of the course is to expand knowledge of non-relativistic quantum collision theory. Expected learning outcomes: Mastering the mathematical apparatus of non-relativistic quantum collision theory. Getting acquainted with the applications of non-relativistic quantum collision theory. Ability to solve complex problems in non-relativistic quantum collision theory.			

COURSE CONTENT
Mathematical foundations. Scattering operator for a single particle. Scattering cross sections expressed by the S-matrix. Scattering particles with and without spin. Invariance principles and conservation laws. The Green's operator and the T-matrix. The Born series. Stationary states in the scattering process. Resonances. Dispersion relations and complex angular moments. Multichannel scattering: scattering operator, scattering cross sections, invariance principles and stationary wave functions. Multichannel resonances. Scattering of identical particles.

LITERATURE	ASSESSMENT OF LEARNING	
1. J. R. Taylor, *Scattering theory: The quantum theory of nonrelativistic collisions*, John Wiley & Sons, New York, 1972. 2. S. Sunakawa, *Kvantovaja teorija rassejanija*, Mir, Moskva, 1979. 3. Dževad Belkić, *Principles of quantum scattering theory*, Institut of Physics Publishing, Bristol, 2004. 4. C. J. Joachain, *Quantum collision theory*, North-Holland, Amsterdam, 1975. 5. L. D. Landau, E. M. Lifšic, *Teoretičeskaja fizika. Tom III: Kvantovaja mehanika. Nereljativistkaja teorija*, Nauka, Moskva, 1989.	Assessment Method	Points
	Homeworks	20
	Seminar paper	40
	Final exam	40
	Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">THEORY OF MULTIPHOTON PROCESSES</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH7081</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The goal of the course is to systematically master the theoretical methods used to analyze multiphoton processes in atomic physics.

Learning Outcomes:

- student understands the basic terms used in the theory of multiphoton processes.

- student will apply the formalism of quantum mechanics to the description of multiphoton processes.

- student master the mathematical tools and methods used in the analysis of multiphoton processes.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Electrons and atoms in the radiation field. Perturbation theory. Perturbation theory renormalization. Non-resonant multiphoton ionization. Theory of the effective Hamiltonian with stationary and time-dependent interactions. Density matrix method. Floquet's theory of multiphoton transitions. Theory of non-Hermitian Hamiltonians of multiphoton transitions. Theory of radiative electron-atom scattering.</td></tr>
</table>

LITERATURE	ASSESSMENT OF LEARNING	
	Assessment Method	Points
1. F. H. M. Faisal, *Theory of multiphoton processes*, Plenum Press, New York, 1987	Homework	20
2. N. B. Delone, V. P. Krainov, *Multiphoton processes in atoms*, Springer-Verlag, Berlin, 2000.	Seminar paper	40
	Final exam	40
3. I. I. Sobelman, *Atomic Spectra and Radiative Transitions*, Springer-Verlag, Berlin, 1979.	Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">ADVANCED COURSE IN ELECTRODYNAMICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH7091</td><td>I / II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The aim of the course is for students to master the concepts of classical electrodynamics at a higher mathematical, theoretical, and algorithmic level. By successfully completing the course, students are able to apply their acquired knowledge in future scientific research work.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Time-varying fields. Maxwell's equations. Conservation laws. Plane electromagnetic waves. Simple radiating systems. Diffraction. Magnetohydrodynamics. Plasma physics. Collisions between charged particles. Energy losses. Scattering. Radiation from moving charges. Bremsstrahlung. Virtual quantum method. Radiative beta processes. Multipole fields. Radiation damping. Scattering and absorption of radiation by bound charges.</td></tr>
<tr><td colspan="3">LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td colspan="3" rowspan="4">- J. D. Jackson, Classical electrodynamics, 3rd Edition, John Wiley & Sons, New York, 1998.
- K. K. Likharev, Classical Electrodynamics: A Modern Perspective, Wiley, Hoboken, New Jersey, 2012.
- A. Taflove and S. C. Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd Edition, Artech House, 2005.
- J. M. Stewart, Python for Scientists, Cambridge University Press, 2014.
- U. S. Inan and R. A. Marshall, Numerical Electromagnetics: The FDTD Method, 1st Edition, Cambridge University Press, 2011.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Written assignment</td><td>50</td></tr>
<tr><td>Project</td><td>50</td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="5">Remarks</td></tr>
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Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**MACHINE LEARNING AND ARTIFICIAL NEURAL NETWORKS IN PHYSICS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PCS8011	**I / II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	The aim of the course is to develop practical skills in machine learning, artificial neural networks, and physics-informed neural networks. Students will learn how to apply these skills and techniques to real-world problems in various branches of physics.

COURSE CONTENT

- Introduction to machine learning (ML) and artificial neural networks (ANN); Notion of supervised and unsupervised learning; Problem of regression, classification and clustering
- Programming tools; Overview of TensorFlow, PyTorch, and Scikit-Learn
- Data preprocessing
- Regression: linear, polynomial, support vector (SVR), decission tree, random forest
- Classification: logistic, k-nearest neighbors (KNN), support vector machines (SVM), decission tree, random forest
- Clustering: k-means
- Artificial neural networks
- Dimensionality reduction: principal component analysis (PCA), linear discriminant analysis (LDA), active subspace method (ASM)
- Applications of ML and ANN in physics
- Physics informed neural networks (PINN)

LITERATURE

1. S. Raschka, Y. Liu, V. Mirjalili, and D. Dzhulgakov, Machine Learning with PyTorch and Scikit-Learn: Develop Machine Learning and Deep Learning Models with Python, Packt Publishing, 2022.
2. N. Thuerey, P. Holl, P. Schnell, F. Trost, K. Um, and M. Mueller, Physics-based Deep Learning, (https://physicsbaseddeeplearning.org), 2021.
3. R. Maziar, P. Perdikaris and G. E. Karniadakis, George E, Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations, Journal of Computational Physics, **378**, 686-707, 2019.

ASSESSMENT OF LEARNING

Assessment Method	Points
Projects	100
Total	100

Remarks

Student will complete three projects, with two focusing on ML and ANN methods, and the third involving the application of PINN. Each of the first two projects will be worth a maximum of 30 points, while the third project will be worth a maximum of 40 points.

LIST OF POSSIBLE ELECTIVE COURSES
HIGH ENERGY PHYSICS

<table>
<tr><td rowspan="2">Study program</td><td>Level of studies</td><td colspan="3">Third cycle</td></tr>
<tr><td>Title of the study program</td><td colspan="3">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">ADVANCED QUANTUM FIELD THEORY</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH8011</td><td>I /II</td><td>Mandatory/Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">- Mastery of the mathematical tools required for exploring quantum field theory.
- Understanding of infrared and ultraviolet divergences.
- Familiarization with methods of renormalization for theories with spontaneously broken symmetries of Abel and Yang-Mills type.
- Acquisition of the mathematical apparatus necessary for studying processes within the standard model of elementary particle physics and its extensions.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Radiative corrections in quantum field theory. Examples of infrared and ultraviolet divergences in quantum electrodynamics. Classification of operators and their level of divergence in quantum field theory. Introduction of mathematical apparatus related to the calculation of divergent integrals. Ward-Takahashi identities in quantum electrodynamics. Renormalization of perturbative theories. Renormalization of theories with spontaneous breaking of local Abelian symmetry. Study of renormalization group equations. Calculation of the Coleman-Weinberg potential. Calculation of higher (second) order radiative corrections. Example of a Yang-Mills type theory: quantum chromodynamics. Higgs mechanism. Massive vector fields. Anomalies in quantum theories with spontaneously broken Yang-Mills symmetry. Renormalization of theories with spontaneously broken non-Abelian symmetries. Magnetic monopoles. Unification of interactions and associated coupling constants present in the standard model of elementary particle physics.</td></tr>
</table>

<table>
<tr><td>LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td rowspan="6">- Matthew D. Schwartz, Quantum Field Theory and the Standard Model, Cambridge University Press, 2014
- Michael E. Peskin, Dan V. Schroeder, An Introduction To Quantum Field Theory (Frontiers in Physics), Westview Press, Reprint edition (October 2, 1995).
- A. Zee, Quantum Field Theory in a Nutshell, Princeton University Press, 2 edition (February 1, 2010).
- Claude Itzykson, Jean-Bernard Zuber, Quantum Field Theory (Dover Books on Physics), Dover Publications (February 24, 2006).</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Homework</td><td>30%</td></tr>
<tr><td>Seminar paper</td><td>30%</td></tr>
<tr><td>Final exam</td><td>40%</td></tr>
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<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">ADVANCED ELEMENTARY PARTICLE PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH8021</td><td>I /II</td><td>Mandatory/Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">- Understanding of the Standard Model of particle physics.
- Understanding of the phenomenology at particle colliders.
- Acquisition of basic knowledge necessary for research work in modern particle physics.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Construction of the Standard Model of particle physics. Symmetries and field representations. Anomalies. Flavor mixing in the Standard Model. Charged and neutral currents. Consequences of flavor mixing in the Standard Model: Glashow-Iliopoulos-Maiani mechanism. Cabibbo-Kobayashi-Maskawa mixing matrix. Neutrino physics. Pontecorvo-Maki-Nakagawa-Sakata mixing matrix. Mikheyev-Smirnov-Wolfenstein effect of neutrino oscillations in matter. Stability of matter. Deep inelastic scattering. Parton distribution functions.</td></tr>
</table>

<table>
<tr><td>LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td rowspan="6">- Y. Grossman & Y. Nir, The Standard Model: A uniquely beautiful theory,
- Matthew D. Schwartz, Quantum Field Theory and the Standard Model, Cambridge University Press, 2014
- Michael E. Peskin, Dan V. Schroeder, An Introduction To Quantum Field Theory (Frontiers in Physics), Westview Press, Reprint edition (October 2, 1995).</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Homework</td><td>30%</td></tr>
<tr><td>Seminar paper</td><td>30%</td></tr>
<tr><td>Final exam</td><td>40%</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="3">Remarks</td></tr>
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<tr><td rowspan="2">Study program</td><td>Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td>Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">SYMMETRIES IN ELEMENTARY PARTICLE PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PTH8031</td><td>I/II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">Strengthening student knowledge of Symmetries in Physics, a subject from master's studies, is the goal of this course. With a focus on particle physics, students will study the function of symmetries in physics.

Upon the completion of course, students should be able to:
- make computations with Lie groups and Lie algebras and construct root and weight diagrams
- analyze the properties of physical systems under spacetime symmetry
- analyse gauge theories and a gauge transformation for electromagnetic field</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Symmetries and particles. Intro to Lie groups and Lie algebras. SU(2) and Isospin. SU(2) in particle physics. SU(3) and Quark model. Roots and Weights in SU(3) groups. Spacetime Symmetry. Gauge theories. Electromagnetism as a Gauge theory. Unified theory, SU(5) and SU(10).</td></tr>
</table>

ITERATURE	ASSESSMENT OF LEARNING	
1. Howard Georgi, *Lie Algebras In Particle Physics: from Isospin To Unified Theories* (Frontiers in Physics), Westview Press; 2 edition (October 22, 1999).Yourk, 1999. 2. A. Zee, *Quantum Field Theory in a Nutshell*, Princeton University Press, 2 edition (February 1, 2010). 3. I. Doršner, Simetrije u fizici, Prirodno-matematički fakultet, Sarajevo, 2013. 4. I.J.R. Aitchison, A.J.G. Hey, Gauge Theories in Particle Physics Vol1, CRC Press, 2013	Assessment Method	Points
	Homeworks	20
	Seminar paper	40
	Final exam	40
	Total	100

Remarks

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**MEDIUM ENERGY PARTICLE PHYSICS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PTH8041	**I/II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes

The aim of the course is to prepare students to take an active role in monitoring and quantifying the process of elastic and inelastic scattering of mesons and baryons at medium energies.

Upon the completition of the course, student should be able to:

-analyse particle physics processes at medium energy.

-explain connections and complementaries of elastic and inelastic -scattering proceses.

-analyse analytic properties of invaraint amplitudes in physical and unphysical region.

-apply methods for extracting resonance parameters.

COURSE CONTENT

Mandelstam's hypothesis. Pion-nucleon system. S and T matrix. Analytic properties of partial wave and scattering amplitudes. Relations between measurable quantities and scattering amplitudes. Expansion of scattering amplitudes in terms of partial waves. Partial wave dispersion relations.
Methods of partial wave and amplitude analyses. Inelastic partial wave analysis – the continuum ambiguity. Invariant amplitudes in the unphysical region and near threshold. Analytic continuation of the invariant amplitudes in the unphysical region. Polarisation phenomena for meson production. The interactions between mesons and nucleons. Kinematics of two-body and three-body interactions. Phase shifts.
A methods for ectracting the resonance parameters.

LITERATURE

1. Joh. R. Taylor, *Scattering Theory: The Quantum Theory of Nonrelativistic Collisions*, Dover Publications, New York, 2006.

2. D. Martin, T.D. Spearman, *Elementary Particle Theory*, North-Holland , Amsterdam, 1970.

3. John R. Taylor, *Scattering Theory*, John Wiley & Sons, Inc., New York, 1972.

4. G. Hoehler, *Elastic and Charge Exchange Scattering of Elementary Particles*; Subvolume b: *Pion-Nucleon Scattering*, Part 2. Methods and results of Phenomenological Analysis. Landolot-Boernstein, Numerical Data and Functional Relationships in Science and Technology, Ed. H. Schopper, Springer-Verlag Berlin-Heidelberg-New York 1983.

5. B. H. Bransden, R. G. Moorhouse, *Pion-Nucleon Sistem*, Princeton University Press, Princeton 1973.

6. T. Ericson and W. Weise: *Pions and Nucleons*, Oxford Science Publications , 1988.

ASSESSMENT OF LEARNING

Assessment Method	Points
Homeworks	20
Seminar paper	40
Final exam	40
Total	100

Remarks

LIST OF POSSIBLE ELECTIVE COURSES

APPLIED PHYSICS

Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**ADVANCED RADIOLOGICAL IMAGING**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PAP7011	**I /II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	Aim: To acquire theoretical and practical knowledge of imaging methods in diagnostic radiology and nuclear medicine. Outcome: To master and understand modern methods and imaging techniques in medicine.

COURSE CONTENT
1. DETECTORS IN RADIOLOGY: Detectors in radiography, fluoroscopy, computed tomography, ultrasonography, magnetic resonance, scintillation cameras, single-photon emission tomography, positron emission tomography, and more. 2. IMAGING METHODS IN RADIOLOGY: Classical imaging methods, Tomosynthesis in mammography and radiography, multi-energy computed tomography, magnetic resonance spectroscopy, Image quality evaluation, Phantoms. 3. IMAGING METHODS IN NUCLEAR MEDICINE: Single-photon emission tomography, Positron emission tomography, Hybrid systems, Image quality evaluation, Phantoms. 4. COMPUTATIONAL METHODS: Image reconstruction methods, Artificial intelligence, Design and production of phantoms.

LITERATURE
Suetens P. Fundamentals of medical imaging. Cambridge university press; 2017 May 11. Iniewski K. Advanced X-ray Detector Technologies. Springer International Publishing; 2022. Ranschaert ER, Morozov S, Algra PR, editors. Artificial intelligence in medical imaging: opportunities, applications and risks. Springer; 2019 Jan 29.

ASSESSMENT OF LEARNING	
Assessment Method	Points
Seminar paper	45
Final exam	55
Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">ADVANCED MEDICAL PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PAP7021</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">Aim: To acquire advanced knowledge in medical radiation physics and radiation protection.

Outcomes: Understand the basics of ionizing radiation dosimetry and radiation biology; master and understand the methods and techniques used in modern radiotherapy, diagnostic radiology, and nuclear medicine, and apply them in medical practice.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">1. PHYSICS IN RADIOTHERAPY: Physical, radiobiological and clinical aspects of hadron therapy, Accelerator technology, equipment and room design in hadron therapy, Radiation delivery in hadron therapy, Radiotherapy planning, Quality assurance in hadron therapy, Artificial intelligence in radiotherapy
2. PHYSICS IN NUCLEAR MEDICINE: Production of radionuclides, Radiopharmaceuticals in diagnostic and therapeutic nuclear medicine, Internal dosimetry in clinical practice, Quantitative nuclear medicine, Advanced imaging systems in nuclear medicine, Artificial intelligence in nuclear medicine
3. PHYSICS IN RADIOLOGY: Advanced imaging systems in diagnostic and interventional radiology, Image quality in radiology, Phantoms for evaluating image quality in diagnostic and interventional radiology, Artificial intelligence in radiology</td></tr>
</table>

<table>
<tr><td>LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td rowspan="6">DOSANJH, Manjit; BERNIER, Jacques (ed.). Advances in Particle Therapy: A Multidisciplinary Approach. CRC Press, 2018.
Saha GB. Physics and radiobiology of nuclear medicine. Springer Science & Business Media; 2012 Sep 28.
DENDY, Philip Palin; HEATON, Brian. Physics for diagnostic radiology. CRC press, 2011.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Seminar paper</td><td>45</td></tr>
<tr><td>Final exam</td><td>55</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="3">Remarks</td></tr>
<tr><td colspan="3"></td></tr>
</table>

Study program	Level of studies		**Third cycle**	
	Title of the study program		**Doctoral studies in physics**	
Course title	**OPTICAL FIBER SENSORS**			
Course ID	Semester	Course status	ECTS credits	Teaching hours
PAP7031	**I/II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes

To prepare candidates to use optical fibers to measure a wide range of physical phenomena.

Learning outcomes include:

- learning the basic theories of light traveling through fibers;
- training the candidate to select an appropriate optical fiber for a suitable physics experiment; and
- training the candidate to realize a wide range of light fiber-based experiments.

COURSE CONTENT

Basics of optical fiber technology; Briulion, Rayleigh and Raman scattering; Single-mode and multimode operation; Multiclading fiber; Photonic fibers; Fiber with polarization maintenance; Modulation techniques; Interferometers based on optical fibers; Gyroscope; Light transmitter; Light signal detectors at different wavelengths; Fibers with a Bragg grating - FBG; Light collimators; Spatially distributed sensors; Remote sensors; Optical fibers in medicine;

LITERATURE

- Yin, Shizhuo, Paul B. Ruffin, and T. S. Francis, eds. *Fiber optic sensors*. CRC press, 2017.
- Fang, Zujie, et al. *Fundamentals of optical fiber sensors*. Vol. 226. John Wiley & Sons, 2012.
- Maria de Fátima, F. Domingues, and Ayman Radwan. *Optical Fiber Sensors for LoT and Smart Devices*. Springer, 2017.
- Milatović, Dragoljub, and Vasvija Ajdinović. *Optoelektronika*. Svjetlost, 1987.

ASSESSMENT OF LEARNING

Assessment Method	Points
Tests/Partial exams	20
Seminar paper/project	20
Practial work	20
Final exam	30
Homeworks	10
Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">MICROCONTROLLERS IN PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PAP7041</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">Candidates will be trained to use microprocessors/microcontrollers in research and education.
Learning outcomes include: - becoming familiar with the architecture and elements of microprocessors/microcontrollers.
training the candidate to select an appropriate microcontroller for a suitable physics experiment; and -
training the candidate to carry out experiments.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Microcontroller classification; Processor cores; Memories; Digital and analog inputs/outputs; Interrupts; Timers; Communication interfaces: UART, SPI, IIC, Ethernet; Software: assembler, software development, debugging; Code execution speed calculation; Sensors: communication with sensors, data analysis, Internet of Things - IoT; Display of measurement results: display in real time, spreadsheet programs, web, java; System on a chip - SOC;</td></tr>
</table>

LITERATURE	ASSESSMENT OF LEARNING	
	Assessment Method	Points
• Godse, Atul P., and Deepali A. Godse. Microprocessor and Interfacing. Technical Publications, 2020.	Tests/Partial exams	20
• Parab, Jivan, et al. *Practical aspects of embedded system design using microcontrollers*. Springer Science & Business Media, 2008.	Seminar paper/project	20
• Gridling, Gunther, and Bettina Weiss. "CT-403: Introduction to Microcontrollers First Semester Text Book."	Final exam	30
	Homeworks	10
	Performing laboratory work	20
	Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td>Level of studies</td><td colspan="3">Third cycle</td></tr>
<tr><td>Title of the study program</td><td colspan="3">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">ACCELERATOR PHYSICS I</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PAP7051</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">The course is aimed to introduce students to the principles and applications of accelerator physics. The course covers the basic concepts of particle acceleration and beam dynamics, and the design and operation of various types of accelerators, including linear and circular accelerators.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Lecture 1: Introduction to Accelerator Physics
Lecture 2: Electromagnetism and Relativity
Lecture 3: Transverse Motion of Particles
Lecture 4: Longitudinal Motion of Particles
Lecture 5: Linear Accelerators
Lecture 6: Circular Accelerators
Lecture 7: Storage Rings
Lecture 8: Colliders
Lecture 9: High-Intensity Beams
Lecture 10: Accelerator Components
Lecture 11: Accelerator Diagnostics
Lecture 12: Radiation Protection
Lecture 13: Applications of Accelerators
Lecture 14: Future Developments in Accelerator Technology</td></tr>
</table>

<table>
<tr><td>LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td rowspan="6">1.Pierre M._ Septier, Albert L. Linear Accelerators
2. Wille, Klaus - The physics of particle accelerators an introduction
3. Michiko G. Minty, Frank Zimmermann (auth.) - Measurement and Control of Charged Particle Beams</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Practice/Project</td><td>20</td></tr>
<tr><td>Seminar paper</td><td>30</td></tr>
<tr><td>Presentation</td><td>50</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="3">Remarks</td></tr>
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<table>
<tr><td rowspan="2">Study program</td><td colspan="2">Level of studies</td><td colspan="2">Third cycle</td></tr>
<tr><td colspan="2">Title of the study program</td><td colspan="2">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">ADVANCED EXPERIMENTAL TECHNIQUES IN NUCLEAR PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PAP7061</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">To understand the importance and methods of measurement and to have knowledge of measurement techniques. To learn properties of various types of detectors and their usage, about radiation measurements of charged and non-charged particles. To gain experience in data analysis with modem methods and tools (computers, software and programming).</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">1.Introduction
2.Interactions of Particles in Matter
3.Sources of Radiation
4.Linear Accelerators
5.& 6. Gas Based Detectors I and II
7.& 8.Semiconductor detectors I and II
9.& 10. Scintillation Detectors I and II
11. Neutron Detectors
12. & 13. & 14. Electronics for Particle Detectors I and II and III</td></tr>
</table>

<table>
<tr><td>LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td rowspan="6">1. Measurement and Detection of Radiation Nicholas Tsoulfanidis, Sheldon Landsberger
2. Alpha,Beta, Gamma-ray Spectroscopy; K.Siegband,
3. Experimental Techniques in Nuclear and Particle Physics by Stefaan Tavernier
4. Radiation Detection and Measurement by Glen Knoll
5. Techniques for Nuclear and Particle Physics Experiments by W.R. Leo</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Practice/Project</td><td>20</td></tr>
<tr><td>Seminar paper</td><td>30</td></tr>
<tr><td>Presentation</td><td>50</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
<tr><td colspan="3">Remarks</td></tr>
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Study program	Level of studies	**Third cycle**
	Title of the study program	**Doctoral studies in physics**
Course title	**MONTE CARLO SIMULATIONS IN RADIATIONS PHYSICS**	

Course ID	Semester	Course status	ECTS credits	Teaching hours
PAP7071	**I /II**	**Elective**	**10**	**30**

Course aims and expected learning outcomes	The aim of the course is to educate students about the capabilities of the Monte Carlo simulations in particle physics. To understand the importance of the relevant phyisics determing the applicability of the simulation. To learn how, with what limits simulations can be used in real world problems raging from shileding calulation to radiaoactive meterial production. And at the end to have gained the releveant experiennce with the code FLUKA for general use.

COURSE CONTENT

Lecture 1: Monte-Carlo Method

Lecture 2: FLUKA Introduction

Lecture 3: Input, Output and Plotting

Lecture 4: Physics models

Lecture 5: Sampling, Biasing and Transport

Lecture 6: Scoring and Running Options

Lecture 7: Combinatorial Geometry

Lecture 8: Electro-magnetic interactions

Lecture 9: Nuclear and Heavy Ion Interactions

Lecture 10: Neutron

Lecture 11: The FLUKA User Routines

Lecture 12: Applications – Dosimetry applications

Lecture 13: Voxels and Medical Applications

LITERATURE	ASSESSMENT OF LEARNING	
1.https://fluka.cern/ 2. https://www.fluka.org/fluka.php	Assessment Method	Points
	Practice/Project	20
	Seminar paper	30
	Presentation	50
	Total	100

Remarks

<table>
<tr><td rowspan="2">Study program</td><td>Level of studies</td><td colspan="3">Third cycle</td></tr>
<tr><td>Title of the study program</td><td colspan="3">Doctoral studies in physics</td></tr>
<tr><td>Course title</td><td colspan="4">APPLICATIONS OF RADITION AND NUCLEAR PHYSICS</td></tr>
<tr><td>Course ID</td><td>Semester</td><td>Course status</td><td>ECTS credits</td><td>Teaching hours</td></tr>
<tr><td>PAP7081</td><td>I /II</td><td>Elective</td><td>10</td><td>30</td></tr>
<tr><td>Course aims and expected learning outcomes</td><td colspan="4">This course is designed to provide an understanding of the applications of radiation and nuclear physics in various fields, including medicine, industry, and research. The course covers the basic principles of radiation physics, radiation detection and measurement, and the various applications of radiation in various fields.</td></tr>
<tr><td colspan="5">COURSE CONTENT</td></tr>
<tr><td colspan="5">Lecture 1: Radiation and Nuclear Physics
Lecture 2: Radioactive Decay and Radiation Interactions
Lecture 3: Radiation Detection and Measurement
Lecture 4: Radiation Protection and Safety
Lecture 5: Industrial Applications of Radiation
Lecture 6: Nuclear and Radiation Medicine
Lecture 7: Activation Analysis
Lecture 8: Foood as food stufs treatment
Lecture 9: Material modifications
Lecture 10: Safety and security
Lecture 11: Nuclear Power Generation
Lecture 12: Radiation in Space and Satelites
Lecture 13: Other topics</td></tr>
<tr><td colspan="3">LITERATURE</td><td colspan="2">ASSESSMENT OF LEARNING</td></tr>
<tr><td colspan="3" rowspan="6">1. Various published papers and reviews updated every year.</td><td>Assessment Method</td><td>Points</td></tr>
<tr><td>Practice/Project</td><td>20</td></tr>
<tr><td>Seminar paper</td><td>30</td></tr>
<tr><td>Presentation</td><td>50</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total</td><td>100</td></tr>
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