Sveučilište u Rijeci • University of Rijeka
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Course description

Basic description			
Course coordinator	Ilvana Jelovica Badovinac		
Course title	Scanning electron microscopy		
Study programme	Doctoral study in Physics		
Course status	Optional		
Year	1		
ECTS credits and teaching	ECTS student 's workload coefficient	7	
	Number of hours (L+E+S)	10+30+10	

1. COURSE DESCRIPTION

1.1. Course objectives

Acquiring of advanced knowledge in electron microscopy, structure of scanning electrone microscope, acquiring the knowledge in recording high-quality SEM images. Developing a sense of and interest for measurement.

1.2. Course enrolment requirements

Prerequisite is completed appropriate graduate university study program or regularly enrolled PhD studies in physics.

1.3. Expected course learning outcomes

After passing the exam, the student will be able to independently conduct SEM research on various types of samples, or to apply the acquired theoretical knowledge in practice.

1.4. Course content

Basics of scanning electron microscopy. Introduction. Resolution. Interaction of electrons with the sample. The secondary electrons. Backscattered electrons. The characteristic x-rays. Auger electrons. Transmitted electrons. Catodoluminiscence. Parts of scanning electron microscopes. Types of electron guns. Lenses and coils. Detectors. The vacuum system. The creation of SEM images. The basic parameters of the SEM image. Depth of focus. Image quality. The consequences of charging. EDS (Energy Dispersive X-Ray Spectrometer) analysis. Sample preparation. Preparation of nonconductive and biological materials for SEM. Fixation and drying of the samples. Dehydration and drying in air. The freeze-drying. Critical point draying. Coating of non-conductive materials with a thin conductive layer. Characteristics of the microscope in the Laboratory for Surface and Material Science: JEOL JSM-7800F, field emission scanning electron microscope. Examples from practice.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☐ multimedia and network ☒ laboratories ☒ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Student is obliged to attend lectures in accordance with the Regulations of the study.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	1.5	Experimental work	2.0
Written exam		Oral exam	1.5	Essay		Research	2.0
Project		Sustained knowledge check		Report		Practice	

Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Student's work in the course will be evaluated and assessed during the semester and on the final exam. Detailed elaboration of monitoring and evaluation of students' work will be shown in the final plan of the course.

1.10. Assigned reading (at the time of the submission of study programme proposal)

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: Third Edition*, Springer Science & Business Media, 2012.

1.11. Optional / additional reading (at the time of proposing study programme)

1. Joseph Goldstein, Dale E. Newbury, Patrick Echlin, David C. Joy, Charles Fiori, Eric Lifshin, *Scanning Electron Microscopy and X-Ray Microanalysis: A Text for Biologists, Materials Scientists, and Geologists*, Springer, 1992.
2. Joseph I. Goldstein, Harvey Yakowitz, *Practical Scanning Electron Microscopy*, Springer, 1975.
3. L. Reimer, *Scanning Electron Microscopy — Physics of Image Formation and Microanalysis*, Springer, 1985.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
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: Third Edition*, Springer Science & Business Media, 2012.	1	0
Joseph Goldstein, Dale E. Newbury, Patrick Echlin, David C. Joy, Charles Fiori, Eric Lifshin, *Scanning Electron Microscopy and X-Ray Microanalysis: A Text for Biologists, Materials Scientists, and Geologists*, Springer, 1992.	1	0
Joseph I. Goldstein, Harvey Yakowitz, *Practical Scanning Electron Microscopy*, Springer, 1975.	1	0
L. Reimer, *Scanning Electron Microscopy — Physics of Image Formation and Microanalysis*, Springer, 1985.	1	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Because of the expected small number of students and mainly mentoring work, quality of work will be monitored through direct interaction with students. Also, the implementation of the acquired knowledge in their future scientific work will be monitored (the number of scientific publications).

Basic description		
Course coordinator	Katja Džepina	
Course title	Atmospheric Chemistry	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	35 + 0 + 10

1. COURSE DESCRIPTION

1.1. Course objectives

Objectives of the course is to develop working knowledge on the application of chemical principles to the Earth's atmosphere and getting familiarized with diverse areas of atmospheric chemistry and its significance to the climate change, air pollution and human health.

1.2. Course enrolment requirements

General chemistry, physics and math. Undergraduate degree in natural sciences.

1.3. Expected course learning outcomes

After finishing the course, the students will master chemical composition of the atmosphere, chemical transformations of atmospheric constituents, and the importance of atmospheric chemical compounds in the climate change, as well as their role in human health, ecosystems and the air pollution.

1.4. Course content

Composition of the atmosphere, atmospheric pressure, simple atmospheric models, atmospheric transport, geochemical cycles, the greenhouse effect, photochemistry, chemistry of the troposphere and stratosphere, atmospheric aerosol, acid rain, and the influence of the air pollution on human health and ecosystems.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☐ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Students must attend classes. Homework will be regularly given to students during the course and will have to be turned in by certain deadline (normally one week). Two written exams will take place during the course. Finally, students will select one topic from the area of atmospheric chemistry and choose two appropriate research papers, which will be presented as a seminar in class during the course.

1.8. Evaluation of student's work

Course attendance	YES	Activity/Participation	YES	Seminar paper	YES	Experimental work	
Written exam	YES	Oral exam		Essay		Research	
Project		Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

25% activity and participation in the class; 25% seminar; 25% homework; 25% exams

1.10. Assigned reading (at the time of the submission of study programme proposal)

Daniel J. Jacob: Introduction to Atmospheric Chemistry, Princeton University Press, 1999.

1.11. Optional / additional reading (at the time of proposing study programme)

Barbara J. Finlayson-Pitts and James N. Pitts: Chemistry of the upper and lower atmosphere: Theory, experiments, and applications, Academic Press, 2000.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Daniel J. Jacob: Introduction to Atmospheric Chemistry	Textbook is available on line: http://acmg.seas.harvard.edu/people/faculty/djj/book/	

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Students are encouraged to active and constructive discussion during the course with course coordinator. Outside of class periods, course coordinator will be available daily to students for office hours within jointly agreed time periods. Outside of working hours, course coordinator will be available for potential additional consulting via phone and email.

Basic description		
Course coordinator	Slaven Jurković, Assistant Professor	
Course title	Radiological physics and dosimetry	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	20 + 20 + 10

1. COURSE DESCRIPTION

1.1. Course objectives

Knowledge of basic physical terms and relations related with sources of ionizing radiation and application in medicine (radiotherapy, diagnostic and interventional radiology). Understanding of physical phenomena's associated with ionizing radiation and basic interactions of ionizing radiation with matter. Accepting basic working principles of electrical devices used for production of ionizing radiation as well as auxiliary systems/devices used for radiotherapy and diagnostic/interventional radiology. Understanding of basic principles of ionizing radiation detectors and measuring systems used in medicine. Basic physical quantities used for description of ionizing radiation. Understanding of basic principles of ionizing radiation protection with accent on beams used in medicine. Developing of skills in scientific research as well as writing and talking abilities and public appearance.

1.2. Course enrolment requirements

Enrolled PhD in Physics.

1.3. Expected course learning outcomes

1. Learn basic physical principles of diagnostic and therapeutic methods based on application of ionizing radiation
2. Understand main principles of devices which produce ionizing radiation and auxiliary systems/devices used in medicine
3. Understand physical principles of ionizing radiation detectors and measuring systems used in medicine
4. Awareness of medical physicist's role in modern medicine
5. Understand interactions of different types of ionizing radiation with various tissues in human body
6. Identify ALARA principle of radiation protection and recognize importance of development different procedures related with use of ionizing radiation to assure safety of patients and staff
7. Application of knowledge on some practical problems in medical physics

1.4. Course content

1. Introduction in radiological physics
   1.1. Historical view on application of ionizing radiation in medicine
   1.2. Types of ionizing radiation and its origins
   1.3. Interactions of ionizing radiation with matter
   1.4. Physical quantities and units related with ionizing radiation
   1.5. Detection of ionizing radiation and dosimetry

2. Physical basis for application of ionizing radiation for diagnostic/interventional radiology
   2.1. X-ray tube, production of X-rays and X-ray spectrum
   2.2. X-ray devices for planar radiography (radiograph, mammography, fluoroscopy and interventional radiology)
   2.3. Physical and geometrical conditions for X-ray imaging and image parameters
   2.4. Computerized tomography
   2.5. Dosimetry quantities in diagnostic radiology
   2.6. Quality control of diagnostic X-ray devices
   2.7. Role of medical physicist in radiology

3. Physical basis for application of ionizing radiation for radiotherapy
   3.1. Characteristics of beams used for radiotherapy

3.2. Basic principles of radiotherapy
3.3. Devices for radiotherapy
3.4. Treatment planning devices
3.5. Dosimetry of high energy photon and electron beams used for radiotherapy
3.6. Quality control of radiotherapy devices
3.7. Role of medical physicist

4. Basic principles and concepts of dosimetry
4.1. Flux and energy
4.2. Stochastic nature of absorbed dose
4.3. Dosimetric quantities
4.4. Specific dosimetric quantities related to different diagnostic radiology techniques
4.5. Relation of photon flux with KERMA and absorbed dose
4.6. Charge particle equilibrium and stopping power
4.7. Basics of cavity theory; Bragg-Gray theory and Spencer-Attix addendum

5. Dosimetry of beams used for radiotherapy
5.1. N_{DW} based formalism
5.2. International Code of Practice for absorbed dose determination in
5.2.1. high energy photon beams
5.2.2. low energy photon beams
5.2.3. medium energy photon beams
5.2.4. high energy electron beams
5.3. Clinical implementation

6. Radiation protection in medicine and quality assurance system
6.1. Principles of radiation protection
6.2. Specific aspects of radiation protection in radiology, radiotherapy and nuclear medicine. Dosimetric surveillance.
6.3. Room shielding calculations
6.4. Potential hazards, prevention and solutions
6.5. Quality assurance program for use of ionizing radiation in medicine

1.5. Teaching methods	☐ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☐ multimedia and network ☐ laboratories ☒ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Students are required to participate in all forms of the course and acquired theoretical knowledge on radiological physics. They are also obligated to perform experimental work in particular part of radiological physics which is of special student's interest. The results shall be presented as seminar paper.

1.8. Evaluation of student's work

Course attendance	x	Activity/Participation	x	Seminar paper	x	Experimental work	x
Written exam		Oral exam	x	Essay		Research	x
Project	x	Sustained knowledge check	x	Report		Practice	x
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Assessment of student's work will be performed by the evaluation of theoretical and experimental parts. In theoretical part knowledge of general concepts and methods of radiological physics will be evaluated. Experimental work will be evaluated according to their performance in solving practical problems. This part of the course will be carried out using medical devices which produce ionizing radiation and dosimetric equipment from Medical Physics Department.The students are required to solve practical problem related to application of ionizing radiation in medicine. Written reports will bes evaluated prior to student's application for the exam.

1.10. Assigned reading (at the time of the submission of study programme proposal)

1. Radiation oncology physics: A handbook for teachers and students: E.B. Podgorsak (Editor); IAEA, Vienna. http://www-pub.iaea.org/mtcd/publications/pdf/pub1196_web.pdf
2. Diagnostic radiology physics: A handbook for teachers and students: D.R. Dance (Editor); IAEA, Vienna. http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1564web-82725456.pdf
3. Nuclear Medicine Physics-A Handbook for Teachers and Students D.L. Bailey (editor), http://www-pub.iaea.org/MTCD/publications/PDF/Pub1617web-1294055.pdf

1.11. Optional / additional reading (at the time of proposing study programme)

1. Introduction to radiological physics and radiation dosimetry: P.H. Attix; Wiley, New York.
2. The physics of radiation therapy: F. M. Kahn; Williams and Williams, Baltimore.
3. IAEA Technical Report Series 398:Absorbed Dose Determination in External Beam Radiotherapy An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water; IAEA Vienna. http://www-pub.iaea.org/mtcd/publications/pdf/trs398_scr.pdf
4. Modern technology of radiation oncology: J. Van Dyk (Editor); Medical Physics Publishing, Madison Wisconsin.
5. Radiation physics for medical physicists: E.B. Podgorsak; Springer, New York.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Radiation oncology physics: A handbook for teachers and students: E.B. Podgorsak (Editor); IAEA, Vienna, 2005.	3	0
Diagnostic radiology physics: A handbook for teachers and students: D.R. Dance (Editor); IAEA, Vienna, 2014.	2	0
Nuclear Medicine Physics-A Handbook for Teachers and Students D.L. Bailey (editor), Vienna, 2014.	2	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Permanent interaction with students, conformation of course curriculum to student's interests. Monitoring students performance in practical application of acquired knowledge for the scientific work.

Basic description		
Course coordinator	Marin Karuza	
Course title	Experimental methods in quantum optics	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	15+40+5

1. COURSE DESCRIPTION

1.1. Course objectives

During this course students will make a hands-on experience in quantum optics experiments, quantum description of fundamental optical elements and photodetection techniques. Photodetectors will be described and the spectral analysis of the photocurrents will be introduced.

1.2. Course enrolment requirements

A degree in physics is required.

1.3. Expected course learning outcomes

1. construct a simple interferometer and characterize it
2. describe an interferometer by using quantum mechanical formalism
3. perform photon counting experiments
4. construct optical cavitiy and lock-it
5. use homodoyne and heterodyne detection schemes
6. understand sensitivity limits of optical measurements

1.4. Course content

1. Classical models of light
2. Quantum models of light
3. Basic optical components
4. Interferometers
5. Cavities
6. Basic photodetection techniques and measurements

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☐ individual assignment ☐ multimedia and network ☒ laboratories ☐ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Students are expected to setup simple experiments and write a report about their work.

1.8. Evaluation of student's work

Course attendance	3	Activity/Participation		Seminar paper	1	Experimental work	
Written exam		Oral exam		Essay		Research	
Project		Sustained knowledge check		Report	2	Practice	
Portfolio							

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1.9. Assessment and evaluation of student's work during classes and on final exam

The evaluation will be done on the basis of the written report and the quality of the work done in the laboratory.

1.10. Assigned reading (at the time of the submission of study programme proposal)

H. A Bachor, Timothy C. Ralph,, A quide to experiments in quantum optics,WILEY-VCH Verlag GmbH

1.11. Optional / additional reading (at the time of proposing study programme)

A. Garg, Classical Electromagnetism in a Nutshell, Princeton University Press

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
H. A Bachor, Timothy C. Ralph,, A quide to experiments in quantum optics,WILEY-VCH Verlag GmbH, 2004	1	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Quality control through the Physics Department quality assurance system.

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Basic description		
Course coordinator	Nikša Krstulović	
Course title	Plasma Technologies	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	30 + 15 + 10

1. COURSE DESCRIPTION

1.1. Course objectives

The aim of the course is to acquaint the students with the latest technologies based on the use of plasma. For this purpose, a review of the various types of plasma and demonstration their fundamental physical properties (cold and hot, sparsely and very ionized, thermal and non-thermal) will be given. The plasmas of interest are the laser-produced plasma, atmospheric plasma jets, dielectric barrier bursts and the low pressure cold plasma. A review of the application of these plasma in the technological purposes is the following: synthesis and processing of materials, analysis of samples, the treatment and modification of surfaces, synthesis of nanoparticles and nanoobjects, coating of materials, functionalization of materials.
The students will be given a review of diagnostic techniques used to study of these types of plasma, with particular emphasis on optical absorption and emission spectroscopy.

1.2. Course enrolment requirements

There are no course enrolment requirements.

1.3. Expected course learning outcomes

It is expected that students will learn basic physical mechanisms of occurrence of plasma and ways of their application in technology. Students will handle with the basic physical concepts and physical terms that are used to describe the plasma such as the composition of the plasma (electrons, ions, atoms, molecules, nanoparticles), plasma temperature, degree of ionization, plasma modes. In the applications of the plasma will be an emphasis on the development of new-generation photolithography EUV, the synthesis of nanoparticles, the elemental analysis of samples, generating of high harmonics for ultrafast imaging of objects and processes, fabrication of thin films by pulsed laser deposition, the treatment of biological samples, the use of plasma technology in food and agriculture, industry and high technology.

1.4. Course content

- the basics of lasers and laser types (continuous/ms/ns/fs/ps/as)
- the process of laser ablation in various atmospheres (vacuum, gases, atmosphere, liquids)
- fundamentals of laser interactions with matter and plasma (inversely Brehmssthralung radiation, photoionisation, collisional processes, radiative recombination, self-absorption)
- the basics of low pressure plasma
- fundamentals of atmospheric plasma jets
- the basics of atomic and molecular spectroscopy
- Basic detection techniques for plasmas: optical emission and absorption spectroscopy, time-of-flight mass spectrometry, visualization (iCCD imaging, interferometry, laser induced fluorescence, Langmuir probes, Thompson's scattering, pump-probe techniques)
- the dynamics of the laser produced plasmas
- calculating the electronic and atomic density and temperature (qualitative and quantitative analysis)
- models: Calibration-free models, collision and collisional-radiative models
- application of plasmas in technologies

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☒ exercises	☒ individual assignment ☒ multimedia and network ☐ laboratories

	☐ long distance education ☐ fieldwork	☐ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Attendance and active participation in lectures and seminars, writing and presenting seminars (theme by arrangement), oral exam

1.8. Evaluation of student's work

Course attendance		Activity/Participation	3	Seminar paper	4	Experimental work	
Written exam		Oral exam	3	Essay		Research	
Project		Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

The activity on lectures and seminars and the quality of the given seminars will be assessed and foster knowledge from the courses at the final oral exam.

1.10. Assigned reading (at the time of the submission of study programme proposal)

1. David A. Cremers and Leon J. Radziemski, Handbook of Laser-Induced Breakdown Spectroscopy, John Wiley & Sons, 2006, West Sussex, England
2. Vivek Bakshi, EUV Sources for Lithography, SPIE Press Monograph, 2006
3. T. Pfeifer, C. Spielmann and G. Gerber, Femtosecond X-Ray Science, Rep. Prog. Phys. 69 (2006) 443–505
4. U. Panne, I. Gornushkin, Radiative models of laser-induced plasma and pump-probe diagnostics relevant to laser-induced breakdown spectroscopy, Spectrochimica Acta Part B 65 (2010) 345–359, Review Article
5. G. Yang, Laser ablation in liquids, Pan Stanford Publishing, 2012
6. Ken Ostrikov, Shuyan Xu, Plasma-aided nanofabrication, Wiley, 2007

1.11. Optional / additional reading (at the time of proposing study programme)

Scientific papers

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
David A. Cremers and Leon J. Radziemski, Handbook of Laser-Induced Breakdown Spectroscopy	1	0
Vivek Bakshi, EUV Sources for Lithography	1	0
T. Pfeifer, C. Spielmann and G. Gerber, Femtosecond X-Ray Science	5	0
U. Panne, I. Gornushkin, Radiative models of laser-induced plasma and pump-probe diagnostics relevant to laser-induced breakdown spectroscopy	5	0
G. Yang, Laser ablation in liquids	2	0
Ken Ostrikov, Shuyan Xu, Plasma-aided nanofabrication	1	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Continuous monitoring of the work of students, customize the theme of the seminar to the theme of the thesis

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Basic description		
Course coordinator	Zdravko Lenac	
Course title	Many-Particle Quantum Physics	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	30+15+15

1. COURSE DESCRIPTION

1.1. Course objectives

Explain some general principles of quantum mechanics and describe their close connection with many-particle quantum physics. Show how the standard many-body theories (second-quantization and quantization of the electromagnetic field, Green's functions and Feynman's diagrams, correlative and dielectric functions) are successfully applied in solving various problems in the solid state physics, and point out that similar methods are also accepted in solving problems in other branches of physics (nuclear physics, atomic physics, particle physics).

1.2. Course enrolment requirements

No requirements

1.3. Expected course learning outcomes

Develop the students' mindset in a way to allow them to understand which of the displayed theoretical model is suitable for solving certain classes of problems in physics, in order to be able to adapt and apply existing models to similar problems they are expected to solve.

1.4. Course content

Second quantization. Coherent states. Quantization of the electromagnetic field. Photons and polaritons. Spin Hamiltonian. Green's functions. Feynman's diagrams. Dyson equation. Self-energy. Localized state in the continuum. Correlative functions. Response and dielectric functions. Electron gas. Electron-phonon interaction. Superconductivity. Optical properties.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☒ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☒ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.6. Comments	Level of activity in lectures, seminars and exercises is estimated. Final exam is oral.	

1.7. Student's obligations

Regularly attend lectures, seminars and exercises; write and deliver on time (earlier) identified number of seminars; pass the final (oral) exam.

1.8. Evaluation of student's work

Activity in the course	3 ECTS
Seminar work	4 ECTS
Oral exam	3 ECTS

1.9. Assessment and evaluation of student's work during classes and on final exam

The activity of students in the course is evaluated during the semester and the final exam. The total number of percentage points that a student can achieve during the class is 70% (assessed activities are indicated in Table 1.8), while the final (oral) exam can achieve 30%.

1.10. Assigned reading (at the time of the submission of study programme proposal)

C. Kittel, *Quantum Theory of Solids*, 2. edition, Wiley, 1987.
Gerald D. Mahan, *Many-Particle Physics*, 3. edition, Kluwer Academic / Plenum Publishers, 2000.
Michael P. Martder, *Condensed Matter Physics*, 2. edition, Wiley, 2010.

1.11. Optional / additional reading (at the time of proposing study programme)

Articles in scientific journals.
Marijan Šunjić, *Kvantna fizika mnoštva čestica*, Školska knjiga, 2002.
Bruus H., Flensberg K., *Many-Body Quantum Theory in Condensed Matter Physics. An Introduction*, Oxford University Press, Oxford, 2004.
Coleman P., *Introduction to Many-Body Physics*, Cambridge University Press, Cambridge, 2015.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
C. Kittel, Quantum Theory of Solids	2	
Gerald D. Mahan, Many-Particle Physics,	1	
Michael P. Martder, Condensed Matter Physics	2	
Marijan Šunjić, Kvantna fizika mnoštva čestica	2	

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Constant interaction with students. Flexible customization of teaching to interests and needs of students.

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Basic description		
Course coordinator	Darko Mekterović	
Course title	Data analysis in high energy physics	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	20+20+10

1. COURSE DESCRIPTION

1.1. Course objectives

Data analysis is the last, and very important, step of research in experimental high energy physics. For PhD students in this field it is almost compulsory. For them this course will give a detailed introduction to methods and tools that will make the basis of their PhD thesis. The couse could also be very useful for PhD students of experimental nuclear physics or astroparticle physics because their data analysis is based on the same software tool and similar statistical methods.

1.2. Course enrolment requirements

Knowledge of basics of statistics and computer programming is advantage but not necessary. There are no formal enrolment requirements.

1.3. Expected course learning outcomes

1. Understanding the basics of research in experimental high energy physics: types of detectors and their properties, typical experimental setup, basic principles of particle detection.
2. Introduction to software package ROOT which is the basic tool in data analysis in high energy physics, nuclear physics and astroparticle physics.
3. Introduction to analysis workflow and common statistical methods.
4. Practical experience: students are expected to perform selected parts of analysis

1.4. Course content

1. Basics of experimental techniques and setup in high energy physics
   - 1.1. Accelerators
   - 1.2. Types of detectors and their properties
   - 1.3. Experimental setup
   - 1.4. Basic principles of particle detection

2. Introduction to software package ROOT.

3. Fundamental concepts in statistics: expectation values, important distribucije, frequentist vs Bayesian approach..

4. Common statistical methods in data analysis
   - 4.1. Hypothesis testing
   - 4.2. Parameter and interval estimations
   - 4.3. Classification
   - 4.4. Unfolding

5. Basic elements of data analysis
   - 5.1. Simulated (Monte Carlo) data
   - 5.2. Systematic uncertainties
   - 5.3. Selected standard procedures: tag and probe, template fit, efficiency calculation

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1.5. Teaching methods	X☐ lectures ☐ seminars and workshops X☐ exercises ☐ long distance education ☐ fieldwork	X☐ individual assignment ☐ multimedia and network ☐ laboratories ☐ mentorship ☐other
1.6. Comments		

1.7. Student's obligations

Homework, seminar, oral exam.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	2	Experimental work	
Written exam		Oral exam	2	Essay		Research	
Project		Sustained knowledge check		Report		Practice	4
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Final oral exam has a weight of 30% in the grade. Practical work will be evaluated during classes. Students will practice basic statistical methods on real or simulated data (homework, 35% weight) and perform selected parts of data analysis (seminar, 35% weight).

1.10. Assigned reading (at the time of the submission of study programme proposal)

Data Analysis in High Energy Physics, A practical Guide to Statistical Methods; editors Olaf Behnke, Kevin Kroninger, Gregory Schott, Thomas Schorner-Sadenius; Wiley 2013.

1.11. Optional / additional reading (at the time of proposing study programme)

ROOT users guide; availabe online: https://root.cern.ch/root/htmldoc/guides/users-guide/ROOTUsersGuide.html

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Student interview and questionnaire.

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Basic description		
Course coordinator	Saša Mićanović , Tomislav Terzić	
Course title	Experimental Methods in Astroparticle Physics	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	30+30+15

1. COURSE DESCRIPTION

1.1. Course objectives

Familiarisation with operational principles of Imaging Air Cherenkov Telescopes (IACTs) and other cosmic ray detectors, and data analysis. Familiarisation with the process of extensive air shower (EAS) development, simulation principles and simulated data analysis.

1.2. Course enrolment requirements

Enrolment in the Doctoral Study in Physics.

1.3. Expected course learning outcomes

After the exam, students will be able to:
- Explain the mechanisms of EAS creation and development, and the Cherenkov radiation emission
- Explain the detection principles of the Cherenkov radiation
- Explain the EAS reconstruction from detector signal
- Operate IACTs
- Analyse IACT data
- Analyse water Cherenkov detector data
- Produce and analyse EAS simulations

1.4. Course content

Gamma-rays detection principles using IACTs. IACT data analysis. Ultra high energy cosmic ray (UHECR) detection using Pierre Auger Observatory (PAO). Reconstruction of UHECR characteristic parameters and PAO data analysis. Monte Carlo (MC) simulations of EAS and instrument response. Analysis of simulated data.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☒ exercises ☒ long distance education ☒ fieldwork	☒ individual assignment ☒ multimedia and network ☐ laboratories ☒ mentorship ☐ other
1.6. Comments	Students will have an opportunity to observe with MAGIC telescopes and the LST1-CTA prototype telescope (and the future CTA once commissioned), provided sufficient funds for travelling and accommodation in the ORM observatory (La Palma, Canary Islands, Spain) are available.	

1.7. Student's obligations

Lecture attendance according to Rulebook of Studies.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	2.0	Experimental work	
Written exam		Oral exam		Essay		Research	4.0

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Project		Sustained knowledge check		Report		Practice	4.0
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Students will be evaluated during the course and via the final exam. Details will be provided in the detailed course plan.

1.10. Assigned reading (at the time of the submission of study programme proposal)

1. CTA Consortium, *Seeing the High-Energy Universe with the Cherenkov Telescope Array*, Astropart. Phys. 43 (2013) 1-356
2. 2. Pierre Auger Collaboration, *The Pierre Auger Cosmic Ray Observatory*, Nucl. Instrum. Meth. A798 (2015) 172-213
3. D. Heck et al., *CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers*, Forschungszentrum Karlsruhe Report FZKA 6019 (1998) }

1.11. Optional / additional reading (at the time of proposing study programme)

1. A. M. Hillas, 19th Intern. Cosmic Ray Conf. 3 (1985), 445-448
2. J. Albert et al., Nucl. Instrum. Meth. A588 (2008) 424-432
3. T.-P. Li, Y.-Q. Ma, Astrophys. J. 272 (1983) 317-324
4. J. Albert et al., Nucl. Instrum. Meth. A583 (2007) 494-506
5. J. Cortina et al., 31st Intern. Cosmic Ray Conf. (2009), *eprint arXiv:0907.1211*
6. Pierre Auger Collaboration, *PAO Design Report 2. ed.*, The Auger Collaboration (1997)
7. D. Heck, T. Pierog, *Extensive Air Shower Simulations with CORSIKA: A User's Guide*, Karlsruhe Institute for Technology (KIT) (2016)

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Seeing the High-Energy Universe with the Cherenkov Telescope Array	available online free of charge	0
The Pierre Auger Cosmic Ray Observatory	available online free of charge	0
CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers	available online free of charge	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Considering the expected low number of students and mainly tutorial teaching, quality will be monitored through direct teacher-student interaction, and student's application of acquired knowledge and skills in their future scientific work.

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Basic description		
Course coordinator	Aleš Omerzu	
Course title	Selected topics in properties and applications of materials	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	30+15+15

1. COURSE DESCRIPTION

1.1. Course objectives

The main objective of the course is to present novel materials whose properties and possible applications have been extensively studied in recent decades. The choice of particular topics (materials) will be adapted to each individual student according to his/her field of scientific interest.

1.2. Course enrolment requirements

Students should be familiar with Solid-state physics at a graduate level.

1.3. Expected course learning outcomes

Students will get a detailed insight into the properties of novel materials, which are related to their experimental or theoretical research. Because contents of the course exceed a graduate level, students are expected to start using original scientific literature (e. g. review articles) in addition to specialized textbooks.
Students, who will successfully accomplish the course, are expected to have a full knowledge on advantages and applications of new materials. In addition, they should be acquainted with possible weak or undesirable properties of the materials, which should be improved in some future research. In other words, the students should be familiar with new directions and perspectives in material research, which relates to their field of scientific interest.

1.4. Course content

Students are obligated to choose at least two groups of materials from the following list:

Semiconductors – nonstandard semiconductors, quantum confined semiconductors, solar cells, thermoelectric applications

Metals and alloys – metal glasses, porous metals, memory alloys

Dielectrics and ferroelectrics – ferroelectrics in RAM, thermistors and varistors, lithium-ion batteries, fuel cells

Magnetic materials – magnetostrictive materials, giant and colossal magnetoresistance, Faraday and Kerr effect, permanent magnets, magnetic and magneto-optic recording, diluted magnetic semiconductors

Optical materials – optical polarizers, Faraday rotation, optical fibers, LED diodes and semiconductor lasers, photoconductors, electro-optical effect and photorefractive materials

Superconductors – superconducting alloys, superconducting cuprates and pnictides, Josephson effect

Ceramics – silicates, silicon carbide, silicon nitride, zeolites, glasses

Polymers – polymer ionic conductors, conducting polymers, photoresists, piezoelectric polymers, liquid crystals

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1.5. Teaching methods	x☐ lectures x☐ seminars and workshops ☐ exercises x☐ long distance education ☐ fieldwork	x☐ individual assignment ☐ multimedia and network x☐ laboratories x☐ mentorship ☐other
1.6. Comments		

1.7. Student's obligations

Requirements for entering the final exam: two seminar papers and their oral presentations. (At least one should be conducted in English).

1.8. Evaluation of student's work

Course attendance	x	Activity/Participation	x	Seminar paper	x	Experimental work	x
Written exam		Oral exam	x	Essay		Research	
Project		Sustained knowledge check	x	Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Assignment of ECTS coefficients: Activity/Participation: 1.0 ECTS; Seminar papers: 4.0 ECTS; Oral exam: 4.0 ECTS; Sustained knowledge check: 1.0 ECTS.

1.10. Assigned reading (at the time of the submission of study programme proposal)

Joel I. Gersten Frederick W. Smith: The Physics and Chemistry of Materials, John Wiley & Sons, Inc. 2001

1.11. Optional / additional reading (at the time of proposing study programme)

The Science and Engineering of Materials, 6th Edition, by Donald R. Askeland, Pradeep P. Fulay and Wendelin J. Wright, Cengage Learning, Inc. 2010.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
The recommended literature is available in a PDF format		

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

The student's progress will be monitored trough regular oral discussions (personally or using Skype), and by supervision of the student's independent work on seminar papers.

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Basic description		
Course coordinator	Petar Pervan	
Course title	Physics of surfaces and interfaces	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	30+15+10

1. COURSE DESCRIPTION

1.1. Course objectives

The main objective of this course is to present some major physical concepts associated with surfaces such us: crystal structure of well-defined surfaces (low index and vicinal surfaces), influence of different types of defects, electronic surface and interfaces states as well as their dependence on the film thickness (Quantum Well States), growth of thin and ultra-thin films, diffusion at surfaces, concepts of adsorption and desorption. Students will learn which information can be acquired from surface sensitive experimental techniques.

1.2. Course enrolment requirements

No requirements

1.3. Expected course learning outcomes

Expected learning outcomes are: students will be able to define and describe different crystallographic surfaces with corresponding structural and electronic properties, type of defects, analyse electronic properties of particular low-index surfaces. Students will be also able to analyse mechanisms of adsorption, different types of nucleation, growth of ultra-thin films. It is expected that, at the end of this course, students will be able to select appropriate experimental techniques in order to acquire particular information related to physical properties of surfaces and interfaces.

1.4. Course content

Structural properties of surfaces (structure of surfaces, surface crystallography, surface defects); electronic properties (surface states, interface states, surface plasmons, Quantum Size Effect, quantum wells) ; Adsorption, Nucleation and growth, Experimental techniques.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☒ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.6. Comments	*Attendance of the lectures, seminars; students activity will be examined* *Final exam: oral*	

1.7. Student's obligations

Attendance of the lectures, seminars; write and hen dower on time seminars, pass final exam

1.8. Evaluation of student's work

Course attendance	1	Activity/Participation	1	Seminar paper	2	Experimental work	
Written exam	4	Oral exam	2	Essay		Research	
Project		Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

1.10. Assigned reading (at the time of the submission of study programme proposal)

1.11. Optional / additional reading (at the time of proposing study programme)

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Interaction with students, *flexible adjustment of the interaction depending on interests and needs.*

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Basic description		
Course coordinator	Robert Peter	
Course title	Nanomaterials and applications	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	30+0+30

2. COURSE DESCRIPTION

1.14. Course objectives

Main objective of this course is to familiarize students with the technological processes of synthesis of different nanomaterial structures and experimental techniques for their characterization; depict nanostructures and low dimensional structures; demonstrate the application of nanomaterials in electronics, photonics, biotechnology, and magnetic devices.

1.15. Course enrolment requirements

All students can enrolled in the Doctoral study in Physics can attend the course.

1.16. Expected course learning outcomes

Students should learn physical processes and principles related to methods of nanomaterial synthesis and technological application of nanostructures (low dimensional physics, electronic structure of metals and semiconductors, interaction of materials with energetic ion and electron beams, interaction of X-ray with matter, spin-dependent electron conductivity, magnetic properties of materials, superconductivity), be able to depict the application of different nanostructures in technology and to acquire the basic knowledge that will enable them for the independent scientific research.

1.17. Course content

- Synthesis of nanomaterials (optical and X-ray lithography, electron-beam lithography, micromechanical structures, methods for the deposition of thin films, molecular beam epitaxy, focused ion beam milling)
- Experimental techniques for nanomaterial characterization (microscopy techniques: atomic force microscope-AFM, scanning tunnelling microscope- STM, tunnelling electron microscope- TEM; spectroscopy methods based on the interaction of X-rays with the material: X-ray photoemission spectroscopy-XPS, X-ray fluorescence- XRF, electron-dispersive X-ray spectroscopy- EDS, techniques based on the X-ray absorption- XANES)
- Carbon based nanostructures (fullerene, graphene, carbon nanotubes)
- Low dimensional nanostructures (quantum dots, nanowires, 2D materials, nanotubes)
- Properties of thin films and application
- Nanoelectronics (electron interference devices, resonant tunneling diodes, single electron transistors, carbon nanotube sensors, molecular electronics)
- Quantum technologies based on magnetism and superconductivity (giant magnetoresistance- GMR, magnetic random access memory- MRAM, spintronic devices, magnetic logic devices, SQUID magnetometer)
- Introduction to nanophotonics and nanobiotechnology (2D laser devices, biomimetic nanostructures, molecular motors)

1.18. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☐ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.19. Comments		

1.20. Student's obligations

Students are obligated to:
- attend courses,

- write and present seminar paper,
- solve individual assignments on selected topics from literature or scientific publications,
- take the oral exam.

1.21. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	4	Experimental work	
Written exam		Oral exam	3	Essay		Research	
Project		Sustained knowledge check	3	Report		Practice	
Portfolio							

1.22. Assessment and evaluation of student's work during classes and on final exam

Evaluation of student's work during classes is accomplished through student's seminar paper (4 ECTS points) and student's individual assignments – individual studies of selected topics from literature or scientific publications (3 ECTS points). The final evaluation is obtained through oral exam (3 ECTS points).

1.23. Assigned reading (at the time of the submission of study programme proposal)

1. Edward L. Wolf, *Nanophysics and Nanotechnology*, WILEY-VCH Verlag GmbH &Co. KGaA, Weinheim, Germany, 2006.
2. Stuart.M.Lindsay, *Intoduction to Nanoscience*, Oxford University Press Inc., New York, USA 2010.

1.24. Optional / additional reading (at the time of proposing study programme)

1. Ben Rogers, Sumita Pennathur, Jesse Adams, *Nanotechology*, Taylor & Francis Group, LLC, Boca Raton FL, USA, 2011.
2. *Nanomaterials: Synthesis, Properties and Applications*, edited by A. S. Edelstein, CRC Press, Bristol, UK, 1998.

1.25. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Edward L. Wolf, *Nanophysics and Nanotechnology*, WILEY-VCH Verlag GmbH &Co. KGaA, Weinheim, Germany, 2006.	1	
Stuart.M.Lindsay, *Intoduction to Nanoscience*, Oxford University Press Inc., New York, USA 2010.	1	
Ben Rogers, Sumita Pennathur, Jesse Adams, *Nanotechology*, Taylor & Francis Group, LLC, Boca Raton FL, USA, 2011.	1	
Nanomaterials: Synthesis, Properties and Applications, edited by A. S. Edelstein, CRC Press, Bristol, UK, 1998.	1	

1.26. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Student's knowledge and competences are monitored via consultation, and by solving individual assignments and writing seminars. Student's final grade obtained on the oral exam is the indicator of the quality and performance of the course. Feedback on the quality and performance of the course is obtained via student's questionnaire, taken at the end of the course.

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Basic description		
Course coordinator	**Mladen Petravić**	
Course title	**Experimental Methods of Modern Physics**	
Study programme	**Doctoral Study in Physics**	
Course status	**Optional**	
Year	**1.**	
ECTS credits and teaching	***ECTS student 's workload coefficient***	10
	Number of hours (L+E+S)	15+60+15

1. COURSE DESCRIPTION

1.1. Course objectives

To gain the basic knowledge about modern analytical techniques used for the characterisation of advanced materials and to actively use the analytical instruments in real experiments.

1.2. Course enrolment requirements

Undergraduate/graduate courses of Solid State Physics, Experimental Methods in Physics or Physics of Semiconductors

1.3. Expected course learning outcomes

To understand the theoretical background and operation of several analytical techniques, and to be able to use these techniques in solving different analytical problems in science.

1.4. Course content

Students will work in several laboratories of the Department of Physics and Center for Micro- and Nanosciences and Technologies. After theoretical introduction on physical principles of experimental technique, each student will prepare a seminar about one specific technique. Most of the time is devoted to experiments using the following analytical techniques:
-XPS (X-ray Photoelectron Spectroscopy)
-SIMS (Secondary Ion Mass Spectrometry)
-AFM (Atomic Force Microscopy)
-SEM (Scanning Electron Microscopy)
-XRF (X-ray Fluorescence)
These techniques will be used by students for elemental analysis and depth profiling of elements and impurities, study of surface chemical bonds and morphology, characterization of changes and defects onf thin film surfaces of semiconductors heterostructures, compound semiconducting materials and nanosystems, including different nanotubes.
The minimum reasonable time to be spent on at least four of the analytical techniques on ffer (XPS, SIMS, SEM, XRF or AFM), with the growth of samples done by students themselves using ALD (Atomic Layer Deposition) technique, is about 75 hours in order to gain the basic knowledge and experience to start using these techniques with minimal supervision, while 15 hours is dedicated to the theoretical background.

1.5. Teaching methods	X lectures X seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	X individual assignment ☐ multimedia and network X laboratories X mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Active participation in experimental work, data acquisition, analysis and interpretation and oral presentation of experiments. Presentation of a seminar on one of the analytical techniques.

1.8. Evaluation of student's work

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Course attendance		Activity/Participation		Seminar paper	2	Experimental work	3
Written exam		Oral exam		Essay		Research	
Project	4	Sustained knowledge check		Report	1	Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Performance of students will be evaluated for each experiment performed and data analysis as well as oral presentation of each experiment and seminar on one of analytical techniques. There will be no final exam.

1.10. Assigned reading (at the time of the submission of study programme proposal)

1. L.Feldman and J.Mayer: Fundamentals of Surface and Thin Film Analysis, PTR Prentice Hall, New Jersey, 1986.
2. H.Luth: Surfaces and Interfaces of Solid Materials, Springer Study Edition, Berlin, 2007.

1.11. Optional / additional reading (at the time of proposing study programme)

1. D.P.Woodrruff and T.A.Delchar, Modern Tecniques of Surface Science-Second Edition, Cambridge University Press, Cambridge, 1994.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Flexible adaptation of teaching to interests and needs of students.
Feedback from students about quality of teaching will be obtained through the regular and anonymous questionnaires.

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Basic description		
Course coordinator	**Dijana Dominis Prester**	
Course title	**Selected chapters in Astrophysics**	
Study programme	**Doctoral Study in Physics**	
Course status	Optional	
Year	**1.**	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	30+0+30

1. COURSE DESCRIPTION

1.1. Course objectives

Achieving knowledge and competences in astrophysics, focusing on the particular field/topic of the student's doctoral thesis.

1.2. Course enrolment requirements

There are no formal requirements, besides the general requirements for the enrolment in this Doctoral Study.

1.3. Expected course learning outcomes

The expected outcomes will depend in the individual curriculum, agreed at the beginning of the course among the student, PhD thesis supervisor, and the course lecturer (see 1.6.). After the completion of this course, the student is expected to be able to:

- Understand the basic concepts and have a broad basic knowledge of astronomy and astrophysics
- Understand the basic concepts of astroparticle physics
- Understand the gravitational lensing effect
- Apply the gravitational lensing effect to different astrophysical objects, and observed events
- Distinguish the existing methods of searching for extrasolar planets, and understand how to apply their complementarity in practice
- Distinguish different types of Active Galactic Nuclei (AGN)
- Distinguish and complement recent theoretical models of radiation production in AGN, in different energy bands
- Analyse photometric data taken using optical telescopes
- Fit observations of the astronomical objects of interest (depending on the PhD thesis topic) in different energy bands of electromagnetic spectrum (Multiwavelength – MWL)
- Produce observing strategy for objects and events with fast time variability (transients) using selected combination of the available telescopes and instruments
- Optimise observing time of a given telescope or instrument, or a telescope network
- Apply numerical computing methods on the astrophysical problem (within their PhD thesis work)

1.4. Course content

1. **Basic concepts of astronomy and astrophysics, and astroparticle physics**
   (if necessary, i.e. in case of lacking former education of the student in the field)
2. **Selected chapters of astrophysics – theoretical part**
- Gravitational lensing effect
- Extrasolar planets
- Active galactic nuclei (AGN)
3. **Observational methods in astronomy and astrophysics**
- Optical astronomy and astrophysics
- Photometry
- Interferometry and astrometry
- Very-High-Energy (VHE) gamma astronomy

- Space telescopes and satellites
- Multiwavelength (MWL) astronomical obeservations
- Observation scheduling
- Observing strategies of transient events

4. Application of numerical computing methods in data modeling

- Optimization methods in complex parameter spaces
- Fitting observed data in agreement with theoretical models

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☒ exercises ☒ long distance education ☒ fieldwork	☒ individual assignment ☒ multimedia and network ☐ laboratories ☒ mentorship ☐ other
1.6. Comments	The curriculum of this course will be individualized, in connection to the selected PhD thesis topic, and the already existing student's knowledge in astronomy and astrophysics. Therefore, it is not expected that upon the completion of this course students has all the listed outcomes under 1.4, but only those agreed at the beginning of the course.	

1.7. Student's obligations

At least one public seminar talk. Completion of an independent research project. Respecting the agreed deadlines for the tasks taken.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	2	Experimental work	
Written exam		Oral exam	3	Essay		Research	2
Project	2	Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Students who achieve 90% or more of the total points during the course, do not need to be examined at the end in the form of an oral exam.

1.10. Assigned reading (at the time of the submission of study programme proposal)

I. Course web page
II. M. Zeilik and E.P. Smith: "Introductory Astronomy and Astrophysics", 1987, CBS College publishing

1.11. Optional / additional reading (at the time of proposing study programme)

I. Léna, P., Rouan, D., Lebrun, F., Mignard, F., Pelat, D.: "Observational astrophysics", 2012, Springer
II. Gravitational Lensing: Strong, Weak and Micro, Saas-Fee Advanced Course 33, 2004, Authors: Schneider, Peter, Kochanek, Christopher, Wambsganss, Joachim, Editors: Meylan, Georges, Jetzer, Philippe, North, Pierre (Eds.)
III. Extrasolar Planets, Saas Fee Advanced Course 31, 2006, Authors: Cassen, Patrick, Guillot, Tristan, Quirrenbach, A. Editors: Queloz, D., Udry, S., Mayor, M., Benz, W. (Eds.)
IV. Longair, M.S., High Energy Astrophysics, 1981

+ Selected scientific papers

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Discussion of the criteria, the structure of the topic to be treated. Students and the lecturer comment and evaluate the work and its presentation. Interaction with students and student-faculty team work on quality of teaching process. Anonymous questionnaires on quality of teaching. Flexible adaptation of teaching to interests and needs of students.

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Basic description		
Course coordinator	**Dijana Dominis Prester**	
Course title	**Seminar in physics**	
Study programme	**Doctoral study in Physics**	
Course status	Compulsory	
Year	1	
ECTS credits and teaching	ECTS student 's workload coefficient	5
	Number of hours (L+E+S)	4 + 0 + 26

1. COURSE DESCRIPTION

1.1. Course objectives

Learning to solve problems independently, and to deal with theoretical and practical research problems. Training for presenting scientific research results in seminars, journal clubs and conference talks.
Preparing students for the doctoral thesis defense.

1.2. Course enrolment requirements

Basic knowledge of computer usage.

1.3. Expected course learning outcomes

At the end of the course, students will be able to:

- define the objectives and tasks of a scientific paper,
- search and use the literature and other sources of knowledge independently,
- apply and extend the knowledge acquired during their studies on specific topic (procedural knowledge),
- professionally and methodically articulate the selected topic with arguments to interpret cause-effect relationships,
- use metrology of legally prescribed units,
- correctly use mathematical apparatus and mathematical terminology,
- distinguish technical terminology from the terms of standard language,
- use scientific language correctly and easily communicate professionally,
- process statistical data,
- graphically display and interpret data,
- process and display the illustrations (tables, graphs, functions, charts, diagrams, drawings, photographs, diagrams, pictures),
- clearly, simply and concisely express thoughts,
- grammatically and spelling correctly write any text,
- properly cite references,
- orally present the work,
- prepare and present a seminar talk and a conference talk in the given time,
- present own or other's scientific research results,
- learn to distinguish scientific from popular talks,
- take part in the discussions after the talks,
- distinguish presenting their own results from presenting results of others.

1.4. Course content

Collecting and studying the literature. Articulation and writing of research thesis. The structure of scientific work. Relating cause and effect. Preparation of illustrations. Documentation basics (citation and bibliography). Metrological correctness. Spelling, grammar, style and language**.** Methods of presenting of scientific results in a seminar. Preparing presentations in Power point, Open office and Latex. Presenting a seminar talk in front of the audience. Paralel usage of a computer and the blackboard in presentations. Analysis of presented seminars. Basics of giving speeches. Communication at seminars, and international meetings.

1.5. Teaching methods	X lectures X seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	X individual assignment X multimedia and network ☐ laboratories X mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Class attendance. Choosing a topic area of expertise, and labor to collect and study the literature. Student has to demonstrate the outcome of his/hers work in oral presentation, in front of the colleagues and tutors.
Attendance of seminars of the other class participants is mandatory. Active participation in discussions is expected.

1.8. Evaluation of student's work

Course attendance	1	Activity/Participation	1	Seminar paper	3	Experimental work	
Written exam		Oral exam		Essay		Research	
Project		Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

The work and progress of students is monitored continuously through periodical review of their work. Student can obtain up to 100% of the grade during the semester, by fulfilling the obligations given above. Instead of the final exam student will present a seminar.

1.10. Assigned reading (at the time of the submission of study programme proposal)

There is no unique assigned reading mandatory for all the enrolled students.

1.11. Optional / additional reading (at the time of proposing study programme)

Together with their thesis supervisor and the course coordinator, students will choose the seminar topic. They will be advised the most recent scientific publications in the chosen field as the additional reading.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Discussion of the criteria, the structure of the topic to be treated. Students and the course coordinator comment and evaluate the work and its presentation. Interaction with students and student-faculty team work on quality of teaching process. Anonymous questionnaires on quality of teaching. Flexible adaptation of teaching to interests and needs of students.

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Basic description		
Course coordinator	**Predrag Dominis Prester**	
Course title	**Black Hole Physics**	
Study programme	**Doctoral Study in Physics**	
Course status	optional	
Year	**1.**	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	30 + 10 + 10

1. COURSE DESCRIPTION

1.1. Course objectives

Introduction to basic and some advanced aspects of black hole physics.

1.2. Course enrolment requirements

No formal requirements. It assumed that students enter the course with basic knowledge of general relativity (on the level of the diploma course "General Relativity").

1.3. Expected course learning outcomes

Depending on an individual curriculum, outcomes will include: Students will master techniques in general relativity for analysing and constructing black hole solutions, for analysing behaviour of matter and radiation, both classical and quantum, in black hole backgrounds, including gravitational radiation and emission of gravitational waves from simple systems possibly containing black holes. They will acquire advanced knowledge of mathematics of black holes, black hole thermodynamics and microscopic interpretations, and about importance of black holes as theoretical laboratories for understanding quantum gravity.

1.4. Course content

Content is not strictly determined - it will depend on actual trends in the field, and it will be tailored to individual needs of the student and his PhD research. The content will be chosen from the following topics:

1. Schwarzschild and Kerr solutions
- space-time structure and properties: horizons and singularities
- particle and radiation dynamics
- gravitational lensing

2. Mathematical properties of black hole solutions
- no-hair theorems
- singularity theorems
- black holes in generalised gravity theories
- laws of black hole thermodynamics

3. Mechanisms of formation and dynamics of black holes
- collapse of matter
- astrophysical systems with black holes
- gravitational radiation from systems containing black holes
- primordial black holes
- current and future experiments: status

4. Quantum field theory in the black hole background
- dynamics and effective action
- Hawking radiation
- microscopic origin of black hole entropy, information paradox and possible solutions
- black holes as theoretical laboratories for quantum gravitation

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises	☒ individual assignment ☐ multimedia and network ☐ laboratories

	☐ long distance education ☐ fieldwork	☐ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Doing home assignments and completing one project.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper		Experimental work	
Written exam		Oral exam		Essay		Research	
Project	4	Sustained knowledge check	4	Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Evaluation of homework assignments and one project assignment. Final exam only in case of need.

1.10. Assigned reading (at the time of the submission of study programme proposal)

1. V. P. Frolov, A. Zelnikov, Introduction to Black Hole Physics (Oxford Univ. Press), 2011.
2. D. L. Meier, Black Hole Astrophysics: The Engine Paradigm (Springer Praxis Books), 2012.
3. L. Parker, D. Toms, Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity (Cambridge Monographs on Mathematical Physics), 2009.

1.11. Optional / additional reading (at the time of proposing study programme)

1. R. Wald, General Relativity (Univ. Of Chicago Press), 1984.
2. E. Poisson, A Relativist's Toolkit: The Mathematics of Black Holes (Cambridge Univ. Press), 2007.
3. V. P. Frolov, I. D. Novikov, Black Hole Physics: Basic Concepts and New Developments (Fundamental Theories of Physics), 1998.
4. R. Wald, Quantum Field Theory in Curved Spacetime and Black Hole Thermodynamics (Chicago Lectures in Physics), 1994.
5. B. O'Neill, The Geometry of Kerr Black Holes (Dover Books on Physics), 2014.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Consultations, anonymous polls, and discussions after fulfilling the requirements of the course.

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Basic description		
Course coordinator	**Predrag Dominis Prester**	
Course title	**Selected Topics of Elementary Particle Physics**	
Study programme	**Doctoral Study in Physics**	
Course status	optional	
Year	**1.**	
ECTS credits and teaching	ECTS student 's workload coefficient	10
	Number of hours (L+E+S)	45 + 0 + 15

1. COURSE DESCRIPTION

1.1. Course objectives

Extending and deepening of the understanding of the theory and techniques of the elementary particle physics, tailored to the individual needs of a student's PhD research.

1.2. Course enrolment requirements

No formal requirements. It is assumed that student has at least a basic knowledge of the Standard Model, on the level of the standard diploma course (*Elementary Particle Physics I* at University of Rijeka), and at least some basic knowledge of quantum field theory (free fields, simple Feynmann diagrams).

1.3. Expected course learning outcomes

Depending on the individual curriculum, expected outcomes are: Understanding of the Standard Model, and its possible extensions, on the advanced level. Mastering of the perturbative techniques, especially Feynmann diagrams, and being able to use them, without supervision, to calculate higher order processes in quantum field theories. Advanced understanding and application of methods of quantisation of quantum field theories, including quantum anomalies important for theoretical classification of consistent theories. Understanding of the role and uses of symmetries, and mechanisms of their breaking, and being able to understand and calculate their phenomenological consequences. Understanding of some important nonperturbative effects, and their phenomenological consequences, in quantum field theory. Understanding of the problems with the attempts to quantize gravity using standard quantum field theory methods, and mastering some of the main ideas and theories which pretend to solve this problem, such as superstring theory.

1.4. Course content

Curriculum is tailored to the needs of students PhD research, so there is no fixed content. The topics from which the content will be determined are:

1. Advanced aspects of quantum field theory
- quantisation of non-Abelian QFT's
- renormalisation group methods
- quantum effective actions: Euler-Heisenberg effective action
- anomalies
- topological aspects: monopoles, instantons, vacuum and its stability

2. Phenomenology
- symmetries and their breaking: soft, spontaneous and anomalous
- processes in Standard model and calculating techniques: higher order Feynmann diagrams
- low energy effective action: sigma models of mesons and barions, nonrenormalisabitity
- beyond Standard Model physics

3. Quantum gravity and unification of forces
- problems with quantisation of gravity
- supersymmetry and supergravity
- higher spin theories
- superstring theory

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises	☒ individual assignment ☐ multimedia and network ☐ laboratories

	☐ long distance education ☐ fieldwork	☐ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Completing one or two project assignments, and one seminar presented to public.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	5	Experimental work	
Written exam		Oral exam		Essay		Research	
Project	5	Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Project(s) and seminar will be evaluated. Final exam only in case of need.

1.10. Assigned reading (at the time of the submission of study programme proposal)

As a curriculum is individual, there is no obligatory reading.

1.11. Optional / additional reading (at the time of proposing study programme)

1. S. Weinberg, Quantum Theory of Fields I, II, III (Cambridge University Press), 2005.
2. M. D. Schwartz, Quantum Field Theory and the Standard Model (Cambridge Univ. Press), 2013.
3. M. E. Peskin, D. V. Schroeder, An Introduction To Quantum Field Theory (Frontiers in Physics), 1995.
4. T.-P. Cheng, L.-F. Li, Gauge Theory of Elementary Particle Physics: Problems and Solutions (Oxford Univ. Press), 1988.
5. A. Seiden, Particle Physics: A Comprehensive Introduction (Pearson), 2004.
6. L. Parker, D. Toms, Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity (Cambridge Monographs on Mathematical Physics), 2009.
7. C. Kiefer, Quantum Gravity (International Series Monographs on Physics, 3rd edition), 2012.
8. J. Polchinski, String theory I i II (Cambridge Univ. Press), 2005.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Consultations, anonymous polls, and discussions after fulfilling the requirements of the course.

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Basic description		
Course coordinators	Željko Svedružić , Marta Žuvić	
Course title	Computational Methods in Biophysics	
Study programme	PhD in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	7
	Number of hours (L+E+S)	10+40+10

1. COURSE DESCRIPTION

1.1. Course objectives

Understanding the structure and function of biologically important molecules and their interactions.
Familiarization with the software options for analysing the structure and function of biologically important large and small molecules.
The application of computational methods in the study of mechanisms of biochemical processes (organic and biochemical reactions) through molecular interactions modelling.
A critical evaluation of the computational analysis and predictions based on the results obtained.

1.2. Course enrolment requirements

Enrolled PhD in Physics.

1.3. Expected course learning outcomes

Upon completion of the course, students will be capable of : autonomous application and customization of the computational analyses of the structure and function of biologically relevant molecules, independent use and adaptation of analysis for biochemical reactions computation, interpretation and evaluation of the computational results, prediction of the molecules' behaviour on the basis of the computational results, identification of strengths and limitations of computational methods in analysis of the structure and function of molecules and their interactions, and critical approach to scientific literature areas.

1.4. Course content

The structure and function of biologically important macromolecules (proteins, nucleic acids, lipids and carbohydrates) as well as small molecules, which interact as ligands and substrates.

Biochemical processes and their characterization through intermolecular interactions: description of protein-ligand interactions, description of the enzyme-substrate reactions, mechanisms of activation and inhibition of the enzymatic activity, mechanisms of agonistic and antagonistic activity, a steady-state kinetics and overstabile-state kinetics, the pH profiles of enzymatic activity, isotope effects of solvents, enzymatic reactions with multiple substrates, processivity of enzymes on DNA molecules, metabolic pathways.

The classical and quantum-mechanical approach to the description of intermolecular interactions. Computer analysis of the structure of molecules (using appropriate software applications, such as: WinGamess, Avogadro, MacMolPlt, Abalone, Wavefunction Spartan): comparison UFF, MMFF94, and QM approach to the analysis of conformation and energy of small and large molecules, molecular mechanics analysis of the structure and MonteCarlo simulation, application of the basic quantum-mechanical calculations: optimization of molecular conformation, calculation of energy bond in the molecule, calculation and mapping of energy fields at selected values of electron density.

Computational analysis of the dynamics of large and small molecules and their interactions using methods of Molecular Dynamics (using appropriate software applications, such as:: NAMD-VMD, Gromacs-VMD, UCSF Chimera):
- Parameterization and topology of ligands, RMSD analysis, RMSF, g(r) values and changes in energy;
- Molecular dynamics of protein-ligand interactions: modelling the force field, enthalpy, entropy and free energy of binding.
- Simulation guided molecular dynamics (MD stirred). Rough molecular dynamics (coarse-grained MD). Maxwell-Boltzmann distribution. Combining a series of Maxwell-Boltzmann distributions with umbrella method (umbrella sampling).

QM / MM analysis. Effective Field Potential protocols. Different QM models and selection of QM approach. Ab-initio vs.

semi-empirical methods. Hartree-Fock method, post Hartree-Fock methods (RHF, URF, ROHF), DFT, MP2, correlation methods. IR spectra, Raman spectra, Hesse matrix. The kinetic isotope effects.
Simulation reaction coordinates for the different reaction mechanisms. Imaginary vibrational frequency, search for the saddle point, calculation of the energy for the transition state (TS, IRC, DRC, MEP protocols). Scanning the sequence of steps in the reaction mechanism (string methods and nudged elastic band method).
Practical examples of QM analysis in behaviour of small molecules. Simulations of UV-VIS spectrum, CD spectrum, fluorescence, phosphorescence, polarization, anisotropy and FRET. Intrinsic fluorescence of biomolecules and fluorescent labelling of biomolecules. Examples of QM / MM analysis: catalytic mechanism of selected enzymes, DNA damage analysis, simulation of chemical processes in the evolution of life on earth.

1.5. Teaching methods	☐ lectures ☐ seminars and workshops ☐ exercises X ☐ long distance education ☐ fieldwork	X ☐ individual assignment ☐ multimedia and network X ☐ laboratories X ☐ mentorship ☐ other
1.6. Comments	Computational analyses and simulations will be in part performed individually on a personal computer and in part on the university supercomputer Bura.	

1.7. Student's obligations

Students are required to independently perform given tasks of computer analysis and simulation. Students will be involved in a scientific project work together with the mentor, where timely performance of the assigned tasks is expected.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper		Experimental work	x
Written exam		Oral exam		Essay		Research	x
Project	x	Sustained knowledge check		Report		Practice	x
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Students' work in the course will be evaluated and assessed during the course and on the final exam. Detailed analysis of monitoring and evaluation of students' work will appear in the course executive plan.

1.10. Assigned reading (at the time of the submission of study programme proposal)

1. I.N. Serdyuk, N.R. Zaccai, J. Zaccai:: Methods in Molecular Biophysics - Structure, Dynamics, Function. Cambridge University Press, 2007.
2. R. Kaźmierkiewicz: Introduction to Molecular Modeling. Intercollegiate Faculty of Biotechnology UG-MUG, 2011.

1.11. Optional / additional reading (at the time of proposing study programme)

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Readings will be available as a pdf documents within the e-course.		

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Continuous monitoring of each student's personal progress by providing feedback on assignment solutions.

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Basic description		
Course coordinator	Silvia Silvia Tomić	
Course title	Molecular Materials of Reduced Dimensionality	
Study programme	Doctoral study in Physics	
Course status	Optional	
Year	1	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	20+20+10

1. COURSE DESCRIPTION

1.1. Course objectives

The aim of this course is to present physical concepts and phenomena specific to advanced quantum materials of reduced dimensionality composed of organic molecules: strong electron correlations, superconductivity, charge and spin density waves, charge orders, electronic ferroelectricity and multiferroicity. Modern experimental methods and procedures commonly used in the studies of static and dynamic properties in charge and spin sectors in order to achieve better description of novel physical phenomena will be introduced.

1.2. Course enrolment requirements

No requirements

1.3. Expected course learning outcomes

Once the course will be completed, students will be able to describe the phase diagrams, crystallographic and electronic structures and their relationship, and the properties of the electronic transport and dynamics in different electronic phases. They will master to analyze measured data of the electronic transport and dynamics by using basic theoretical models. Students will also learn to chose the most appropriate experimental methods in order to characterize the physical properties of molecular materials.

1.4. Course content

Structural properties; Phase diagrams; Electronic Phases: superconductivity, charge and spin density waves; charge orderings; ferroelectricity; Experimental Methods

1.5. Teaching methods	x☐ lectures x☐ seminars and workshops x☐ exercises ☐ long distance education ☐ fieldwork	x☐ individual assignment x☐ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.6. Comments	Activity level at lectures, seminars and exercises are assessed. Final exam: oral	

1.7. Student's obligations

Regular attendance of lectures, seminars and exercises; write and deliver on time the number of seminars previously identified; pass the final exam (oral).

1.8. Evaluation of student's work

Course attendance		Activity/Participation	2	Seminar paper	4	Experimental work	
Written exam		Oral exam	2	Essay		Research	

Project		Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Student's work is assessed during the teaching hours (70%) and at the final exam (30%)

1.10. Assigned reading (at the time of the submission of study programme proposal)

Organic Superconductors, Springer Series in Solid-State Sciences, Ed. T. Ishiguro and K. Yamaji, Springer Verlag, Berlin, Heidelberg (1990).
The physics of Organic Superconductors and Conductors, Springer Series in Materials Science, Ed. A. Lebed, Springer Verlag, Berlin, Heidelberg (2008).

1.11. Optional / additional reading (at the time of proposing study programme)

Relevant scientific papers such as:

D.Jerome, Organic Superconductors: when correlations and magnetism walk in, Journal of Superconductivity and Novel Magnetism 25, 633 (2012).
S.Tomić and M.Dressel, Ferroelectricity in molecular solids, a review od electrodynamic properties, Rep.Prog.Phys. 78, 096501 (2015).

1.1. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*

1.2. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Interaction with students, *flexible adjustment of the interaction depending on interests and needs.*

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Basic description		
Course coordinator	Gordana Žauhar, PhD, Associate professor	
Course title	Ultrasound in Medicine	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1.	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	25+15+10

1. COURSE DESCRIPTION

1.1. Course objectives

Aim of the course is to give a comprehensive overview of techniques and physical principles which are used in medical application of ultrasound. To develop understanding of: (1) physical phenomena which are used for generation of ultrasonic waves; (2) interaction of ultrasonic waves with matter; (3) basic principles of operation of ultrasonic imaging scanners and Doppler devices; (4) the purpose and techniques of acoustic output measurements.

1.2. Course enrolment requirements

Enrolled PhD in Physics.

1.3. Expected course learning outcomes

After completing the course students should be able to:

- understand the basic physical principles of medical application of ultrasound in diagnostic and therapy
- explain how the pulse-echo principle is used in sonography
- explain how ultrasound detects and measure tissue motion and blood flow by Doppler instruments
- understand the quality control procedures for ultrasound devices
- understand the biological effects of ultrasound on tissues which are the basis for therapeutic application of ultrasound in medicine
- understand the purpose and techniques of acoustic output measurements
- explain regulations that ensure safe operation of the ultrasonic instruments, and importance of their implementation
- critically follow scientific literature in the field of medical ultrasound

1.4. Course content

Ultrasonic waves and their properties
Ultrasound waves, plane wave, spherical wave, ultrasound beam.
Reflection, scattering and refraction of ultrasound waves in media and their boundaries
Intensity and energy of ultrasound waves
Forces in media and on the reflectors exposed to ultrasound.
Attenuation of ultrasound by passing through tissue.
Generation of ultrasound waves
Piezoelectric effect, composite transducers and arrays
The ultrasound echoscopes
The basic principles of operation
Resolution
Quality control of ultrasound scanners
Doppler effect for plane wave
Velocity measurement using Doppler effect.
Doppler Ultrasound devices.
The continuous and pulsed systems.

Sampling theorem and consequences for measurement accuracy.
Therapeutic ultrasound
The use of ultrasound in physical therapy
High intensity focused ultrasound devices and their application.
The purpose and techniques of acoustic output measurements
Hydrophones, ultrasound balances.
The phenomena that may occur as a result of the propagation of ultrasound through the media: heating, cavitation, acoustic streaming
Safety in medical application of ultrasound

1.5. Teaching methods	☐ lectures ☒ seminars and workshops ☒ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☐ multimedia and network ☐ laboratories ☒ mentorship ☐ other
1.6. Comments		

1.7. Student's obligations

Students are required to independently develop tasks that will be given. Students will be involved in scientific work together with the mentor.

1.8. Evaluation of student's work

Course attendance		Activity/Participation		Seminar paper	X	Experimental work	
Written exam		Oral exam	X	Essay		Research	X
Project		Sustained knowledge check		Report		Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

The student is required to perform calculations of one numerical problem related to acoustics and his written report is evaluated before he could apply for the exam.

1.10. Assigned reading (at the time of the submission of study programme proposal)

C.R. Hill, Physical Principles of Medical Ultrasonics, John Wiley & Sons, Chichester, 2005.
B. Breyer, Medicinski dijagnostički ultrazvuk, Školska knjiga, Zagreb, 1991.

1.11. Optional / additional reading (at the time of proposing study programme)

F.A. Duck, A.C. Baker, H.C.Starritt, Ultrasound in Medicine, IOP Publishing Ltd, 1998.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
C.R. Hill, Physical Principles of Medical Ultrasonics, John Wiley & Sons, Chichester, 2005.	1	0
B. Breyer, Medicinski dijagnostički ultrazvuk, Školska knjiga, Zagreb, 1991.	1	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

The continued monitoring of personal progress of each student by providing feedback on the development of solutions tasks.

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Basic description		
Course coordinator	Prof. Saša Zelenika, D. Sc.	
Course title	Micro- and Nano-Electromechanical Systems	
Study programme	Postgraduate doctoral study in Physics	
Course status	Optional	
Year	1st	
ECTS credits and teaching	ECTS student 's workload coefficient	8
	Number of hours (L+E+S)	25+15+10

1. COURSE DESCRIPTION

1.1. Course objectives

Systematic understanding as well as critical analysis and assessment of most recent scientific information in the field of micro- and nano-electromechanical systems (MEMS & NEMS). Acquisition of knowledge about the application of scaling phenomena, about production technologies as well as about the handling and assembly of MEMS and NEMS devices, about innovative materials and their applications, and about the modelling of the behaviour and the experimental validation of performances of MEMS and NEMS devices – all related to an autonomous approach and resolution of complex technological problems.
Acquisition of skills of scientific and research work as well as of synthesis of new and complex ideas. Capability of communication with experts and peers in the considered research field.

1.2. Course enrolment requirements

None

1.3. Expected course learning outcomes

Classify types and characteristics of MEMS and NEMS devices as well as of the respective production technologies.
Assess advantages and disadvantages of thus developed MEMS and NEMS devices, of the approaches available to model their behaviour, as well as of the approaches of experimentally validating their performances.
Autonomously implement principles of treated topics on project assignments.
Synthetize acquired knowledge and generate innovative technological solutions.
Organise and plan work on project assignments.
Present achieved results in a scientifically sound manner with development of skills of writing of scientific and professional publications.

1.4. Course content

Introduction to MEMS & NEMS devices.
Historical development of usage of MEMS and NEMS. Scaling phenomena.
Production technologies and handling and assembly of MEMS and NEMS.
Properties of used (especially innovative) materials.
Approaches to the modelling and simulation of the behaviour of MEMS and NEMS.
Reliability of devices. Optimisation of systems. Compensation of errors.
Experimental validation of the behaviour of MEMS and NEMS devices – from the component to the system level. Usage of SPM, nanoindentation and related measurement techniques in the treated field of work.
Ethical aspects in using the nanotechnologies.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☐ exercises ☐ long distance education ☐ fieldwork	☒ individual assignment ☐ multimedia and network ☒ laboratories ☒ mentorship ☐ other
1.6. Comments	/	

1.7. Student's obligations

Attendance of classes (consultations), work on project assignment as well as preparation and presentation of seminar.

1.8. Evaluation of student's work

Course attendance	0.5	Activity/Participation		Seminar paper	2	Experimental work	
Written exam		Oral exam		Essay		Research	5
Project		Sustained knowledge check		Report	0.5	Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Attendance of consultations, project work, seminar paper and report.

1.10. Assigned reading (at the time of the submission of study programme proposal)

B. Bhushan B. (ed.): «Springer Handbook of Nanotechnology» - 3rd ed., Springer Verlag, Berlin (DE), 2010.
S. Zelenika and E. Kamenar: «Precizne konstrukcije i tehnologija mikro- i nanosustava (Precision Engineering and Micro- and Nanosystems Technologies I – Precision Engineering)», University of Rijeka (HR) – Faculty of Engineering, 2015.
F. De Bona and E. Enikov (ed.): «Microsystems Mechanical Design – CISM Courses and Lectures No. 478», Springer Verlag, Wien (A), 2006.

1.11. Optional / additional reading (at the time of proposing study programme)

M. J. Jackson: «Microfabrication and Nanomanufacturing», CRC Press, Boca Raton (FL, USA), 2006.
M. J. Madou: «Fundamentals of Microfabrication – The Science of Miniaturisation», CRC Press, Boca Raton (FL, USA), 2002.
Schmidt R. M., Schitter G., Rankers A. and van Eijk J.: «The Design of High Performance Mechatronics – High-tech Functionality by Multidisciplinary System Integration» - 2nd ed., Delft University Press, Delft (NL), 2014.

1.12. Number of assigned reading copies with regard to the number of students currently attending the course

Title	*Number of copies*	*Number of students*
B. Bhushan B. (ed.): Springer Handbook of Nanotechnology	1	0
S. Zelenika and E. Kamenar: Precision Engineering and Micro- and Nanosystems Technologies	10	0
F. De Bona and E. Enikov (ed.): Microsystems Mechanical Design – CISM Courses and Lectures No. 478	2	0
M. J. Jackson: Microfabrication and Nanomanufacturing	1	0
M. J. Madou: Fundamentals of Microfabrication – The Science of Miniaturisation	1	0
Schmidt R. M., Schitter G., Rankers A. and van Eijk J.: The Design of High Performance Mechatronics – High-tech Functionality by Multidisciplinary System Integration	1	0

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills and competences

Via the institutionalised quality assurance system of the Department of Physics and the University of Rijeka. Constant interaction and work with the students with the aim of improving the quality of teaching.
Flexible adaptation of classes to interests and needs of attending students.

Sveučilište u Rijeci • University of Rijeka
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Basic description		
Course coordinator	Igor Žutić	
Course title	CONTEMPORARY CONCEPTS OF MAGNETISM AND SUPECONDUCTIVITY	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1. year	
ECTS credits and teaching	***ECTS student 's workload coefficient***	8
	Number of hours (L+E+S)	30 + 15 + 10

1. COURSE DESCRIPTION

1.1. Course objectives

The main objectives of the course are:

- to provide the basic theoretical knowledge on several aspects in quantum magnetism, BCS theory of superconductivity and beyond, due to correlated electrons;
- to point out that phenomena are realizations of thermodynamic states which break certain continuous symmetries. In the case of magnetism, they break rotational invariance. In the case of superconductivity, they break gauge invariance.

1.2. Course enrolment requirements

No prerequisites are required.

1.3. Expected course learning outcomes

After passing the exam, the student will be able:

1. to clarify the basic phenomenology and applications of magnetism and superconductivity;
2. to describe the key physical principles of magnetism and superconductivity;
3. to solve simple and more complex problems using advanced calculational tools, such as the Green's function approach;
4. to derive most important theoretical results starting from the underlying assumptions;
5. to be able to successfully interpret important papers from the field

1.4. Course content

PART I: BASICS Orbital and spin magnetism without interactions. Exchange interactions. Phase transitions. Mean field theory. The Ising model. Linear response. Spin waves. Itinerant magnetism. Macroscopic aspects of superconductivity. Ginzburg-Landau theory. The BCS theory of superconductivity. Vortices in Type II Superconductors. The Josephson Effect and Quantum Interferometers.
PART II: FURTHER TOPICS
Theory of strong electron correlation. RPA theory of ferromagnetism in metals. Magnetism of dilute alloys. Green's function method in magnetism. Green's function of a superconductor. Andreev reflection. Paramagnetic impurities in superconductors. Magnetically ordered superconductors. Heavy fermion superconductors. High T_c superconductors. Organic superconductors.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☒ exercises ☒ long distance education ☐ fieldwork	☒ individual assignment ☒ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.6. Comments	Seminars and reports (5-10 minutes) will consist of additional topics that are not covered during the course.	

1.7. Student's obligations

- regular attendance of lectures and exercises
- students are required to solve, write, and submit specified number (usually 10) of homework on time
- to prepare a seminar in PowerPoint and present it to the class
- to pass two midterm written exams and the final oral exam

1.8. Evaluation of student's work

Course attendance	0.5	Activity/Participation	0.5	Seminar paper	1.5	Experimental work	
Written exam	3.0	Oral exam	3.0	Essay		Research	
Project		Sustained knowledge check	1.0	Report	0.5	Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Student will be evaluated and assessed during the course and final exam. Maximum total percentage which student can achieve during the lessons is 70%, while the final exam provides 30% at most.
Detailed elaboration of ways of monitoring and evaluation of students' work will be displayed in the Working Plan!

1.10. Assigned reading (at the time of the submission of study programme proposal)

Bennemann K. H. and Ketterson J. B. (editors), *Superconductivity - Conventional and Unconventional Superconductors*, vol. 1 and vol. 2, Springer-Verlag, Berlin, 2008.
Kakehashi Y., *Modern Theory of Magnetism in Metals and Alloys*, Springer-Verlag, Berlin, 2012.
Kruchinin S., Nagao H. and Aono S., *Modern Aspects of Superconductivity – Theory of Superconductivity*, World Scientific, Singapore, 2011.
Levy L-P., *Magnetism and Superconductivity*, Springer-Verlag, Berlin, 2000.
Stöhr J and Siegmann H. C., *Magnetism from Fundamentals to Nanoscale Dynamics*, Springer-Verlag, Berlin, 2008.

1.11. Optional / additional reading (at the time of proposing study programme)

Fazekas P., *Electron Correlation and Magnetism*, World Scientific, Singapore, 1999.
Tinkham M., *Introduction to Superconductivity*, 2nd ed., McGraw-Hill, New York, 1996.
Yosida K., *Theory of Magnetism*, Springer-Verlag, Berlin, 1996.
Nolting W. and Ramakanth A. *Quantum Theory of Magnetism*, Springer-Verlag, Berlin, 2009.
Fossheim K. and Sudbø, *Superconductivity: Physics and Applications*, John Wiley & Sons, New York, 2004.

1.12. Number of assigned reading copies regarding the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Levy L-P., *Magnetism and Superconductivity*, Springer-Verlag, Berlin, 2000.	2	5
Stöhr J and Siegmann H. C., Magnetism from Fundamentals to Nanoscale Dynamics, Springer-Verlag, Berlin, 2008.	2	5

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills, and competences

Regular monitoring of the student's activity and attitude towards work. In the last week of classes, anonymous surveys will be conducted in which students will evaluate the quality of teaching. At the end of each semester (1 March and 30 September of the current academic year) student' success in examinations will be analyzed.

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Basic description		
Course coordinator	Igor Žutić	
Course title	THEORETICAL FOUNDATIONS OF SPINTRONICS	
Study programme	Doctoral Study in Physics	
Course status	Optional	
Year	1. year	
ECTS credits and teaching	***ECTS student 's workload coefficient***	8
	Number of hours (L+E+S)	30 + 15 + 10

1. COURSE DESCRIPTION

1.1. Course objectives

The main objectives of the course are:
- to provide the theoretical knowledge on the basic physical principles underlying the generation of carrier spin polarization, spin dynamics, and spin-polarized transport in semiconductors and metals;
- to review experimental work with the emphasis on projected applications, in which external electric and magnetic fields and illumination by light will be used to control spin and charge dynamics to create new functionalities not feasible or ineffective with conventional electronics.

1.2. Course enrolment requirements

No prerequisites are required.

1.3. Expected course learning outcomes

After passing the exam, the student will be able:

6. to clarify the basic phenomenology and applications of spintronics;
7. to describe the key physical principles of spintronics;
8. to solve simple and more complex problems by analytical and numerical calculations with well-known software packages, such as Mathematica or Matlab;
9. to derive most important theoretical results starting from the underlying assumptions;
10. to be able to successfully interpret important papers from the field

1.4. Course content

PART I: *Introduction*. Overview. History and background. Spin-polarized transport and magnetoresistive effects. Spin injection and optical orientation. PART II: *Generation of spin polarization*. Optical spin orientation. Theories of spin injection. Experiments on spin injection. PART III: *Spin relaxation and spin dephasing*. Mechanisms of spin relaxation. Spin relaxation in metals. Spin relaxation in semiconductors. PART IV: *Spintronic devices and applications*. Spin-polarized transport. Materials considerations. Spin filters. Spin diodes. Spin transistors. Spin qubits in semiconductor nanostructures. Semiconductor spin-lasers.

1.5. Teaching methods	☒ lectures ☒ seminars and workshops ☒ exercises ☒ long distance education ☐ fieldwork	☒ individual assignment ☒ multimedia and network ☐ laboratories ☐ mentorship ☐ other
1.6. Comments	Seminars and reports (5-10 minutes) will consist of additional topics that are not covered during the course.	

1.7. Student's obligations

- regular attendance of lectures and exercises
- students are required to solve, write, and submit specified number (usually 10) of homework on time

- to prepare a seminar in PowerPoint and present it to the class
- to pass two midterm written exams and the final oral exam

1.8. Evaluation of student's work

Course attendance	0.5	Activity/Participation	0.5	Seminar paper	1.5	Experimental work	
Written exam	3.0	Oral exam	3.0	Essay		Research	
Project		Sustained knowledge check	1.0	Report	0.5	Practice	
Portfolio							

1.9. Assessment and evaluation of student's work during classes and on final exam

Student will be evaluated and assessed during the course and final exam. Maximum total percentage which student can achieve during the lessons is 70%, while the final exam provides 30% at most.
Detailed elaboration of ways of monitoring and evaluation of students' work will be displayed in the Working Plan!

1.10. Assigned reading (at the time of the submission of study programme proposal)

Žutić I., Fabian J., and Das Sarma S., ''Spintronics: Fundamentals and applications'', Rev. Mod. Phys. **76**, p. 323 - 410, 2004.
Tsymbal E. Y., Žutić I., *Handbook of Spin Transport and Magnetism*, CRC Press, Boca Raton, 2012.
Fabian J. Matos-Abiague A., Ertler C., Stano P., Žutić I., ''Semiconductor Spintronics'', Acta Physica Slovaca **57**, No. 4&5, p. 565-907, 2007. (downloadable at http://www.physics.sk/aps/pubs/2007/aps-07-04/aps-07-04.pdf)

1.11. Optional / additional reading (at the time of proposing study programme)

Bandyopadhyay S., Cahay M., *Introduction to Spintronics*, CRC Press, Boca Raton, 2015.
Maekawa S. (editor), *Concepts in Spin Electronics*, Oxford University Press, Oxford, 2006.
Xu Y., Awschalom D. D., Nitta J. (editors)., *Handbook of Spintronics*, Springer-Verlag, Berlin, 2016.

1.12. Number of assigned reading copies regarding the number of students currently attending the course

Title	*Number of copies*	*Number of students*
Žutić I., Fabian J., and Das Sarma S., ''Spintronics: Fundamentals and applications'', Rev. Mod. Phys. 76, p. 323 - 410, 2004.	1	5
Tsymbal E. Y., Žutić I., Handbook of Spin Transport and Magnetism, CRC Press, Boca Raton, 2012.	2	5

1.13. Quality monitoring methods which ensure acquirement of output knowledge, skills, and competences

Regular monitoring of the student's activity and attitude towards work. In the last week of classes, anonymous surveys will be conducted in which students will evaluate the quality of teaching. At the end of each semester (1 March and 30 September of the current academic year) student' success in examinations will be analyzed.