DFC.113.FTC *Physics of mesoscopic systems*

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Graduate/Master
1.6. Study program/Qualification	Theoretical and Computational Physics (in English)
1.7. Mode of study	Full-time study

2. Course unit

2.1. Course title		**Physics of mesoscopic systems**						
2.2. Teacher			Prof. dr. Lucian Ion					
2.3. Tutorials instructor(s)			Prof. dr. Lucian Ion					
2.4. Practicals instructor(s)								
2.5. Year of study	1	2.6. Semester	1	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1]	**DA**
							Type[2]	**DFac**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: lecture	**2**	Tutorials/Practicals	**2/0**
3.2. Total hours per semester	**56**	distribution: lecture	**28**	Tutorials/Practicals	**28/0**
Distribution of estimated time for study					**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography					**10**
3.2.2. Research in library, study of electronic resources, field research					**10**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks					**20**
3.2.4. Examination					**4**
3.2.5. Other activities					

3.3. Total hours of individual study	**40**
3.4. Total hours per semester	**100**
3.5. ECTS	**4**

4. Prerequisites (if necessary)

4.1. curriculum	Electricity and magnetism, Optics, Equations of Mathematical Physics, Solid State Physics
4.2. competences	• Using of software tools for data analysis/processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Multimedia infrastructure (PC, videoprojector, internet conection)
5.2. for tutorials/practicals	-

6. Acquired specific competencies

Professional competencies	• Identificartion and adequate use of physics laws in a given context; identification and adequate use of notions and specific physics laws for mesoscopic systems. • Solving physics problems in given conditions. • Creative use of acquired physical knowledge to understand and to construct models for physical processes and properties of mesoscopic systems/nanostructures. • Analysis and communication of scientific data, communication for physics popularisation. • Use and development of specific software tools.
Transversal competencies	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Introduction and analysis of the physical properties of mesoscopic systems
7.2. Specific objectives	Study of electronic structure, transport and optical properties of mesoscopic systems. Analysis of specific charge transport models. Highlighting of essential problems in understanding of specific phenomena, in order to stimulate creative and critical thinking în solving problems.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations
Introduction: description of mesoscopic systems. Growth and processing methods. Length scales.	Systematic exposition - lecture. Examples.	4 hours
Electronic structure of mesoscopic systems. Envelope wavefunction method.	Systematic exposition - lecture. Examples.	4 hours
Anderson localization. Scaling theory of localization. Reduced dimensionality. Case $d \leq 2$. Case $d > 2$. Metal-insulator transition	Systematic exposition - lecture. Examples.	6 hours
Quantum interference effects în charge transport. Landauer-Büttiker formalism. Applications.	Systematic exposition - lecture. Examples.	4 hours
Chrage transport în magnetic fields. Shubnikov – de Haas oscillations. Integer quantum Hall effect.	Systematic exposition - lecture. Examples.	4 hours
Aharonov-Bohm effect. Berry phase.	Systematic exposition - lecture. Examples.	4 hours
Coulomb blockade în semiconductor nanostructures	Systematic exposition - lecture. Examples.	2 hours

References:

1. D.K. Ferry, S.M. Goodnick, *Transport in nanostructures* (Cambridge University Press, Cambridge, UK, 1997).
2. P.A. Lee, T.V. Ramakrishnan, Rev. Mod. Phys. **57**, 287 (1985).
3. H. Bouchiat, Y. Gefen, S. Gueron, G. Montambaux, J. Dalibard (Eds.), *Nanophysics: Coherence and*

Transport (Elsevier, Amsterdam, Netherland, 2005).
4. V.F. Gantmakher, *Electrons and disorder în solids* (Clarendon Press, Oxford, UK, 2005)
5. L. Ion, Course notes

8.2. Tutorials [main tutorial subjects]	Teaching and learning techniques	Observations
Electronic states în mesoscopic systems. Envelope wavefunction method. Aplications.	Exposition. Guided work	4 ore
Effect of disorder in 1D and 2D electronic systems.	Exposition. Guided work	4 ore
Electronic states in 2D electron systems in magnetic fields. Disorder effects.	Exposition. Guided work	4 ore
Charge transport în mesoscopic structures. R-matrix formalism.	Exposition. Guided work	4 ore
Charge transport in quantum wires. *Ab initio* models.	Exposition. Guided work	4 ore
Weak localization regime.	Exposition. Guided work	4 ore
Electron-phonon interaction în low-dimensional systems. Peierls transition.	Exposition. Guided work	4 ore

Bibliography:
1. L. Mihaly, M.C. Martin, *Solid State Physics – Problems and solutions* (Wiley, New York, USA, 1996)
2. S. Datta, *Electronic Transport în Mesoscopic Systems* (Cambridge University Press, Cambridge, UK, 1997).
3. Y. Imry, *Introduction to Mesoscopic Physics* (Oxford University Press, Oxford, UK, 1997)

8.3. Practicals [research subjects, projects]	Teaching and learning techniques	Observations
	Guided practical work	4 ore

8.4. Research project [if applicable]	Teaching and learning techniques	Observations

Bibliography:

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical and practical competencies and skills corresponding to national and international standards, which are important for a master student in the field of modern Physics and technology. The contents and teaching methods were selected after a thorough analysis of the contents of similar course units in the syllabus of other universities from Romania or the European Union (Universite Paris-Sud, University of Cambridge, Universite Catholique Louvain-la-Neuve). The contents are in line with the requirements of the main employers of the graduates (industry, research institutes, high-school teaching).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight în final mark
10.4. Lecture	- Explicitness, coherence and concision of scientific statements; - Correct use of physical models and of specific mathematical methods; - Ability to analyse specific	Written and oral exam	50%

	examples;		
10.5.1. Tutorials	- Use of specific physical and mathematical methods and techniques;	Homework, research projects	50%
10.5.2. Practicals	- Knowledge and correct use of specific experimental techniques - Data processing and analysis;	Colloquium	
10.5.3. Project [if applicable]			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) Correct solving of subjects indicated as required for obtaining mark 5.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
25.06.2019	Prof. dr. Lucian Ion	Prof. dr. Lucian Ion

Date of approval

Head of department,
Prof.dr. Virgil Băran

DFC.114.FTC Advanced methods for parallel computing

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Advanced methods for parallel computing							
2.2. Teacher	Assoc. Prof. Alexandru Nicolin							
2.3. Tutorials instructor(s)	Assoc. Prof. Alexandru Nicolin							
2.4. Practicals instructor(s)	Assoc. Prof. Alexandru Nicolin							
2.5. Year of study	1	2.6. Semester	2	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1]	**DA**
							Type[2]	**DFac**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**0/2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**0/28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**10**
3.2.2. Research in library, study of electronic resources, field research	**10**
3.2.3. Preparation for practicals/tutorials/projects/reports/homework	**20**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**40**
3.4. Total hours per semester	**100**
3.5. ECTS	**4**

4. Prerequisites (if necessary)

4.1. curriculum	Programing languages
4.2. competences	Working with software packages which do not require a license for data analysis and data processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Videoprojector
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	• Understanding the basic principles of advanced scientific computing, especially high-performance computing and high-throughput computing. • Understanding the OpenMP and MPI paradigms • Understanding CPU and GPU based computing architectures. Understanding FPGA architectures • Understanding new paradigms in scientific programming
Transversal competences	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Presenting the basic elements of high-performance computing and high-throughput computing, both from the perspective of computing infrastructures and from the perspective of software implementations
7.2. Specific objectives	Study the basic principles of high-performance computing and high-throughput computing Study programming techniques which rely on OpenMP and MPI Study of computing architectures (CPU, GPU, FPGA) Study of new scientific programming languages (Julia)

8. Contents

8.1. Lecture	Teaching techniques	Observations/ hours
The basic elements of modern computing architectures. Flynn's taxonomy. Overview of programming languages.	Systematic exposition - lecture. Examples	2 hours
Legacy codes, serial code optimizations. Fortran code case study for collective modes in atomic nuclei.	Systematic exposition - lecture. Examples	4 hours
The two-language problem. An introduction to the Julia scientific programing language.	Systematic exposition - lecture. Examples	4 hours
Basic principles of high-throughput computing.	Systematic exposition - lecture. Examples	4 hours
Parallel optimizations using OpenMP and MPI. The basic principles of high-performance computing. Fortran code case study for collective modes in atomic nuclei.	Systematic exposition - lecture. Examples	4 hours
Natively parallel numerical methods. The Gauss-Seidel method. Numerical integration methods.	Systematic exposition - lecture. Examples	4 hours
Parallel computing libraries. Parallel implementations for BLAS, LAPACK	Systematic exposition - lecture. Examples	8 hours
Scientific computing using GPU and FPGA processing units.	Systematic exposition - lecture. Examples	4 hours
Introduction to the Julia libraries for solving ordinary differential equations and partial differential equations, and optimization problems.	Systematic exposition - lecture. Examples	4 hours

Bibliography:

1. W.P. Petersen și P. Arbenz, *Introduction to parallel computing. A practical guide with examples in C*, Oxford University Press, 2004.
2. R.W. Shonkwilerși L. Lefton, *An introduction to parallel and vector scientific computation*, Cambridge University Press, 2006.
3. The Julia Language, https://docs.julialang.org/en/v1/.

8.2. Tutorials	Teaching and learning techniques	Observations

8.3 Laboratory	Teaching and learning techniques	Observations
Solving linear systems of equations. C implementations.	Supervised practical activity	6 hours
Computing eigenvectors and eigenvalues. C implementations.	Supervised practical activity	6 hours
Numerical integration of multidimensional integrals. C implementations.	Supervised practical activity	6 hours
Numerical solution for ordinary differential equations and partial differential equations. Julia implementations.	Supervised practical activity	10 hours

Bibliography:

1. W.P. Petersen şi P. Arbenz, *Introduction to parallel computing. A practical guide with examples in C*, Oxford University Press, 2004.
2. The Julia Language, https://docs.julialang.org/en/v1/

8.4 Project	Teaching and learning techniques	Observations

Bibliography:

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

In order to sketch the contents, to choose the teaching/learning methods, the coordinator of the course consulted the content of similar disciplines taught at Romanian universities and abroad. The content of the discipline is according to the requirements of employment in research institutes in physics and materials science, as well as in education (according to the law).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials			
10.5.2 Laboratory	- Ability to use specific problem-solving methods	Homework	40%
10.5.3 Project			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
11-VI-2019	Assoc. Prof. Alexandru Nicolin,	Assoc. Prof. Alexandru Nicolin,

Date of approval

Head of Department

Prof. Virgil Băran

DFC.210.FTC Computational approaches in high-energy physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Computational approaches in high-energy physics							
2.2. Teacher			Prof. dr. Virgil Baran / Lect. dr. Roxana Zus					
2.3. Tutorials/Practicals instructor(s)			Lect. dr. Roxana Zus					
2.4. Year of study	II	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DC**
							Type[2]	**DF ac**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**40**	Lecture	**20**	Practicals/Tutorials	**20**
Distribution of estimated time for study					**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography					**7**
3.2.2. Research in library, study of electronic resources, field research					**7**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks					**7**
3.2.4. Preparation for exam					**4**
3.2.5. Other activities					**0**

3.3. Total hours of individual study	**21**
3.4. Total hours per semester	**75**
3.5. ECTS	**3**

4. Prerequisites (if necessary)

4.1. curriculum	Algebra, Analysis, Quantum mechanics
4.2. competences	Knowledge about: mechanics, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	- understanding the dynamics of nuclear systems and elementary particles with realistic numerical methods; - developing abilities to apply appropriate numerical methods for modelling physical systems - ability to analyze and interpret relevant numerical results and to formulate rigorous conclusions
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Describing and understanding of the structure of the nuclear and subnuclear systems based on numerical investigations;
7.2. Specific objectives	Development of the skill to apply mathematical models for modelling various physical processes Acquire the appropriate understanding of the connections between computational methods and physics

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Computational methods in nuclear structure: algorithms for nuclear models, numerical solutions for the study of nuclear matter properties in Hartree-Fock theory with pairing interaction, numerical approaches in RPA theory for collective nuclear response,	Systematic exposition - lecture. Examples	8 hours
Computational methods for nuclear reactions description.	Systematic exposition - lecture. Examples	6 hours
Numerical methods for matter structure investigation. Deep inelastic scattering. Hadron-hadron scattering.	Systematic exposition - lecture. Examples	6 hours

Bibliography:

1. K. Langanke, J.A. Maruhn, S.E. Koonin, Computational Nuclear Physics, vol 1 and 2, Springer – Verlag, 1991
2. R. K. Ellis, W. J. Stirling, and B. R. Webber, QCD and collider physics, Cambridge University Press, 2003

8.2. Tutorials/ Practicals [main themes]	Teaching and learning techniques	Observations/hours
Numerical applications to collective geometric model study and to interacting boson approximation study.	Problem solving	6 hours

Numerical simulations for relativistic kinematics and cross-sections for elementary particles collisions.	Problem solving	6 hours
Electron-proton collisions associated to HERA-DESY experiments.	Problem solving	4 hours
Proton-proton collisions associated to LHC-CERN experiments.	Problem solving	4 hours

Bibliography:

1. T. Sjostrand, S. Mrenna, and P. Z. Skands, Comput. Phys. Commun. 178, 852 (2008), arXiv:0710.3820
2. PYTHIA http://home.thep.lu.se/~torbjorn/Pythia.html
3. ROOT http://root.cern.ch

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date
10.06.2019

Teacher's name and signature

Prof. dr. Virgil Baran
Lect. dr. Roxana Zus

Practicals/Tutorials instructor(s) name(s) and signature(s)

Lecturer dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

DFC.211.FTC Extensions of the standard model of elementary particles

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Extensions of the standard model of elementary particles							
2.2. Teacher				Prof. Dr. Virgil Baran/ Lecturer dr. Roxana Zus				
2.3. Tutorials/Practicals instructor(s)				Lecturer dr. Roxana Zus				
2.4. Year of study	II	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DC**
							Type[2]	**DF ac**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**40**	Lecture	**20**	Practicals/Tutorials	**20**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**7**
3.2.2. Research in library, study of electronic resources, field research	**7**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**7**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**21**
3.4. Total hours per semester	**75**
3.5. ECTS	**3**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum field theory, Statistical mechanics, Theory of relativity, Nuclear physics
4.2. competences	Knowledge about: electrodynamics, quantum mechanics

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum field theory, concepts, notions and problems in the area of particle physics • Ability to use this knowledge in interpretation of experimental result and understand experiments at CERN; acquire the appropriate understanding of studied fundamental mechanisms
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding the foundations of structure of the matter: fundamental constituents and interactions between them; Understanding the unified theories of physics and their possible extensions.
7.2. Specific objectives	Acquire the skills to describe and calculate the physical properties of quantum fields and their interactions. Development of the skill to apply mathematical models and numerical method for modelling various physical processes

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
The open questions from the standard model	Systematic exposition - lecture. Examples	2 hours
Hierarchy problem. Supersymmetries (SUSY). SUSY Algebra and SUSY Group.	Systematic exposition - lecture. Examples	5 hours
Superfields formulation. Irreducible representation of SUSY. Chiral superfields and vector superfields.	Systematic exposition - lecture. Examples	5 hours
Spontaneous SUSY breaking	Systematic exposition - lecture. Examples	4 hours
Extradimensions	Systematic exposition - lecture. Examples	4 hours
Bibliography: 1. S. Weinberg, *The quantum theory of fields*, Vol. III Cambridge University Press, 2005. 2. T. Morii, C. S. Lim and S. N. Mukherjee, *The physics of Standard Model and beyond.* World Scientific 2005		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Aspects of grand unification theories (GUT). Magnetic monopoles.	Problem solving	4 hours
Construction of supersymmetric Lagrangians.	Problem solving	4 hours

The Minimal Supersymmetric Standard Model	Problem solving	4 hours
Composite Higgs models: Technicolor, Higgs as Pseudo-Goldstone boson, LHC signatures	Problem solving	4 hours
The role of string theories	Problem solving	4 hours

Bibliography:

1. S. Weinberg, *The quantum theory of fields*, Vol. III Cambridge University Press, 2005.
2. H. Georgi, *"The Future Of Grand Unification*", Prog. Theor. Phys. Suppl. 170 (2007)
3. S. P. Martin, "*A Supersymmetry Primer*", arXiv:hep-ph/9709356.
4. R. Rattazzi, "*Cargese lectures on extra dimensions*", arXiv:hep-ph/0607055.
5. Barton Zwiebach, *A first course in string theory*, Cambridge University Press, 2009

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date 10.06.2019	Teacher's name and signature Prof. dr. Virgil Baran Lecturer dr. Roxana Zus	Practicals/Tutorials instructor(s) name(s) and signature(s) Lecturer. dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

DI.101 Quantum Statistical Physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Quantum Statistical Physics							
2.2. Teacher				Prof. Dr. Virgil Baran				
2.3. Tutorials/Practicals instructor(s)				Lect. Dr. Victor Dinu				
2.4. Year of study	I	2.5. Semester	1	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DA**
							Type[2)]	**DI**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Classical Statistical Mechanics, Equations of Mathematical Physics
4.2. competences	Knowledge about: mechanics, thermodynamics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of quantum statistical physics • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in the area of many-body systems at finite temperature • Ability to use this knowledge in various branches of physics
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding the fundamental aspects related to the study of quantum statistical physics
7.2. Specific objectives	Assimilation of formalism of quantum statistical theory: concepts, methods of statistical ensambles, quantum distributions. Explaining the peculiar fenomena of quantum domain, which have no classical analogue. Acquire the skills to describe and calculate the physical properties of quantum systems involved in different physical conditions.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Quantum states. Microstates and macrostates of a quantum system. Statistical (density) operator: definition and properties. Time evolution.	Systematic exposition - lecture. Examples	2 hours
Quantum entropy. Boltzmann-von Neumann formula. Physical interpretation. Principle of maximum entropy. Equilibrium distributions. Statistical operator in equilibrium. Boltzmann-Gibbs formula.	Systematic exposition - lecture. Examples	4 hours
Partition functions: definition and properties. Entropy in thermodynamic equilibrium, natural variables. Equilibrium statistical ensembles. Ensemble averages. Canonical, grand-canonical and microcanonical ensembles.	Systematic exposition - lecture. Examples	4 hours
The indistinguishability of quantum particles. Occupations number representation. Pauli principle. Applications.	Systematic exposition - lecture. Examples	6 hours
Grand-canonical partition functions for systems of independent fermions. Fermi-Dirac statistics. Applications.	Systematic exposition - lecture. Examples	2 hours
Grand-canonical partition functions for systems of independent bosons. Bose-Einstein statistics. Applications.	Systematic exposition - lecture. Examples	2 hours
Equilibrium radiation, Planck law. The black-body radiation. Applications.	Systematic exposition - lecture. Examples	4 hours
Quantum liquids. Helium three. Helium four and Bose-Einstein condensation.	Systematic exposition - lecture. Examples	4 hours

Bibliography: **1.** R. Balian, From Microphysics to Macrophysics Vol. 1, 2, Springer 2006 **2.** L.D. Landau, E.E. Lifsit, Fizică Statistică, Editura Tehnică **3.** K. Huang, Statistical Mechanics, John Wiley & sons, 1987 **4.** Radu Paul Lungu, Elemente de mecanica statistica cuantica, Editura UB, 2017.

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
The statistical thermodynamics of the ideal fermionic gas. White dwarf stars. Neutron stars.	Problem solving	6 hours
The statistical thermodynamics of the ideal bosonic gas.	Problem solving	6 hours
Statistical mechanics of lattice vibrations. Phonons. Debye model.	Problem solving	4 hours
Heisenberg model and applications.	Problem solving	4 hours
Landau two-fluids model. Maxon-roton spectrum.	Problem solving	4 hours
Linear response. Fluctuation-dissipation theorem.	Problem solving	4 hours

Bibliography: **1.** R. Balian, From Microphysics to Macrophysics Vol. 1, 2, Springer 2006 **2.** D. Dalvit, J. Frastai, I. Lawrie, *Problems on statistical mechanics*, IOP 1999. **3.** Radu Paul Lungu, Elemente de mecanica statistica cuantica, Editura UB, 2017

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
10.06.2019	Prof. dr. Virgil Baran	Lect. dr. Victor Dinu

Date of approval

Head of Department

Prof.dr. Virgil Baran

DF 402 Group theory with applications in physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Group theory with applications in physics								
2.2. Teacher				Prof. dr. Lucian Ion					
2.3. Tutorials instructor(s)				Prof. dr. Lucian Ion					
2.4. Practicals instructor(s)									
2.5. Year of study	1	2.6. Semester	2	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1]	DS	
							Type[2]	DO	

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

2. Course unit

2.1. Course unit title								
2.2. Teacher				Lecturer Virgil Baran				
2.3. Tutorials/Practicals instructor(s)				Lecturer Victor Dinu				
2.4. Year of study	I	2.5. Semester	1	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DF**
							Type[2]	**DI**

[1] fundamental (DF), speciality (DS), complementary (DC); [2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**20**
3.2.2. Research in library, study of electronic resources, field research	**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**25**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**65**
3.4. Total hours per semester	**125**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Linear algebra, Quantum mechanics
4.2. competences	Knowledge about: mechanics, atomic physics, solid state physics, nuclear physics

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	Ability to use this knowledge in various branches of physics Ability of analyse and interpret experimental data, formulate rigorous theoretical conclusions. - Ability to employ mathematical models based on symmetries to describe the physical phenomena.
Transversal competences	Evidence the relation between irreducible representations and invariant subspaces of Hilbert space ; evidence the connection between energy spectrum and irreducible representations.

7. Course objectives

7.1. General objective	Understanding the fundamental aspects related to the study of symmetries in physics. Expose the basic properties of groups and their matrix representations. The study of the role of group theory in quantum mechanics.
7.2. Specific objectives	Assimilation of the formalism of group theory: concepts, methods, representations. Acquire the skills to describe and calculate the physical properties of physicsl systems based on symmetries.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Introductory notions:symmetries of a physical system, the role of group theory in physics, groups clasification.	Systematic exposition - lecture. Examples	1 hours
Group axioms, group multiplication table, subgroups,mappings of groups, direct product of groups.	Systematic exposition - lecture. Examples	1 hours
Conjugate elements, equivalence classes, invariant subgroups, cosets, quotient group	Systematic exposition - lecture. Examples	1 hours
Matrix representation of a group, equivalent representations, irreducible representation. Schur lemma's.	Systematic exposition - lecture. Examples	1 hours
Orthogonality relations for irreducible representations of a finite group, inequivalent representations for finite groups, characters and their orthogonality relations, character table.	Systematic exposition - lecture. Examples	2 hours
Group theory and quantum mechanics. From degeneracy to group representations:classification of the eigenvalues and of the eigenstates of energy according to the irreducible representations of symmetry group. Applications.	Systematic exposition - lecture. Examples	2 hours
Discrete symmetries. Rotation group in quantum mechanics. Tensor operators. Wigner-Eckart theorem. Aplications in atomic and nuclear physics.	Systematic exposition - lecture. Examples	4 hours

Bibliography:

1. J.F. Corwell, *Group theory in physics. An Introduction*. Academic Press, 1997.
2. A. Zee, *Group theory in a nutshell for physicist*, Princeton University Press, 2017

3. W.K. Tung, *Group theory in physics*, World Scientific, 1985
4.

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Basic group theory. Aplications.	Problem solving	1 hours
Discrete groups representations.	Problem solving	1 hours
Permutation groups. Dihedral groups.	Problem solving	2 hours
Group theory and harmonic motion.	Problem solving	2 hours
Unitary representations for rotations, Wigner matrices, Spherical tensors.	Problem solving	4 hours
Discrete translations.	Problem solving	2 hours

Bibliography:

1. A. Zee, *Group theory in a nutshell for physicist*, Princeton University Press, 2017
2. W.K. Tung, *Group theory in physics*: *Problems and solutions*, World Scientific, 1991
3. S. Sternberg, *Group theory and physics*, Cambridge University Press, 1994

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Date 10.06.2019	Teacher's name and signature Lecturer. dr. Victor Dinu	Practicals/Tutorials instructor(s) name(s) and signature(s) Lecturer dr. Victor Dinu

Date of approval

Head of Department

Prof.dr. Virgil Baran

DI.104 Experimental methods in Physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Electricity, Solid State Physics and Biophysics
1.4. Field of study	Physics
1.5. Course of study	Graduate/Master
1.6. Study program/Qualification	Physics of advanced materials and nanostructures (in English)/Physics of advanced materials and nanostructures
1.7. Mode of study	Full-time study

2. Course unit

2.1. Course title	**Experimental methods în Physics**
2.2. Teacher	Conf. dr. Vasile Bercu
2.3. Tutorials instructor(s)	
2.4. Practicals instructor(s)	Conf. dr. Vasile Bercu, Prof. dr. Alexandru Jipa, Lect. dr. Adriana Bălan, Lect. dr. Ovidiu Toma, Conf. dr. Cristian Necula

2.5. Year of study	1	2.6. Semester	2	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1]	**DA**
							Type[2]	**DI**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**5**	distribution: lecture	**2**	Tutorials/Practicals	**0/3**
3.2. Total hours per semester	**70**	distribution: lecture	**28**	Tutorials/Practicals	**0/42**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**25**
3.2.2. Research in library, study of electronic resources, field research	**25**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**26**
3.2.4. Examination	**4**
3.2.5. Other activities	

3.3. Total hours of individual study	**76**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Electricitate și magnetism, Optică, Fizica solidului I, Electrodinamică, Mecanică cuantică
4.2. competences	• Using of software tools for data analysis/processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Multimedia infrastructure (PC, videoprojector, internet conection)
5.2. for tutorials/practicals	- research infrastructure for morphological, optical, magnetic and microstructural characterizations

6. Acquired specific competencies

Professional competencies	• Use of methods for morphological, optical, magnetic and microstructural characterizations. • Knowledge of physics of interaction of radiation with matter • Creative use of acquired physical knowledge related to morphological, optical, magnetic and microstructural characterizations. • Analysis and communication of scientific data, communication for physics popularisation. • Use of specific software tools.
Transversal competencies	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Introduction to techniques for microstructural, morphological, magnetic and optical characterizations of materials
7.2. Specific objectives	Study of magnetic properties of materials AFM studies of surface morphology Measuring optical coefficients of thin films Micro-structural studies based on ion beams Highlighting of essential problems in understanding of specific phenomena, in order to stimulate creative and critical thinking în solving problems.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations
Atomic force microscopy (AFM) – physical principles. Working modes (non-contact, contact). Characterization of surface morphology. Magnetic force microscopy (MFM), Scanning tunneling microscopy (STM). Applications	Systematic exposition - lecture. Examples.	6 hours
Electron spin resonance. Investigation of defects în semiconductors.	Systematic exposition - lecture. Examples.	6 hours
Ellipsometry. Physical principles. Optical coefficients of thin films.	Systematic exposition - lecture. Examples.	6 hours
Magnetic propeties of condensed systems. Vibrating Sample Magnetometer and measurement of magnetic susceptibility at room temperature. Temperature effects on magnetic properties.	Systematic exposition - lecture. Examples.	4 hours
Characterization techniques of condensed systems using accelerated ion beams (RBS, ERDA, PIXE). Applications.	Systematic exposition - lecture. Examples.	6 hours
References: 1. M. Nastasi, J.W. Mayer, Y. Wang, *Ion beam analysis – Fundamentals and applications* (CRC Press,		

Boca Raton, USA, 2015). 2. M. Fox, *Optical properties of solids* (Oxford University Press, Oxford, UK, 2001). 3. C. Necula, *Determinarea proprietăţilor magnetice ale rocilor pe baza histerezisului magnetic* (Ars Docendi, Bucureşti, 2017), 4. J.A. Weil, J.R. Bolton, *Electron paramagnetic resonance* (Wiley, New Jersey, USA, 2007)

8.2. Tutorials [main tutorial subjects]	Teaching and learning techniques	Observations
Bibliography: 1.		

8.3. Practicals [research subjects, projects]	Teaching and learning techniques	Observations
AFM in contact and non-contact mode. Surface morphology characterizations	Guided practical work	6 hours
MFM experiments	Guided practical work	3 hours
Characterization of magnetic domains by FORC (First Order Reversal Curves) and Preisach diagrams, using PMC VSM 3900 system. Distribution of magnetic particles from susceptibility measurements.	Guided practical work	6 hours
Determination of blocking temperature and of the temperature dependent coercitive force.	Guided practical work	6 hours
Ellipsometric measurements. Dispersion of optical coefficients of thin films.	Guided practical work	6 hours
Electron spin resonance. Characterization of structural defects în semiconductors.	Guided practical work	6 hours
Characterization of microstructure of condensed systems using accelerated ion beams (RBS, ERDA, PIXE)	Guided practical work	9 hours

8.4. Research project [if applicable]	Teaching and learning techniques	Observations
Bibliography:		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical and practical competencies and skills corresponding to national and international standards, which are important for a master student in the field of modern Physics and technology. The contents and teaching methods were selected after a thorough analysis of the contents of similar course units in the syllabus of other universities from Romania or the European Union. The contents are in line with the requirements of the main employers of the graduates (industry, research institutes, high-school teaching).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight în final mark
10.4. Lecture	- Explicitness, coherence and concision of scientific statements; - Correct use of physical models and of specific mathematical methods; - Ability to analyse specific examples;	Written and oral exam	50%

10.5.1. Tutorials	- Use of specific physical and mathematical methods and techniques;		
10.5.2. Practicals	- Knowledge and correct use of specific experimental techniques - Data processing and analysis;	Colloquium	50.00%
10.5.3. Project [if applicable]			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) Correct solving of subjects indicated as required for obtaining mark 5.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
25.05.2019	Conf. dr. Vasile Bercu	Prof. dr. Alexandru Jipa Conf. dr. Vasile Bercu Conf. dr. Cristian Necula Lect. dr. Adriana Bălan Lect. dr. Ovidiu Toma

Date of approval
10.06.2019

Head of department,
Conf. dr. Petrică Cristea

DI.106.FTC Research activity (traineeship)

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Research activity (traineeship)							
2.2. Teacher	Virgil Băran, Alexandru Nicolin, Roxana Zus							
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)								
2.5. Year of study	1	2.6. Semester	1	2.7. Type of evaluation	V	2.8. Type of course unit	Content[1]	**DS**
							Type[2]	**DI**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture		Practicals/Tutorials	
3.2. Total hours per semester	**56**	Lecture		Practicals/Tutorials	

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**2**
3.2.2. Research in library, study of electronic resources, field research	**2**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**11**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**15**
3.4. Total hours per semester	**75**
3.5. ECTS	**3**

4. Prerequisites (if necessary)

4.1. curriculum	-
4.2. competences	-

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	-
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	Identify and use indicators that describe chaotic behavior in classical and quantum systems Solve the physics problems which are described mathematically by ordinary nonlinear differential equations Apply creatively the knowledge acquired in order to understand and model physical systems with chaotic behavior Communicate and analyze information of a didactic, scientific and popular character in the field of physics
Transversal competences	Efficient use of information sources and resources for communication and training, in Romanian and another language used internationally Carrying out professional tasks effectively, respecting the legislation, ethics and deontology specific to the field.

7. Course objectives

7.1. General objective	Understanding theoretically and computationally the main indicators that describe chaotic behavior
7.2. Specific objectives	Detailed study of some physical systems (classical or quantum) with chaotic behaviour Understanding how these systems are modelled Forming a creative and autonomous way of thinking

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Bibliography:		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Bibliography:		
8.3 Laboratory	Teaching and learning techniques	Observations
Bibliography:		
8.4 Project	Teaching and learning techniques	Observations
Depending on the laboratory/research center which she/he selects, the student will choose a research project from a sub-domain of theoretical and / or computational physics or their applications. Examples of dedicated projects this semester: - Precise calculation of Feigenbaum coefficients for nonlinear maps - Fingerprints of classical chaos in chaotic quantum systems - Energy conservation in implicit Runge-Kutta numerical methods applied to equations with Hamiltonian structure - Numerical solution of shells models equations that describe hydrodynamic turbulence In addition to the extended list of research topics of		

the centers of the faculty, students have available projects that they can carry out within the collaboration agreements that the faculty has with research institutes (for example: Horia Hulubei National Institute for Physics and Nuclear Engineering The National Institute for Laser, Plasma & Radiation Physics etc.).		

Bibliography - sample:

1. S.H. Strogatz, *Nonlinear dynamics and chaos. With applications to physics, biology, and engineering*, CRC Press, 2015.
2. M. Tabor, *Chaos and integrability in nonlinear dynamics. An introduction*, Wiley, 1989.
3. T. Bohr, M.H. Jensen, G. Paladin şi A. Vulpiani, *Dynamical systems approach to turbulence*, Cambridge University Press, 2005.
4. W.-H. Steeb, *The nonlinear workbook: chaos, fractals, etc.*, World Scientific, 2005.
5. B. Leimkuhler și S. Reich, *Simulating Hamiltonian dynamics*, Cambridge University Press, 2004.

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

The content of the discipline allows the student to develop skills and abilities for modeling and/or experimental investigation of the various physical phenomena studied in laboratories/research centers and their applications, in order to integrate them in specific activities of research institutes and companies in the field of Theoretical and Computational Physics, as well as in education.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture			
10.5.1. Tutorials			
10.5.2 Laboratory			
10.5.3 Project	- Attendance - Clarity, coherence and brevity of the exposure of the acquired knowledge and the results obtained - The correct use of models, formulas and relations of calculation; - Correctly applying specific methods of solving for the given problem and interpreting the numerical results;	Colloquium	100%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Date
10.06.2019

Course coordinator
name(s) and signature(s)

Prof. Dr. Virgil Băran
Assoc. Prof. Dr. Alexandru Nicolin
Lect. Dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

DI.108 Theory of nuclear systems and photonuclear reactions

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Theory of nuclear systems and photonuclear reactions							
2.2. Teacher				Prof. Dr. Virgil Băran				
2.3. Tutorials/Practicals instructor(s)				Assoc.prof. dr. Mădălina Boca				
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DS**
							Type[2]	**DI**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**25**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**35**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Quantum Statistical Physics, Electrodynamics
4.2. competences	Knowledge about: mechanics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of theoretical nuclear physics • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in the area of modern nuclear physics • Ability to use this knowledge in interpretation of experimental results
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding peculiarities of physical properties of atomic nuclei. Ability to connect physical concepts to experimental information in nuclear physics.
7.2. Specific objectives	Gain the ability to work with theoretical methods of quantum many-body systems adapted to nuclear systems Acquire the skills to describe and calculate the physical properties of quantum many-body systems involved in different physical conditions.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Fundamental properties of nucleon-nucleon interaction. The origin of nuclear interactions, properties of the nuclear forces as derived from experimental observations. The nuclear matter, saturation properties. Observables of interest in nuclear physics	Systematic exposition - lecture. Examples	4 hours
Phenomenological nuclear models: Bohr-Mottelson model, interacting bosons models.	Systematic exposition - lecture. Examples	6 hours
Microscopic nuclear models: shell model and its extensions.	Systematic exposition - lecture. Examples	4 hours
Many-body methods for describing the quantum states of nuclear systems: Hartree-Fock , Bardeen-Cooper -Schrieffer, Time-dependent Hartree-Fock, Random-Phase Approximation .	Systematic exposition - lecture. Examples	6 hours
Electromagnetic transitions in nuclear physics: the interaction between electromagnetic field and nucleus. Multipole electromagnetic transitions, reduced transition probabilities. One particle matrix elements in a spherical basis set, Weisskopf units. The giant dipole resonance and the cross section of absorption of dipole radiation. Sum- rules. Collective excitations in atomic nuclei.	Systematic exposition - lecture. Examples	4 hours
Fundamentals of nuclear astrophysics: supernova explosion, properties of neutron stars, stellar	Systematic exposition - lecture. Examples	4 hours

nucleosynthesis, elements abundance. Theoretical basis of nuclear astronomy and cosmology.		
Bibliography: 1. J.L. Basdevant, J Rich, M. Spiro, *Fundamentals in nuclear physics,* Springer, 2005. 2. W. Greiner, J.A. Maruhn, *Nuclear Models,* Springer, 1996. 3. P.Ring and P. Schuck, *Nuclear many body problem,* Springer, 2004.		

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Fermi gas model for nuclear matter.	Problem solving	1 hours
Pauli quantization for quadrupole degrees of freedom. Collective states of a deformed nucleus. Group theoretical methods for low-lying states.	Problem solving	7 hours
Single particle properties in various potential wells for nuclear systems.	Problem solving	2 hours
Many-body calculations of nuclear properties.	Problem solving	8 hours
Photonuclear reaction. Electromagnetic transitions.	Problem solving	6 hours
Properties of neutrons stars. Supernova explosions.	Problem solving	4 hours
Bibliography: 1. P.A. Martin, F. Rothen, Many-body problems and quantum field theory, Springer, 2002 2. J.Eisenberg and W. Greiner, *Nuclear models*, vol. 1,2, 3		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date
10.06.2019

Teacher's name and signature

Prof. dr. Virgil Baran

Practicals/Tutorials instructor(s) name(s) and signature(s)

Assoc.prof. dr. Mădălina Boca

Date of approval

Head of Department

Prof.dr. Virgil Baran

D0.109 Simulation methods in theoretical physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Simulation methods in theoretical physics							
2.2. Teacher			Assoc. Prof. Alexandru Nicolin					
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)			Dr. Mihai Marciu					
2.5. Year of study	1	2.6. Semester	2	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1)]	**DA**
							Type[2)]	**DI**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**20**
3.2.2. Research in library, study of electronic resources, field research	**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homework	**25**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**65**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Programing languages, Analytical mechanics, Thermodynamics and Statistical Physics
4.2. competences	Working with software packages which do not require a license for data analysis and data processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	• Understanding classical and quantum Monte-Carlo methods used in the study of physical systems • Understanding the Monte-Carlo methods used to calculate multi-dimensional integrals • Understanding the use of genetic algorithms for the study of multi-particle systems • Understanding Runge-Kutta methods used for the numerical solution of ordinary differential equations • Understanding Laplace transformations and their use for the numerical treatment of integral equations • Understanding the main discrete models of earthquake simulation and the emergence of self-organized criticality • Understanding the emergence of fractal distributions in complex systems
Transversal competences	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Presentation of advance methods for numerical simulations in theoretical physics
7.2. Specific objectives	Study of the classical and quantum Monte-Carlo methods used in the description of physical systems Study of Monte-Carlo methods applied in the calculation of multi-dimensional integrals Study of genetic algorithms Study of Runge-Kutta methods applied in numerical solution of differential equations with Hamiltonian structure The study of Laplace transforms for the numerical treatment of integral equations The study of complex systems from the perspective of earthquake models, fractal distributions, and self-organized criticality

8. Contents

8.1. Lecture	Teaching techniques	Observations/ hours
Presentation of Monte-Carlo methods, in particular the Ising model and the simulated annealing computational processes. Calculation of multidimensional integrals by Monte-Carlo methods.	Systematic exposition - lecture. Examples	6 hours
Monte-Carlo quantum algorithms (variational, diffusive and integral path type). Quantum dots. He clusters on graphite surfaces.	Systematic exposition - lecture. Examples	6 hours
Presentation of the fundamental aspects regarding genetic algorithms and their use in the study of physical systems	Systematic exposition - lecture. Examples	4 hours
Presentation of the implicit Runge-Kutta methods, with emphasis on symplecticness, volume conservation in phase space and numerical rigidity. Presentation of Gaussian quadratures. Case study: differential equations of Hamiltonian structure.	Systematic exposition - lecture. Examples	4 hours
Presentation of integral transformations, in particular Laplace transformations, and their use in the numerical treatment of integral equations	Systematic exposition - lecture. Examples	4 hours

Presentation of discrete models that describe the occurrence of earthquakes. Presentation of self-organized criticality and fractal distributions	Systematic exposition - lecture. Examples	4 hours
Bibliography: 1. D.P. Landau și K. Binder, *A guide to Monte Carlo simulations in statistical physics*, Cambridge University Press, 2014. 2. J.B. Anderson, *Quantum Monte Carlo. Origins, development, applications*, Oxford University Press, 2007. 3. T. Pang, *An introduction to Quantum Monte Carlo methods*, Morgan & Claypool Publishers, 2016. 4. D.A. Coley, *An introduction to genetic algorithms for scientists and engineers*, World Scientific, 1999. 5. J.C. Butcher, *Numerical Methods for Ordinary Differential Equations*, Wiley, 2016. 6. D. Porterși D.S.G. St irling, *Integral equations: from spectral theory to applications*, Cambridge University Press, 1991.		
8.2. Tutorials	Teaching and learning techniques	Observations
One- and two-dimensional Ising systems	Lecture. Problem solving	2 hours
Analytic solutions of the equations which describe implicit Runge-Kutta methods using Gaussian quadratures	Lecture. Problem solving	2 hours
Bibliography: 1. B.M. McCoy și T.T. Wu, *The two-dimensional Ising model*, Harvard University Press, 1973. 2. E. Hairer *et al.*, *Geometric numerical integration: Structure-preserving algorithms for ordinary differential equations*, Springer, 2002		
8.3 Laboratory	Teaching and learning techniques	Observations
Determination of critical temperature in high dimensional Ising systems using Monte-Carlo methods. Code in Octave/python/C/C ++	Supervised practical activity	2 hours
Calculation of Ising integrals using Monte-Carlo methods. Code in Octave/python/C/C ++	Supervised practical activity	2 hours
Numerical studies on quantum dots using quantum Monte-Carlo algorithms. Code in Octave/python/C/C++	Supervised practical activity	2 hours
Determination of the fundamental state energy for a spin glass using genetic algorithms	Supervised practical activity	2 hours
Numerical solution of non-linear oscillator equations by implicit Runge-Kutta methods. Energy conservation. Code in Octave/python/C/C++	Supervised practical activity	4 hours
Determination of the volumes in the space of the phases populated by the regular and chaotic trajectories for a non-linear system with four dimensions. Code in Octave/python/C/C ++	Supervised practical activity	2 hours
Solving Volterra-type integral equations by means of Laplace transforms. Code in Octave/python/C/C++	Supervised practical activity	2 hours
Numerical resolution of the Olami-Feder-Christensen seismic model. Code in Octave/python/C/C++	Supervised practical activity	2 hours
Determining the distribution of earthquake waiting times. Code in Octave/python/C/C ++	Supervised practical activity	2 hours

Bibliography: 1. D.P. Landau și K. Binder, *A guide to Monte Carlo simulations in statistical physics*, Cambridge University Press, 2014. 2. T. Pang, *An introduction to Quantum Monte Carlo methods*, Morgan & Claypool Publishers, 2016. 3. D.A. Coley, *An introduction to genetic algorithms for scientists and engineers*, World Scientific, 1999. 4. E. Hairer *et al.*, *Geometric numerical integration: Structure-preserving algorithms for ordinary differential equations*, Springer, 2002

8.4 Project	Teaching and learning techniques	Observations
Bibliography:		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

In order to sketch the contents, to choose the teaching/learning methods, the coordinator of the course consulted the content of similar disciplines taught at Romanian universities and abroad. The content of the discipline is according to the requirements of employment in research institutes in physics and materials science, as well as in education (according to the law).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem-solving methods	Homework	10%
10.5.2 Laboratory	- Ability to use specific problem-solving methods	Homework	30%
10.5.3 Project			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date 11-VI-2019	Teacher's name and signature Assoc. Prof. Alexandru Nicolin	Practicals/Tutorials instructor(s) name(s) and signature(s) Dr. Mihai Marciu

Date of approval

Head of Department

Prof. Virgil Băran

DI.112.FTC Research activity (traineeship)

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Research activity (traineeship)							
2.2. Teacher	Virgil Băran, Alexandru Nicolin, Roxana Zus							
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)								
2.5. Year of study	1	2.6. Semester	2	2.7. Type of evaluation	V	2.8. Type of course unit	Content[1]	**DS**
							Type[2]	**DI**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture		Practicals/Tutorials	
3.2. Total hours per semester	**56**	Lecture		Practicals/Tutorials	

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**2**
3.2.2. Research in library, study of electronic resources, field research	**2**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**11**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**15**
3.4. Total hours per semester	**75**
3.5. ECTS	**3**

4. Prerequisites (if necessary)

4.1. curriculum	-
4.2. competences	-

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	-
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	Identify and use appropriately theoretical and computational methods which describe real physical systems Solve the physics problems which are described mathematically by differential and integral equations Apply creatively the knowledge acquired in order to understand and model real physical systems Communicate and analyze information of a didactic, scientific and popular character in the field of physics
Transversal competences	Efficient use of information sources and resources for communication and training, in Romanian and another language used internationally Carrying out professional tasks effectively, respecting the legislation, ethics and deontology specific to the field.

7. Course objectives

7.1. General objective	Understanding theoretically and computationally the models which describe real physical systems
7.2. Specific objectives	Detailed study of some physical systems of utmost scientific interest Understanding how these systems are modelled Forming a creative and autonomous way of thinking

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Bibliography:		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Bibliography:		
8.3 Laboratory	Teaching and learning techniques	Observations
Bibliography:		
8.4 Project	Teaching and learning techniques	Observations
Depending on the laboratory/research center which she/he selects, the student will choose a research project from a sub-domain of theoretical and / or computational physics or their applications. Examples of dedicated projects this semester: - Calculation of improper integrals using Monte-Carlo methods - The discrete fractional Fourier transform and its applications in physics - Mathematical models used in the study of quasi-crystals - Representations of symmetry groups and applications - Quantum computers and quantum algorithms In addition to the extended list of research topics of		

the centers of the faculty, students have available projects that they can carry out within the collaboration agreements that the faculty has with research institutes (for example: Horia Hulubei National Institute for Physics and Nuclear Engineering The National Institute for Laser, Plasma & Radiation Physics etc.).		

Bibliography - sample:

1. D.P. Landau și K. Binder, *A guide to Monte Carlo simulations in statistical physics*, Cambridge University Press, 2014.
2. J.B. Anderson, *Quantum Monte Carlo. Origins, development, applications*, Oxford University Press, 2007.
3. T. Pang, *An introduction to Quantum Monte Carlo methods*, Morgan & Claypool Publishers, 2016
4. A. Zee, *Group theory in a nutshell for physicist*, Princeton University Press, 2017
5. A.O. Pittenger, *An introduction to quantum computing algorithms*, Birkhauser, 2001

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

The content of the discipline allows the student to develop skills and abilities for modeling and/or experimental investigation of the various physical phenomena studied in laboratories/research centers and their applications, in order to integrate them in specific activities of research institutes and companies in the field of Theoretical and Computational Physics, as well as in education.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture			
10.5.1. Tutorials			
10.5.2 Laboratory			
10.5.3 Project	- Attendance - Clarity, coherence and brevity of the exposure of the acquired knowledge and the results obtained - The correct use of models, formulas and relations of calculation; - Correctly applying specific methods of solving for the given problem and interpreting the numerical results;	Colloquium	100%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Date
10.06.2019

Course coordinator
name(s) and signature(s)

Prof. Dr. Virgil Băran
Assoc. Prof. Dr. Alexandru Nicolin
Lect. Dr. Roxana Zus

Head of Department

Date of approval

Prof.dr. Virgil Baran

DI.201 Introduction to quantum theory of fields

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Introduction to quantum theory of fields							
2.2. Teacher				Prof. dr. Virgil Baran/ Lect. dr. Roxana Zus				
2.3. Tutorials/Practicals instructor(s)				Lect. dr. Roxana Zus				
2.4. Year of study	II	2.5. Semester	1	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DI**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**25**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**35**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Electrodynamics, Theory of relativity
4.2. competences	Knowledge about: mechanics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of the quantum field theory • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in the area of particle physics • Ability to use this knowledge in interpretation of experimental result and understand experiments at CERN
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding peculiarities of physical properties of quantum fields. Ability to connect physical concepts to experimental information in particle physics.
7.2. Specific objectives	Gain the ability to work with theoretical methods of quantum fields theory Acquire the skills to describe and calculate the physical properties of quantum fields and their interactions.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Fundamental properties of elementary particles. Relevant experimental facts. Orders of magnitude in elementary particle physics, dimensional analysis.	Systematic exposition - lecture. Examples	2 hours
The Lorentz (LG) and Poincare (PG) groups: definition and basic properties. Generators and Lie algebra of the Lorentz and Poincare groups. Finite irreducible representations of LG and classification of classical fields. Scalar, vectorial, spinorial fields.	Systematic exposition - lecture. Examples	2 hours
Variational principle for classical fields and Noether theorem. Dynamical invariants.	Systematic exposition - lecture. Examples	2 hours
Free fields: Klein-Gordon field, Weyl field, Dirac field, Majorana field, Maxwell field, Proca Field. Frequency decomposition of the fields. Spin and charge.	Systematic exposition - lecture. Examples	8 hours
Quantization of the fundamental fields, elementary particles, commutation relations, spin-statistics theorem.	Systematic exposition - lecture. Examples	4 hours
Local gauge invariance and interaction. Spontaneous breaking of symmetries. Goldstone	Systematic exposition - lecture. Examples	4 hours

model. Higgs mechanism.		
Interacting quantum fields. Feynman diagrams. Fundamentals of renormalization.	Systematic exposition - lecture. Examples	4 hours

Bibliography:

1. M. Maggiore, *A modern introduction to Quantum Field Theory,* Oxford University Press, 2005.
2. M.E. Peskin, D.V. Schroeder *An Introduction to Quantum Field Theory*, Advanced Book Program, Addison-Wesley Publishing Company, 1995.
3. N.N. Bogoliubov, D.V. Shirkov, *Introduction to The Theory of Quantized Fields*, John Wiley and Sons, 1980.
4. S. Weinberg, *The quantum theory of fields*, Vol. I and Vol. II Cambridge University Press, 2005.
5. V.B. Berestetskii, E.M. Lifshitz , L.P. Pitaevskii , *Quantum Electrodynamics*, Perg. Press, 1989.
6. T.D. Lee, *Particle Physics and Introduction to Field Theory*, Hardwood Academic, 1981.
7. A. Zee, *Quantum Field Theory in a Nutshell*, Princeton University Press,2003.

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Lorentz Group algebra. Poincare group algebra. Pauli-Lubansky four-vectors. Casimir operators.	Problem solving	4 hours
Dynamical invariants for classical fields. Frequency decompositions.	Problem solving	4 hours
Commutation functions for free fields. Causality.	Problem solving	3 hours
Discrete symmetries of physical fields.	Problem solving	3 hours
Models for spontaneous global symmetry breaking. Goldstone theorem.	Problem solving	4 hours
Models for Higgs mechanism.	Problem solving	4 hours
Perturbative methods for interacting quantum fields. Renormalization.	Problem solving	6 hours

Bibliography:

1. Voja Radovanovich, *Problem book in quantum field theory,* Springer, 2005
2. C. Itzykson and J.B. Zuber, *Quantum Field Theory*, McGraw-Hill, New York, 1980
3. M. Kaku, *Quantum Field Theory: A Modern Introduction*, Oxford University Press, 1993
4. F. Mandl and G. Show, *Quantum Field Theory*, New York, 1999

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			

Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
10.06.2019	Prof. dr. Virgil Băran Lect. dr. Roxana Zus	Lect. dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

DI.203.FTC Relativistic quantum mechanics and Quantum electrodynamics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	***Relativistic quantum mechanics and Quantum electrodynamics***							
2.2. Teacher				Lect. dr. Cristian Stoica Conf. dr. Madalina Boca				
2.3. Tutorials/Practicals instructor(s)				Lect. dr. Cristian Stoica Conf. dr. Madalina Boca				
2.4. Year of study	II	2.5. Semester	I	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DI**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**29**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum Mechanics, Electrodynamics and theory of relativity, Equations of mathematical physics
4.2. competences	Solving of problems in quantum mechanics, higher mathematics

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Computer, Video projector

5.2. for practicals/tutorials	Computer, Video projector

6. Specific competences acquired

Professional competences	Identify and proper use of the main physical laws and principles in a given context; Identify and proper use of the main physical laws and principles of relativistic quantum mechanics and electrodynamics. Using in a creative way of the knowledge acquired in modeling of processes in relativistic quantum mechanics and electrodynamics. Disemination and analyzing of the scientific information in physics Using and development of specific software tools for numerical and analytical calculations in QED processes
Transversal competences	Efficient use of sources of information and communication resources and training assistance in a foreign language. Carrying out professional tasks in an efficient and responsible manner, in compliance with the specific legislation, ethics and deontology.

7. Course objectives

7.1. General objective	-Understanding the fundamental aspects related to the study of quantum mechanics. Training capacities to approach and solve specific problems. Developing analytics skills of calculation.
7.2. Specific objectives	- Understanding the formalism of relativistic quantum mechanics and of quantum electrodynamics - Understanding the properties of Dirac equation solutions - Understanding the physical implications of the mathematical properties of Dirac equation solutions (spin, the positron existence) - Understanding of the quantization methods - Description of some fundamental processes în quantum electrodynamics - Developing the capability to analyse and compare diverse phenomena, starting from basic principles - Obtaining a good theoretical understanding of the studied problems - Developing the capability to use the theoretical knowledge to describe some physical systems

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Dirac equation. Bispinors. Dirac matrices. The Pauli theorem. The relativistic invariance of Dirac equation.	Systematic exposition - lecture. Examples	4 hours
Lorentz transformations; the transformation of the solutions of Dirac equation. Continuous transformations (rotations, special Lorentz transformations) and discrete transformations (spatial and temporal inversion)	Systematic exposition - lecture. Examples	4 hours
Basic solutions of Dirac equation for the free particle. Plane waves. Positive and negative frequencies. Spin ½. Projection operators. The helicity.	Systematic exposition - lecture. Examples	4 hours
Charge conjugation. Transformation of characteristic quantities to charge conjugation. The	Systematic exposition - lecture. Examples	2 hours

reinterpretation of the negative frequency states. The positron.		
The scalar field, the Klein-Gordon equation; fundamental solutions, quantization of the real scalar field. Creation and annihilation operators. The covariant form of the commutation relations. The normal and chronological product	Systematic exposition - lecture. Examples	3 hours
The electron-positron field. The Dirac Lagrange and Hamilton functions, The Dirac equation. Quantization of the electron-positron field. The electromagnetic interaction and the gauge invariance.	Systematic exposition - lecture. Examples	2 hours
The electromagnetic field. The covariant form of the electromagnetism laws. The Lagrange function of the electromagnetic field. Quantization of the electromagnetic field. Gupta-Bleuler conditions.	**Systematic exposition - lecture. Examples**	2 hours
Interacting fields. The interaction Hamiltonian în QED. The S matrix. Series expansion on the S matrix. Expansion of the S matrix. Wick theorem, Feynman diagrams and rules.	Systematic exposition - lecture. Examples	4 hours
Cross sections, examples for fundamental processes	Systematic exposition - lecture. Examples	3 hours

Bibliography:

- C. Stoica, Introducere in mecanica cuantica relativista, note de curs.
- F. Schwabl, Advanced Quantum Mechanics, Springer Verlag, 2005.
- W. Greiner, Relativistic Quantum Mechanics, Springer Verlag , 2000
- A. Wachter, Relativistic Quantum Mechanics, Springer, 2011
- F. Mandl, G. Shaw, Quantum Field Theory, John Wiley&Sons, 2010
- M. Peskin, D. Schroeder, An Introduction to Quantum Field Theory, Addison Wesley, 1996
- W. Greiner, J. Reinhardt, Quantum Electrodynamics, Springer,2009
- J.M. Jauch, F. Rohrlich, The Theory of Photons and Electrons, Springer Verlag, 1980
- C. Itzykson, J.-B. Zuber, Quantum Field Theory, McGraw-Hill, 1980
- **A.I. Akhiezer, V.B. Berestetskii, Quantum Electrodynamics, Interscience, 1965**

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Properties of the Dirac matrices	Lecture. Problem solving.	4 hours
Bilinear covariants of Dirac bispinors. Representations of Dirac matrices. Calculation of the traces.	Lecture. Problem solving.	4 hours
Completeness and orthogonality of the plane waves solutions of the Dirac equation	Lecture. Problem solving.	2 hours
Relativistic electron in constant magnetic field.	Lecture. Problem solving.	2 hours
Solutions of the 1D Dirac equation	Lecture. Problem solving.	2 hours
Complex scalar field and charge conservation	Lecture. Problem solving.	2 hours
The Feynman propagator for the Klein Gordon and Dirac equations	Lecture. Problem solving.	6 hours
The Feynman propagator for the electromagnetic field	Lecture. Problem solving. Examples.	2 hours
Calculation of cross section for some fundamental processes	Lecture. Problem solving.	4 hours

Bibliography:

1. B. Thaller , The Dirac Equation, Springer Verlag, 1992
2. W. Greiner, Relativistic Quantum Mechanics, Springer Verlag , 2000
3. W. Greiner, J. Reinhardt, Quantum Electrodynamics, Springer,2009

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

The contents and teaching methods were selected after a thorough analysis of the contents of similar course units in the syllabus of other universities from Romania or the European Union. The contents are in line with the requirements/expectations of the main employers of the graduates (industry, research, academic, secondary school teaching).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- coherence and clarity of exposition - correct use of equations/mathematical methods/physical models and theories - ability to indicate/analyse specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- ability to use specific problem solving methods	Homeworks/written tests	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) Correct solutions for all homeworks At least 50% of exam score and 50% of total score.			

Date 25.06.2019

Teacher's name and signature

Lect. dr. Cristian Stoica
Conf. dr. Madalina Boca

Practicals/Tutorials instructor(s) name(s) and signature(s)

Lect. dr. Cristian Stoica
Conf. dr. Madalina Boca

Date of approval

Head of Department
Prof.dr. Virgil Baran

DI. 205.FTC Research activity (traineeship)

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Research activity (traineeship)							
2.2. Teacher			Virgil Băran, Alexandru Nicolin, Roxana Zus					
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)								
2.5. Year of study	2	2.6. Semester	1	2.7. Type of evaluation	V	2.8. Type of course unit	Content[1]	**DS**
							Type[2]	**DI**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**6**	distribution: Lecture		Practicals/Tutorials	
3.2. Total hours per semester	**84**	Lecture		Practicals/Tutorials	

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**12**
3.2.2. Research in library, study of electronic resources, field research	**40**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**10**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**62**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	-
4.2. competences	-

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	-
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	Identify and use appropriately theoretical and computational methods which describe the interaction of intense fields with matter Apply creatively the knowledge acquired in order to understand and model real physical systems Communicate and analyze information of a didactic, scientific and popular character in the field of physics
Transversal competences	Efficient use of information sources and resources for communication and training, in Romanian and another language used internationally Carrying out professional tasks effectively, respecting the legislation, ethics and deontology specific to the field.

7. Course objectives

7.1. General objective	Understanding theoretically and computationally advanced methods which describe the interaction of intense fields with matter
7.2. Specific objectives	Detailed study by analytical and numerical means of the interaction of intense fields with matter Understanding how these systems are modelled Forming a creative and autonomous way of thinking

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Bibliography:		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Bibliography:		
8.3 Laboratory	Teaching and learning techniques	Observations
Bibliography:		
8.4 Project	Teaching and learning techniques	Observations
Depending on the laboratory/research center which she/he selects, the student will choose a research project from a sub-domain of theoretical and / or computational physics or their applications. Examples of dedicated projects this semester: - Study the interaction of intense and ultra-intense laser pulses with matter using particle-in-cell-type codes - The relativistic study of the interaction between the electromagnetic field and atomic systems - The study of ionization by scattering radiation on atoms (Compton effect on bound states) - Laser-assisted electron-ion (atom) scattering - Compton scattering and laser-assisted Mott scattering In addition to the extended list of research topics of		

the centers of the faculty, students have available projects that they can carry out within the collaboration agreements that the faculty has with research institutes (for example: Horia Hulubei National Institute for Physics and Nuclear Engineering The National Institute for Laser, Plasma & Radiation Physics etc.).		

Bibliography - sample:

1. P. Mulser și D. Bauer, *High power laser-matter interaction*, Springer, 2010.
2. R.W. Hockney și J.W. Eastwood, *Computer simulations using particles*, A. Hilger, 1988.
3. R. Dick, *Advanced quantum mechanics. Materials and photons*, Springer, 2016.
4. W. Greiner și J. Reinhardt, *Quantum electrodynamics*, Springer, 2008.

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

The content of the discipline allows the student to develop skills and abilities for modeling and/or experimental investigation of the various physical phenomena studied in laboratories/research centers and their applications, in order to integrate them in specific activities of research institutes and companies in the field of Theoretical and Computational Physics, as well as in education.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture			
10.5.1. Tutorials			
10.5.2 Laboratory			
10.5.3 Project	- Attendance - Clarity, coherence and brevity of the exposure of the acquired knowledge and the results obtained - The correct use of models, formulas and relations of calculation; - Correctly applying specific methods of solving for the given problem and interpreting the numerical results;	Colloquium	100%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Course coordinator
name(s) and signature(s)

Date
10.06.2019

Prof. Dr. Virgil Băran
Assoc. Prof. Dr. Alexandru Nicolin
Lect. Dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

DI 206 FTC.EN Introduction to gravity theory and cosmology

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	**Introduction to gravity theory and cosmology**							
2.2. Teacher				Conf. dr. Radu Slobodeanu				
2.3. Tutorials/Practicals instructor(s)				Dr. Mihai Marciu				
2.4. Year of study	II	2.5. Semester	IV	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DI**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	1/1
3.2. Total hours per semester	**40**	Lecture	**20**	Practicals/Tutorials	**10/10**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**60**
3.2.2. Research in library, study of electronic resources, field research	**10**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**10**
3.2.4. Preparation for exam	**5**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**81**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Real and Complex Analysis, Algebra, Differential Equations, Equations of Mathematical Physics, Classical Mechanics, Classical Electrodynamics, Relativistic Quantum Electrodynamics, Special Relativity
4.2. competences	Knowledge about: - Classical and Quantum Electrodynamics, Relativistic Quantum Electrodynamics, Special Relativity - Differential and integral calculus, partial differential equations, special functions, orthogonal polynomials -Analytical formalism of classical mechanics; the principle of least action;

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Computer, Video projector Lecture notes

	Bibliography
5.2. for practicals/tutorials	Computer, Video projector Lecture notes Bibliography

6. Specific competences acquired

Professional competences	**C1** Identify and proper use of the main physical laws and principles in a given context. C1.1 Deduction of working formulas for calculations of physical quantities using appropriate principles and laws of physics. C1.2 Description of physical systems, using theories and specific tools (theoretical and experimental models, algorithms, schemes, etc.) C1.3 Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring. - Rigorous knowledge of general relativity theory, concepts, notions and problems - Ability to use this knowledge in various branches of physics.
Transversal competences	**CT3** Efficient use of sources of information and communication resources and training assistance in a foreign language.

7. Course objectives

7.1. General objective	- Understanding the fundamental aspects related to the study of general relativity and cosmology. Training capacities to approach and solve specific problems which require relativistic calculus. Developing analytical and creative skills for questioning and solving open problems in the area of general relativity and cosmology.
7.2. Specific objectives	- Describing and understanding the current evolution of the known Universe and the basic general observables aquired through astrophysical observations. - Assimilation of formalism of general relativity theory: the physical principles of general relativity and various mathematical aspects describing the theory. - Understanding the physical features associated to different relativistic systems: black holes, neutron stars, gravitational waves. - Acquire the skills to describe and calculate the physical properties of relativistic and cosmological systems. - Developing the ability to work in a team

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
1. The principles of special relativity and the Minkowski space	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
2. Manifolds and differential forms	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
3. Curvature, parallel transport and covariant derivatives, geodesic equations	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
4. Einstein’s equations and the variational	Systematic exposition -	2 hours

formulation of general relativity	lecture. Heuristic conversation. Critical analysis. Examples	
5. Black holes and neutron stars	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
6. Gravitational waves	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
7. Einstein's equations and the cosmological constant	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
8. Fundamental questions in modern cosmology: the dark energy and dark matter problems	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
9. Scalar fields in curved space-time	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours
10. Modified gravity theories. Advanced topics in modern cosmology	Systematic exposition - lecture. Heuristic conversation. Critical analysis. Examples	2 hours

Bibliography:

1. **S. Carroll**, *An Introduction to General Relativity: Spacetime and Geometry,* Addison Wesley, 2003.
2. **B. Schutz**, *A First Course in General Relativity*, Cambridge University Press, 1985
3. **S. Weinberg**, *Gravitation and Cosmology*, Wiley, 1972.
4. **C. Misner, K. S. Thorne, J.A. Wheeler.** *Gravitation*, W.H. Freeman, 1973.
5. **J. D. Walecka**, *Introduction to general relativit*, World Scientific, 2007
6. **R. Wald**, *General relativity*, University of Chicago Press, 1984
7. **N. Gray**, *A Student's Guide to General Relativity,* Cambridge University Press, 2019
8. **C. G. Boehmer**, *Introduction to General Relativity and Cosmology*, World Scientific Publishing Co., 2016
9. **S.Nojiri, S.D.Odintsov, V.K.Oikonomou**, *Modified gravity theories on a nutshell: Inflation, bounce and late-time evolution,* Physics Reports, 692, 2017

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Geometry in a four dimensional space-time: vectors, dual vectors and tensors. Basic properties of the Lorentz transformations. Description of the Lorentz and Poincare groups. Einstein's equivalence principle.	Problem solving. Guided work. Case study. Examples.	2 hours
The space-time metric; the Levi-Civita connection; derivation of the geodesic equations. The Riemann curvature tensor and the non-commutativity property of the covariant derivatives.	Problem solving. Guided work. Case study. Examples.	2 hours
Properties of the Riemann curvature tensor: the	Problem solving. Guided	2 hours

Bianchi identity. The Ricci, Weyl and Einstein tensors. Symmetries and Killing vectors for a specific metric. Applications.	work. Case study. Examples.	
Einstein-Hilbert action and the principle of least action. Applications.	Problem solving. Guided work. Case study. Examples.	2 hours
Schwarzschild solution to Einstein's field equations. Applications.	Problem solving. Guided work. Case study. Examples.	2 hours
Tolman-Oppenheimer-Volkoff equations. Applications.	Problem solving. Guided work. Case study. Examples.	2 hours
Linearization of the Einstein's field equations. The gravitational wave equation. Plane wave solutions. Applications.	Problem solving.	2 hours
The Friedmann's equations. Applications.	Problem solving. Guided work. Case study. Examples.	2 hours
Derivation of the Klein-Gordon equations for scalar fields in curved space-time. The modified Friedmann relations.	Problem solving. Guided work. Case study. Examples.	2 hours
Modern extensions to general relativity based on curvature and Gauss-Bonnet scalars: f(R) and f(G) gravitational theories. Theoretical implications and numerical applications.	Problem solving. Guided work. Case study. Examples.	2 hours

Bibliography:

1. **S. Carroll**, *An Introduction to General Relativity: Spacetime and Geometry*, Addison Wesley, 2003.
2. **B. Schutz**, *A First Course in General Relativity*, Cambridge University Press, 1985
3. **S. Weinberg**, *Gravitation and Cosmology*, Wiley, 1972.
4. **C. Misner, K. S. Thorne, J.A. Wheeler.** *Gravitation*, W.H. Freeman, 1973.
5. **J. D. Walecka**, *Introduction to general relativit*, World Scientific, 2007
6. **R. Wald**, *General relativity*, University of Chicago Press, 1984
7. **N. Gray**, *A Student's Guide to General Relativity*, Cambridge University Press, 2019
8. **S.Nojiri, S.D.Odintsov, V.K.Oikonomou**, *Modified gravity theories on a nutshell: Inflation, bounce and late-time evolution*, Physics Reports, 692, 2017
9. **C. G. Boehmer**, *Introduction to General Relativity and Cosmology*, World Scientific Publishing Co., 2016

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences and abilities which are fundamental for a graduate student in the field of theoretical physics, corresponding to national and european/international standards. The contents and teaching methods were selected after a thorough analysis of the contents of similar course units in the syllabus of other universities from Romania, the European Union, or the United States of America. The contents are in line with the requirements/expectations of the main employers of the graduates (industry, research, academic, secondary school teaching).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in

			final mark
10.4. Lecture	- coherence and clarity of exposition - correct use of equations/mathematical methods/physical models and theories - ability to indicate/analyse specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- ability to use specific problem solving methods - ability to analyse the results	Homeworks/written tests	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and 50% of total score.			

Date 25.06.2019

Teacher's name and signature

Conf.dr. Radu Slobodeanu

Practicals/Tutorials instructor(s) name(s) and signature(s)

Dr. Mihai Marciu

Date of approval

Head of Department
Prof.dr. Virgil Baran

DI.208.FTC Research activity (traineeship)

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Research activity (traineeship)							
2.2. Teacher	Virgil Băran, Alexandru Nicolin, Roxana Zus							
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)								
2.5. Year of study	2	2.6. Semester	2	2.7. Type of evaluation	V	2.8. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DI**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**14**	distribution: Lecture		Practicals/Tutorials	
3.2. Total hours per semester	**140**	Lecture		Practicals/Tutorials	

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**146**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**206**
3.4. Total hours per semester	**350**
3.5. ECTS	**14**

4. Prerequisites (if necessary)

4.1. curriculum	-
4.2. competences	-

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	-
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	Understand and use appropriately the test particle method used to solve transport equations Apply creatively the knowledge acquired in order to understand and model real physical systems Communicate and analyze information of a didactic, scientific and popular character in the field of physics
Transversal competences	Efficient use of information sources and resources for communication and training, in Romanian and another language used internationally Carrying out professional tasks effectively, respecting the legislation, ethics and deontology specific to the field.

7. Course objectives

7.1. General objective	Detailed presentation of the test particle methods which is used to solved Boltzmann-Vlasov transport equation
7.2. Specific objectives	Study transport phenomena by computational means through the Boltzmann-Vlasov equation Understanding how these systems are modelled Forming a creative and autonomous way of thinking

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Bibliography:		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Bibliography:		
8.3 Laboratory	Teaching and learning techniques	Observations
Bibliography:		
8.4 Project	Teaching and learning techniques	Observations
Depending on the laboratory/research center which she/he selects, the student will choose a research project from a sub-domain of theoretical and / or computational physics or their applications. Examples of dedicated projects this semester: - The study of collective nuclear modes and the dynamics of nuclear fusion in transport approaches based on Vlasov equations; testing the validity of different equations of state of nuclear matter - Description of nuclear fragmentation and identification of new fragmentation mechanisms In addition to the extended list of research topics of the centers of the faculty, students have available projects that they can carry out within the collaboration agreements that the faculty has with research institutes (for example: Horia Hulubei National Institute for Physics and Nuclear		

Engineering The National Institute for Laser, Plasma & Radiation Physics etc.).		

Bibliography - sample:

1. K. Langanke, J.A. Maruhn şi S.E. Koonin, Eds., *Computational Nuclear Physics 2. Nuclear Reactions*, Springer, 1993.
2. M.R. Feix şi P. Bertrand, *A universal model: The Vlasov equation*, Transport Theory and Statistical Physics 34, 7-62 (2005)

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

The content of the discipline allows the student to develop skills and abilities for modeling and/or experimental investigation of the various physical phenomena studied in laboratories/research centers and their applications, in order to integrate them in specific activities of research institutes and companies in the field of Theoretical and Computational Physics, as well as in education.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture			
10.5.1. Tutorials			
10.5.2 Laboratory			
10.5.3 Project	- Attendance - Clarity, coherence and brevity of the exposure of the acquired knowledge and the results obtained - The correct use of models, formulas and relations of calculation; - Correctly applying specific methods of solving for the given problem and interpreting the numerical results;	Colloquium	100%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Course coordinator
name(s) and signature(s)

Date
10.06.2019

Prof. Dr. Virgil Băran
Assoc. Prof. Dr. Alexandru Nicolin
Lect. Dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

D0.104.1 Nonlinear dynamics, chaos, physics of complex systems

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Nonlinear dynamics, chaos, physics of complex systems							
2.2. Teacher	Assoc. Prof. Alexandru Nicolin, Assoc. Prof. Mihai Dondera							
2.3. Tutorials instructor(s)	Assoc. Prof. Alexandru Nicolin, Assoc. Prof. Mihai Dondera							
2.4. Practicals instructor(s)	Assoc. Prof. Alexandru Nicolin, Assoc. Prof. Mihai Dondera							
2.5. Year of study	1	2.6. Semester	1	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homework	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Analytical mechanics, Thermodynamics and Statistical Physics
4.2. competences	Working with software packages which do not require a license for data analysis and data processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	• Understanding the properties of real fluids. Presentation of the Navier-Stokes equations. The study of the phenomenon of period doubling and the sensitivity of the initial conditions • Understanding the properties of Lyapunov exponents and the appearance of chaotic behavior, with applications on shells type models that describe hydrodynamic turbulence and Lorenz model • Understanding the numerical methods used to solve nonlinear differential equations • Understanding how fractal distributions appear in physical, economic, social systems • Understanding the process of critical self-organization in complex systems
Transversal competences	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Presentation of the basic elements, analytical and computational, concerning nonlinear dynamics, chaos, and complex systems
7.2. Specific objectives	Study of sets of nonlinear differential equations of physical interest that exhibit chaotic behavior Study of numerical methods that can describe the chaotic solutions of nonlinear differential equations Study of simplified models that capture the properties of complex systems

8. Contents

8.1. Lecture	Teaching techniques	Observations/ hours
Fluid dynamics and turbulence. Historical framework and physico-mathematical foundations.	Systematic exposition - lecture. Examples	2 hours
The emergence of turbulence and the theory of dynamic systems. Presentation of the logistics application. Period doubling and the road to chaos. Lyapunov exponent for discrete systems. Feigenbaum numbers. Presentation of the tent and Henon maps.	Systematic exposition - lecture. Examples	4 hours
Presentation of Navier-Stokes equations and shell models (especially Gledzer-Ohkitani-Yamada). Lyapunov exponent for continuous systems. The study of energy conservation and helicity.	Systematic exposition - lecture. Examples	6 hours
Presentation of Lorenz equations. Sensitivity to initial conditions. Strange attractors. The Rössler system.	Systematic exposition - lecture. Examples	4 hours
Presentation of Runge-Kutta numerical methods (explicit and implicit). Volume conservation in phase space.	Systematic exposition - lecture. Examples	4 hours
Presentation of the sandpile model. Self-organized criticality. Fractal distributions. Applications in economics, sociology, astrophysics.	Systematic exposition - lecture. Examples	4 hours
Presentation of complex networks, especially topology, dynamics, and universality. Basic principles of economics.	Systematic exposition - lecture. Examples	4 hours
Bibliography: 1. S.H. Strogatz, *Nonlinear dynamics and chaos. With applications to physics, biology, and engineering,*		

CRC Press, 2015.
2. M. Tabor, *Chaos and integrability in nonlinear dynamics. An introduction*, Wiley, 1989.
3. T. Bohr, M.H. Jensen, G. Paladin și A. Vulpiani, *Dynamical systems approach to turbulence*, Cambridge University Press, 2005.
4. M. Aschwanden, *Self-organized criticality in astrophysics. The statistics of nonlinear processes in universe*, Springer, 2011.
5. S. Lynch, *Dynamical systems with applications with Python*, Birkhauser, 2018.
6. R. Hilborn, *Chaos and nonlinear dynamics. An introduction for scientists and engineers*, Oxford University Press, 2001.
7. P. Bak, *How nature works. The science of self-organized criticality*, Copernicus, 1999.
8. A.L. Barabasi, *Network science*, Cambridge University Press, 2016.
9. R.N. Mantegna și H.E. Stanley, *An introduction to econophysics. Correlations and complexity in finance*, Cambridge University Press, 2007.

8.2. Tutorials	Teaching and learning techniques	Observations
Computing Reynolds numbers.	Lecture. Problem solving	2 hours
Deriving shell-like equations from the Navier-Stokes equation.	Lecture. Problem solving	2 hours

Bibliography:
1. T. Bohr, M.H. Jensen, G. Paladin și A. Vulpiani, *Dynamical systems approach to turbulence*, Cambridge University Press, 2005.
2. L. Biferale, *Shell models of energy cascade in turbulence*, Annual Review in Fluid Mechanics **35**, 441 (2003).

8.3 Laboratory	Teaching and learning techniques	Observations
Determination of the two Feigenbaum constants in the numerical study of the Henon application.	Supervised practical activity	2 hours
Numerical solution of Lorenz equations. Runge-Kutta methods. Numerical algorithms for the Lyapunov exponent.	Supervised practical activity	6 hours
Numerical solution of equations that describe shell models. The Kolmogorov spectrum	Supervised practical activity	6 hours
Numerical study of the sandpile model and the Bak-Sneppen macroevolution model. Fractal distributions. Self-organized criticality.	Supervised practical activity	6 hours
The study of complex networks. The model of preferential attachment. Distributions of words in Romanian.	Supervised practical activity	2 hours
Financial markets. Hurst exponent calculation for time series describing the evolution of the exchange rate of currencies. Solving the Black-Scholes equation.	Supervised practical activity	2 hours

Bibliography:
1. S.H. Strogatz, *Nonlinear dynamics and chaos. With applications to physics, biology, and engineering*, CRC Press, 2015.
2. W.-H. Steeb, *The nonlinear workbook: chaos, fractals, etc.*, World Scientific, 2005.

8.4 Project	Teaching and learning techniques	Observations

Bibliography:

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

In order to sketch the contents, to choose the teaching/learning methods, the coordinator of the course consulted the content of similar disciplines taught at Romanian universities and abroad. The content of the discipline is according to the requirements of employment in research institutes in physics and materials science, as well as in education (according to the law).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem-solving methods	Homework	10%
10.5.2 Laboratory	- Ability to use specific problem-solving methods	Colloquium	30%
10.5.3 Project			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date 11-VI-2019	Teacher’s name and signature Assoc. Prof. Alexandru Nicolin, Assoc. Prof. Mihai Dondera	Practicals/Tutorials instructor(s) name(s) and signature(s) Assoc. Prof. Alexandru Nicolin, Assoc. Prof. Mihai Dondera

Date of approval

Head of Department

Prof. Virgil Băran

DO. 104.2 Special chapters of mathematics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Special chapters of mathematics							
2.2. Teacher			Assoc.prof. dr. Radu Slobodeanu					
2.3. Tutorials/Practicals instructor(s)			Lecturer dr. Adrian Stoica					
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Algebra, Analysis, Quantum mechanics
4.2. competences	Knowledge about: mechanics, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Knowledge and understanding of complex functions derivatives, contour integrals and Laurent series; applications to calculus of definite integrals; Knowledge and understanding of special functions and orthogonal polynomials for use in physics problems. Ability to use modern mathematical concepts in advanced physics.
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding of Fourier's transform; ability to use it in applications. - Understand modern methods of mathematics in physics
7.2. Specific objectives	Development of the skill to apply mathematical models for modelling various physical processes Acquire the appropriate understanding of the connections between mathematics and physics

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Differentiable manifolds. Tangent spaces. Vector fields. Differential forms.	Systematic exposition - lecture. Examples	6 hours
Lie groups and Lie algebra.	Systematic exposition - lecture. Examples	8 hours
Fibre bundles. Applications	Systematic exposition - lecture. Examples	6 hours
Connection in a bundle. Parallel transport. Curvature.	Systematic exposition - lecture. Examples	8 hours
Bibliography: 1. C.J.Isham, *Modern Differential Geometry for Physicists*, World Scientific, 2001		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Fourier transform. Convolution product and its Fourier transform. Fourier transform of generalized functions. Dirac's distribution.	Problem solving	4 hours
Complex functions: derivatives and contour integrals.	Problem solving	4 hours
Taylor and Laurent series. Residues. Examples. Calculus of definite integrals by using residue theorem	Problem solving	4 hours
Tensor calculus. Tensor products.	Problem solving	4 hours
Orthogonal polynomials and special functions. Hypergeometric polynomials. Legendre's polynomials and associated functions. Laguerre's polynomials. Hermite's polynomials	Problem solving	4 hours
Frames and orthonormal bases. The resolution of	Problem solving	4 hours

identity. Systems of coherent states. Quantification based on systems of coherent states or frames.		

Bibliography:

1. G. Teschl, Mathematical Methods in Quantum Mechanics with Applications to Schrodinger Operators, AMS 2009
2. M. Stone and P. Goldbart, *Mathematics for Physicists*, Cambridge University Press 2009

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date	Teacher’s name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
10.06.2019	Assoc.prof.dr. Radu Slobodeanu	Lecturer dr. Adrian Stoica

Date of approval

Head of Department

Prof.dr. Virgil Baran

DO.107.1.FTC Interaction of laser radiation with matter

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	**Interaction of laser radiation with matter**								
2.2. Teacher				Conf. dr. Madalina Boca					
2.3. Tutorials/Practicals instructor(s)				Conf. dr. Madalina Boca					
2.5. Year of study	I	2.6 Semester	II	2.7. Type of evaluation	E	2.8. Type of course unit		Content[1]	**DS**
								Type[2]	**DO**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Electrodynamics and relativity theory, Quantum mechanics
4.2. competences	Numerical / using of approximation methods for solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Computer, Video projector
5.2. for practicals/tutorials	**Computer, Video projector**

6. Specific competences acquired

Professional competences	**-** Identify and proper use of the main physical laws and principles in a given context. Identify and proper use of specific laws for simple systems in interaction with the electromagnetic field. -solving pf physics problems in given conditions - Using the acquired knowledge for understanding / modeling of processes in electromagnetic fields - Communication and analysis of didactic, scientific and general information in physics
Transversal competences	**-** Efficient use of sources of information and communication resources and training assistance in a foreign language. - accomplishment of professional tasks in an professional way, assuming an ethical conduct in scientific research;

7. Course objectives

7.1. General objective	Presentation of the main processes in the interaction of radiation with the substance
7.2. Specific objectives	Understanding the classical / quantum theory of the interaction of electromagnetic radiation with matter - Understanding the evolution in time of some systems in interaction with the electromagnetic field - The ability to use approximate / numerical mathematical models in the analysis of the interaction of electromagnetic radiation with matter

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Physical processes in electromagnetic fields: overview.	Systematic exposition - lecture. Examples	2 hours
Electromagnetic waves and photons; introduction	Systematic exposition - lecture. Examples	2 hours
Classical description of the electromagnetic field, plane wave, Gaussian modes	Systematic exposition - lecture. Examples	4 hours
Description of the electromagnetic field in quantum theory	Systematic exposition - lecture. Examples	4 hours
Free particle in electromagnetic field: classical / quantum description.	Systematic exposition - lecture. Examples	4 hours
Radiation interaction with atomic systems: amplitude / transition rate, effective sections.	Systematic exposition - lecture. Examples	4 hours
Multiphotonic processes, perturbative / non-perturbative description	Systematic exposition - lecture. Examples	2 hours
Radiation scattering (Rayleigh, Raman, Compton).	Systematic exposition - lecture. Examples	4 hours
Elements of quantum electrodynamics in intense fields	Systematic exposition - lecture. Examples	2 hours

Bibliography:

1. M. Dondera, V. Florescu. *Capitole de fizica atomica teoretica, Ed. UB, 2005.*
2. F.H.M. Faisal, *Theory of multiphotonic processes,* Plenum Press, 1987
3. C. J. Joachain, N. Kylstra, R. M. Potvliege, *Atoms in intense laser fields,* Cambridge University Press,

2012.
4. **W. Greiner, *Quantum Mechanics: Special Chapters*, Springer, 1998**

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Numerical / approximate solutions of the Maxwell equations	Lecture. Problem solving.	4 hours
Motion of electrically charged particle in electromagnetic field, approximate / numerical solutions	Lecture. Problem solving.	6 hours
Volkov solutions in non-relativistic quantum mechanics	Lecture. Problem solving.	8 hours
Radiation reaction	Lecture. Problem solving.	4 hours
Perturbative description of the interaction of radiation with simple systems	Lecture. Problem solving.	4 hours
Elements of Floquet theory	Lecture. Problem solving.	2 hours

Bibliography:
1. C. Cohen-Tannoudji, J. Dupont-Roc, G. Grynberg, *Atom-Photon Interactions*, Wiley-VCH Verlag, 2004.
2. J. D. Jackson Classical Electrodynamics (Wiley, 1962).
3. M. Boca, Lecture notes

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

The contents and teaching methods were selected after an analysis of the contents of similar course units in the syllabus of other universities (LMU, KTH) . The contents are in line with the requirements/expectations of the main employers of the graduates (research, academic, secondary school teaching).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- coherence and clarity of exposition - correct use of equations/mathematical methods/physical models and theories - ability to indicate/analyse specific examples	Written test/oral examination	50%
10.5.1. Tutorials	- ability to use specific problem solving methods	Homeworks/written tests	50%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) Solving of all homework, Correct presentation of the subjects indicated for mark 5 in the final exam.			

Date 25.06.2019	Teacher's name and signature Conf. dr. Madalina Boca	Practicals/Tutorials instructor(s) name(s) and signature(s) Conf. dr. Madalina Boca

Date of approval

Head of Department
Prof.dr. Virgil Baran

DO.107.2 Quantum Optics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Quantum Optics							
2.2. Teacher				Associate prof. Iulia Ghiu				
2.3. Tutorials/Practicals instructor(s)				Associate prof. Iulia Ghiu				
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DS**
							Type[2]	**DO**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Optics, Algebra, Quantum mechanics
4.2. competences	

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of quantum optics • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in this area • Ability to use this knowledge in various branches of physics
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language

7. Course objectives

7.1. General objective	Understanding the fundamental aspects related to the study of quantum optics
7.2. Specific objectives	Assimilation of formalism of quantum optics. Explaining the peculiar fenomena of quantum optics, which have no classical analogue. Acquire the skills to describe and calculate the physical properties of quantum systems involved in the problems of quantum optics.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Quantization of the electromagnetic field	Systematic exposition - lecture. Examples	4 hours
The quasi-probability distributions in the phase space: the representation Glauber-Sudarshan, Husimi function and Wigner function	Systematic exposition - lecture. Examples	4 hours
Single-mode squeezed states: definition, properties, the representation in the phase space. Photon antibunching. Two-mode squeezed states	Systematic exposition - lecture. Examples	4 hours
The single-mode thermal state: the quasi-probability distributions	Systematic exposition - lecture. Examples	4 hours
The quantum description of the beam splitter. Applications	Systematic exposition - lecture. Examples	4 hours
Quantum communications using photons: quantum teleportation, quantum cryptography	Systematic exposition - lecture. Examples	4 hours
Interference phenomena with single and double photodetection. The experiment of Hong, Ou, Mandel. The Franson's experiment.	Systematic exposition - lecture. Examples	4 hours
Bibliography: **1.** C. Gerry, P. Knight, *Introductory Quantum Optics*, Cambridge University Press, 2005. **2.** M. O. Scully, M. S. Zubairy, *Quantum Optics*, Cambridge University Press, 2002. **3.** Cohen-Tannoudji, Dupont-Roc, and Grynberg, Atom-Photon Interactions, Wiley, 1998. **4.** D. F. Walls, G. J. Milburn, *Quantum Optics*, Springer Verlag, 1994. **5.** C. W. Gardiner, *Quantum Noise*, Springer Verlag, 1991. **6.** M. D. Al-Amri, M. M. El-Gomati, M. S. Zubairy (Editors), *Optics in Our Time*, Springer Open, 2016.		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
The mixed states of a two-level quantum system. The Bloch sphere	Problem solving	4 hours
Quantum correlation functions	Problem solving	4 hours
Coherent states: definition, properties, the representation in the phase space	Problem solving	4 hours

Entanglement. Condition that the two-photon state to be inseparable	Problem solving	4 hours
Bell inequalities in quantum optics	Problem solving	4 hours
The optical implementation of some quantum gates	Problem solving	4 hours
Quantum eraser	Problem solving	4 hours

Bibliography:

1. C. Gerry, P. Knight, *Introductory Quantum Optics*, Cambridge University Press, 2005.
2. M. O. Scully, M. S. Zubairy, *Quantum Optics*, Cambridge University Press, 2002.
3. D. F. Walls, G. J. Milburn, *Quantum Optics*, Springer Verlag, 1994.

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents and teaching methods were selected after a thorough analysis of the contents of similar course units in the syllabus of other universities from Europe (Oxford University, Royal Institute of Technology - Stockholm). The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of equations/mathematical methods/physical models and theories - The ability to give specific examples	Written test/oral examination	50%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	50%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
11.06.2019	Associate prof. dr. Iulia Ghiu	Associate prof. dr. Iulia Ghiu

Date of approval

Head of Department
Prof.dr. Virgil Baran

DO.110.1 Introduction to quantum theory of identical particles

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Introduction to quantum theory of identical particles							
2.2. Teacher				Prof. Dr. Virgil Baran/ Assoc. prof. Dr. Mihai Dondera				
2.3. Tutorials/Practicals instructor(s)				Lect. Dr. Victor Dinu				
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**20**
3.2.2. Research in library, study of electronic resources, field research	**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**25**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**65**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Classical Statistical Mechanics, Equations of Mathematical Physics
4.2. competences	Knowledge about: mechanics, thermodynamics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of quantum many-body physics • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in the area of many-body systems • Ability to use this knowledge in various branches of physics
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding peculiarities of physical properties of quantum many-body systems. - Understanding occupation number representation of quantum mechanics - Knowledge and understanding of effects related to fermionic or bosonic nature of quantum particles
7.2. Specific objectives	Gain the ability to work with theoretical methods of quantum many-body systems Acquire the skills to describe and calculate the physical properties of quantum many-body systems involved in different physical conditions.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
The indistinguishability of quantum particles. Permutation operators. Particle exchange symmetry. Symmetrization postulate for identical quantum particles. Completely symmetric and antisymmetric quantum states.	Systematic exposition - lecture. Examples	2 hours
Occupation-number representation of quantum mechanics. Fock space.	Systematic exposition - lecture. Examples	2 hours
Creation and annihilation operators. Vacuum state. Fundamental algebraic relations for fermions and bosons creation/annihilation operators. Field operators. Definition and properties.	Systematic exposition - lecture. Examples	4 hours
One-body and two-body observables in many-body systems.	Systematic exposition - lecture. Examples	4 hours
Hartree-Fock approximation. Hartree-Fock method in occupation-number formalism. Density functional theory. Applications	Systematic exposition - lecture. Examples	6 hours
Coulomb interactions in many electron systems. Jellium model. Basic assumptions and Hamiltonian of the model.	Systematic exposition - lecture. Examples	4 hours

Ground state energy in the Hartree-Fock approximation. Hubbard's model in occupation-number formalism. Physical properties.		
Pairing interaction and superconductivity. Experimental observations and phenomenology of superconductivity. London's equations. Effective interaction between electrons and pairing Hamiltonian. Barden-Cooper-Schriffer (BCS) model. Properties. Bogoliubov-Valatin transformation. Quasiparticles. Pairing equations. Properties of superconductors.	Systematic exposition - lecture. Examples	6 hours
Bibliography: 1. J.W. Negele, H. Orland, Quantum Many Particle Systems (Advanced Book Program) 2. P. Nozieres, Theory of Interacting Fermi systems (Advanced Book Program) 3. J.F. Annett, Superconductivity, Superfluidity and Condensates (Oxford University Press) 4. Fetter A.L. , J.D. Walecka Quantum theory of Many Particle systems (McGraw Hill, New-York) 5. P.W. Anderson, Concepts in Solids, World Scientific, 1997 6.W. Nolting, Fundamentals of many-body physics, Springer 2009.		

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Fermi gas in ground state: Fermi's sea, relationship between density and momentum. Applications.	Problem solving	2 hours
One-particle density matrix for fermion systems. Pair correlation function for fermions and bosons. Definition, properties, physical consequences.	Problem solving	4 hours
Observables of interest in terms on creation and annihilation operators: densities, currents.	Problem solving	4 hours
Hartree-Fock approximation: examples. Koopmans' theorem. Density functional theory. Hubbard model.	Problem solving	8 hours
Bogoliubov Theory of the Weakly Interacting Bose Gas	Problem solving	4 hours
Cooper pair problem. Phonon-electron interaction. Superconductivity: constant coupling function. Ground state energy. Derivation of gap equation. Physical interpretation.	Problem solving	6 hours
Bibliography: 1. P.W. Anderson, Concepts in Solids, World Scientific, 1997 2.W. Nolting, Fundamentals of many-body physics, Springer 2009. 3. P.A. Martin, F. Rothen, Many-body problems and quantum field theory, Springer, 2002		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of	Written test and oral	

	exposition - Correct use of the methods/ physical models - The ability to give specific examples	examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date
10.06.2019

Teacher's name and signature

Prof. dr. Virgil Baran
Assoc. Prof.dr. Mihai Dondera

Practicals/Tutorials instructor(s) name(s) and signature(s)

Lect. dr. Victor Dinu

Date of approval

Head of Department

Prof.dr. Virgil Baran

DO.110.2 Theory of critical phenomena

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Theory of critical phenomena							
2.2. Teacher				Prof. Dr. Virgil Băran/ Assoc.prof. dr. Alexandru Nicolin				
2.3. Tutorials/Practicals instructor(s)				Assoc.prof. dr. Alexandru Nicolin				
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**20**
3.2.2. Research in library, study of electronic resources, field research	**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**25**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**65**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Quantum Statistical Physics, Electrodynamics
4.2. competences	Knowledge about: mechanics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts emerging from theory of phase transitions • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of phase transitions, concepts, notions and problems in the area of critical phenomena • Ability to use this knowledge in interpretation of experimental result • Understanding the role of the interaction, of the particle nature and of the dimensionality over the dynamical properties • Developing the computational abilities and a sound theoretical knowledge of the studied problems
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Knowledge and description of physical properties of phase transitions at the critical points Understanding the universal behaviour, the role of the dimension and of the symmetries.
7.2. Specific objectives	Development of the skill to apply mathematical models and numerical method for modelling various physical processes Acquire the appropriate understanding of studied fundamental mechanisms of phase transitions

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Continuous phase transitions and critical points Critical phenomena in nature: liquid-gas phase transition, binary fluid, the ferromagnetic-paramagnetic transition, the transition to superconductivity, the He I-He II transition. Fundamental concepts: order parameter, critical exponents, correlation functions, scale invariance, classes of universality.	Systematic exposition - lecture. Examples	6 hours
Models for description of phase transitions Ising models in one, two and three dimensions. Networks models, XY model, Heisenberg model, Potts model, percolation model	Systematic exposition - lecture. Examples	8 hours
Mean-field theory for critical behaviour Theoretical framework. Landau theory. Critical exponents in Landau theory.	Systematic exposition - lecture. Examples	6 hours
Renormalization group method The basic principles of the method. Renormalization group transformations and recurrence relations.	Systematic exposition - lecture. Examples	8 hours

Bibliography: 1. J.J. Binney, N.J. Dowrick, A.J. Fisher, M.E.J. Newman, *The Theory of Critical Phenomena. An introduction to the renormalization Group*, (Oxford UP 1995) *2.* Leo P. Kadanoff, *Statistical Physics. Statics, Dynamics and Renormalization.* (World Scientific, 2001*)* 3. C. Domb, *The Critical Point, (Taylor&Franciscs, 1996)*		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
The Van der Waals model for the liquid-gas phase transition: critical exponents in the mean-field approximation.	Problem solving	4 hours
The transfer matrix. The Duality transformation. Onsager solution for Ising model in two dimensions.	Problem solving	4 hours
The renormalization group method for Ising model in two dimensions. The Monte-Carlo method for Ising model in three dimensions	Problem solving	4 hours
The Momentum-Shell Renormalization Group	Problem solving	4 hours
Percolation	Problem solving	4 hours
Fixed points of the renormalization group transformations: the physical meaning and properties. Linearized transformations around the fixed point. The origin of the scale behaviour. Renormalization group in differential form.	Problem solving	6 hours
Bibliography: 1. N. Goldenfeld, *Lectures on phase transitions and the renormalization group* (Adison-Wesley PC, 1992) 2. Franz Schwabl, *Statistical mechanics,* Springer-Verlag Berlin Heidelberg 2006		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
10.06.2019	Prof. dr. Virgil Baran Assoc. Prof.dr. Alexandru Nicolin	Assoc.prof. dr. Alexandru Nicolin

Date of approval

Head of Department

Prof.dr. Virgil Baran

DO.111.1 Quantum Information and Communication

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Quantum Information and Communication							
2.2. Teacher				Associate prof. Iulia Ghiu				
2.3. Tutorials/Practicals instructor(s)				Associate prof. Iulia Ghiu				
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**20**
3.2.2. Research in library, study of electronic resources, field research	**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**25**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**65**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Optics, Equations of Mathematical Physics
4.2. competences	Knowledge about: Algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of quantum information theory • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in this area • Ability to use this knowledge in various branches of physics
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language

7. Course objectives

7.1. General objective	Understanding the fundamental aspects related to the study of quantum information processing
7.2. Specific objectives	Assimilation of formalism of quantum information theory: concepts, methods of transmiting, manipulating and storing of the quantum information. Explaining the peculiar fenomena of quantum information theory, which have no classical analogue. Acquire the skills to describe and calculate the physical properties of quantum systems involved in the quantum information processing.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Definition of the qubit. Two-qubit systems. Entangles states. Einstein-Podolsky-Rosen paradox. Bell's inequalities	Systematic exposition - lecture. Examples	4 hours
The density operator for a spin-1/2 particle. The Bloch vector. The reduced density operator. Schmidt decomposition. Purifications	Systematic exposition - lecture. Examples	2 hours
Quantum teleportation. Many-to-many teleportation	Systematic exposition - lecture. Examples	2 hours
No-cloning theorem. Superdense coding. Shannon entropy and von Neumann entropy.	Systematic exposition - lecture. Examples	2 hours
Trace distance. Polar decomposition. Definition of the fidelity. Uhlmann's theorem. Properties of the fidelity. Approximate cloning machine	Systematic exposition - lecture. Examples	4 hours
Quantum cryptography	Systematic exposition - lecture. Examples	2 hours
Quantum gates. Deutsch's algorithm. Deutsch-Jozsa algorithm	Systematic exposition - lecture. Examples	2 hours
Bernstein-Vazirani algorithm. Simon algorithm	Systematic exposition - lecture. Examples	2 hours
Grover's quantum search algorithm. Shor's factoring algorithm	Systematic exposition - lecture. Examples	4 hours
Quantum channels	Systematic exposition - lecture. Examples	2 hours
Description of the IBM-Q quantum computer in the cloud and its application for the implementation of quantum algorithms	Systematic exposition - lecture. Examples	2 hours

Bibliography:

1. M. A. Nielsen and I. L. Chuang, *Quantum computation and quantum information*, Cambridge

University Press, Cambridge, 2000.
2. Asher Peres, *Quantum Theory: Concepts and Methods*, Kluwer Academic Publishers, 1993.
3. D. Bouwmeester, A. Ekert, and A. Zeilinger, *The Physics of Quantum Information*, Springer Verlag, 2000.
4. S. M. Barnett, *Quantum Information*, Oxford Master series in physics, Oxford University Press, 2009.
5. Iulia Ghiu, Lecture notes

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
The Baker-Campbell-Hausdorf identity. Problems with one and two qubits. Condition for a state to be entangled.	Problem solving	4 hours
Applications of the CHSH-Bell inequality. The analysis of the density operator for a qubit.	Problem solving	4 hours
Operator functions. The reduced density operators. Finding the Schmidt decomposition of a bipartite state. The analysis of the density operator of two spin-1/2 particles. The purity of a mixed state.	Problem solving	4 hours
Hadamard gate. Quantum teleportation using the GHZ state as the quantum channel. Entanglement swapping	Problem solving	4 hours
Computing the trace distance and the fidelity for some particular mixed states	Problem solving	4 hours
The generalized quantum teleportation and the evaluation of the average fidelity. The quantum circuit for the gates: SWAP, Toffoli, Fredkin	Problem solving	4 hours
The quantum circuit for teleportation. The CNOT gate with multiple targets	Problem solving	2 hours
Applications using the IBM-Q quantum computer in the cloud	Problem solving	2 hours

Bibliography:

1. M. A. Nielsen and I. L. Chuang, *Quantum computation and quantum information*, Cambridge University Press, Cambridge, 2000.
2. D. Bouwmeester, A. Ekert, and A. Zeilinger, *The Physics of Quantum Information*, Springer Verlag, 2000.
3. S. M. Barnett, *Quantum Information*, Oxford Master series in physics, Oxford University Press, 2009.
4. M. M. Wilde, *Quantum Information Theory*, Cambridge University Press, 2017.
5. W. H. Steeb, Y. Hardy, *Problems and solutions in quantum computing and quantum information*, World Scientific, 2004.

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents and teaching methods were selected after a thorough analysis of the contents of similar course units in the syllabus of other universities from Europe (Oxford University, Royal Institute of Technology - Stockholm). The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3.

			Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of equations/mathematical methods/physical models and theories - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score.			

Date
11.06.2019

Teacher's name and signature

Associate prof. dr. Iulia Ghiu

Practicals/Tutorials instructor(s) name(s) and signature(s)

Associate prof. dr. Iulia Ghiu

Date of approval

Head of Department
Prof.dr. Virgil Baran

DO. 111.1 Collisions theory

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Collisions theory							
2.2. Teacher				Assoc. prof. Dr. Mihai Dondera				
2.3. Tutorials/Practicals instructor(s)				Lect. Dr. Victor Dinu				
2.4. Year of study	I	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DS**
							Type[2]	**DO**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one’s own course notes, manuals, lecture notes, bibliography	**20**
3.2.2. Research in library, study of electronic resources, field research	**20**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**25**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**65**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Classical Statistical Mechanics, Equations of Mathematical Physics
4.2. competences	Knowledge about: mechanics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of quantum collisions • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in the area of quantum collisions • Ability to use this knowledge in various branches of physics
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding peculiarities of physical properties of quantum collisions. - Knowledge and understanding of effects related to fermionic or bosonic nature of quantum particles - Realize the importance of the field in modern physics
7.2. Specific objectives	Gain the ability to work with theoretical methods of quantum collisions theory Acquire the skills to describe the collisions processes and to calculate their cross sections

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Classification of collisions. Cross sections. Potential scattering, The scattering solution and the scattering amplitude.	Systematic exposition - lecture. Examples	2 hours
Scattering on central potentials, partial waves, phase shifts, phase shifts method. Resonances, Breit-Wigner formula, Scattering on Coulomb potential and potentials with Coulomb tail.	Systematic exposition - lecture. Examples	2 hours
The Lippmann-Schwinger equation. Green functions and operators. Born series method.	Systematic exposition - lecture. Examples	4 hours
Scattering on non-central potential	Systematic exposition - lecture. Examples	4 hours

Scattering of particles with spin. Scattering of identical particles	Systematic exposition - lecture. Examples	6 hours
The time dependent integral equation of potential scattering. Propagators.	Systematic exposition - lecture. Examples	4 hours
The relativistic scattering theory. Collision theory for Dirac equation. General scattering theory. In and Out states. Moller operators. The scattering operator. The generalized Fermi Formula**.**	Systematic exposition - lecture. Examples	6 hours
Bibliography: C.J. Joachain, *Quantum collision theory,* North-Holland, 1975 P. Roman, *Advanced quantum theory,* Addison-Wesley Pub. Co., 1965 A. Messiah, *Quantum mechanics,* Dover, 1999 E. Merzbacher, *Quantum mechanics,* John Willey & Sons, 1970 M. Dondera, V. Florescu, *Fizica atomica teoretica, Ed. UB, 2005* J. Taylor, *Scattering theory: the quantum theory of non-relativistic collisions,* John Willey & Sons, 1972		
8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Collision kinematics; relativistic kinematics. Mandelstam variables	Problem solving	2 hours
The optical theorem. The Wronskian theorem and applications.	Problem solving	2 hours
Finite range potentials. The effective range formalism	Problem solving	4 hours
Analytical properties of the scattering amplitude. The Born approximation	Problem solving	4 hours
The R matrix method. Scattering of 1/2 spin particles in the Born approximation. Invariant amplitudes.	Problem solving	4 hours
Coulomb effects in scattering of identical particles	Problem solving	4 hours
Applications of the time dependent perturbation theory in the scattering theory.	Problem solving	4 hours
Inelastic scattering. The generalized optical theorem.	Problem solving	4 hours
Bibliography:		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition	Written test and oral examination	

	- Correct use of the methods/ physical models - The ability to give specific examples		60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date
10.06.2019

Teacher's name and signature

Assoc. Prof.dr. Mihai Dondera

Practicals/Tutorials instructor(s) name(s) and signature(s)

Lect. dr. Victor Dinu

Date of approval

Head of Department

Prof.dr. Virgil Baran

DO.202.1 Advanced methods in statistical physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Advanced methods in statistical physics							
2.2. Teacher				Prof.dr. Virgil Baran/ Prof.dr. Lucian Ion				
2.3. Tutorials/Practicals instructor(s)				Lect.dr. Victor Dinu				
2.4. Year of study	II	2.5. Semester	1	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DS**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**25**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**35**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum mechanics, Quantum Statistical Physics, Electrodynamics
4.2. competences	Knowledge about: mechanics, algebra, solving differential equations

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of statistical quantum mechanics for strongly interacting systems • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum theory, concepts, notions and problems in the area of modern nuclear physics • Ability to use this knowledge in interpretation of experimental result • Understanding the role of the interaction, of the particle nature and of the dimensionality over the dynamical properties • Developing the computational abilities and a sound theoretical knowledge of the studied problems
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	- Understanding the specific feature of the quantum systems composed from strongly correlated identical particles Developing the capability to assimilate, analyse and compare diverse phenomena, starting from basic principles - Developing the ability to analyse and interpret the experimental data and to formulate rigorous theoretical conclusions - Developing the ability to apply mathematical models and adequate numerical procedures
7.2. Specific objectives	Gain the ability to work with theoretical methods of quantum many-body systems adapted to strongly interacting systems Acquire the skills to describe and calculate the physical properties of quantum many-body systems involved in different physical conditions.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
The formalism of the Green functions: General properties of Green functions (symmetry, Lehman representations), physical interpretation for the retarded Green function.	Systematic exposition - lecture. Examples	8 hours
The formalism of the density functional: The theory of the density functional. Hohenberg-Kohn theorems. The Kohn-Sham equations. Approximate functionals. Introduction in the theory of the time dependent density functional.	Systematic exposition - lecture. Examples	6 hours
The dynamics of the Bose-Einstein condensate The Gross-Pitaevskii equation. Elementary excitations and collective modes. Solitons. Traps for condensates for finite temperature.	Systematic exposition - lecture. Examples	6 hours
From the integral Hall effect to the fractional Hall effect : Strong correlated systems and the	Systematic exposition - lecture. Examples	6 hours

quasiparticle concept. Laughlin theory. The theory of compound fermions.		
Ginzburg–Landau theory of superconductivity. Basic equations. From type-I superconductor to type-II superconductors.	Systematic exposition - lecture. Examples	4 hours

Bibliography:

1. E. Lipparini, *Modern many-particle physics. Atomic gases, quantum dots and quantum fluids*, World Scientific, 2003
2. R.G. Paar, W. Yang, *Density functional theory for atoms and molecules,* Oxford UP,*1989*
3. C.A. Ullrich, *Time-Dependent Density Functional Theory*, Oxford UP, 2012
4. J.K. Jain, *Composite fermions*, Cambridge UP, 2007
5. T. Chakraborty, P. Pietilainen, The *quantum Hall effects, Fractional and Integral*, Springer 1995
6. C.J. Pethick, H. Smith, *Bose-Einstein Condensation in Dilute Gases*, Cambridge UP, 2008
7. Z.F. Ezawa, *Quantum Hall effects,* World Scientific, 2007
8. Fetter A.L. , J.D. Walecka, *Quantum theory of Many Particle systems* (McGraw Hill, New-York)
9. W. Buckel, R. Kleiner, *Superconductivity: Fundamentals and Applications,* WILEY-VCH Verlag GmbH 2004

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Galitskii-Migdal theorems. The relation with the observables. Differential equations. Correlation functions:definition, general properties, the similarity with the Green functions.	Problem solving	6 hours
Applications of the Green formalism for various systems. The Thomas-Fermi approximation and its extensions	Problem solving	4 hours
Applications of Density Functional Theory	Problem solving	4 hours
Collective dynamics of Bose-Einstein condensates	Problem solving	4 hours
The theory of compound fermions.	Problem solving	4 hours
Superconductivity: surface energy and thermodynamic critical field in Ghinzburg-Landau theory. Vortex lattice. Josephson tunnelling.	Problem solving	6 hours

Bibliography:

A.S. Alexandrov *Theory of Superconductivity .From Weak to Strong Coupling,* IOP Publishing Ltd 2003

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition	Written test and oral examination	

	- Correct use of the methods/ physical models - The ability to give specific examples		60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date 10.06.2019	Teacher's name and signature Prof.dr. Virgil Băran Prof.dr. Lucian Ion	Practicals/Tutorials instructor(s) name(s) and signature(s) Lect.dr. Victor Dinu

Date of approval

Head of Department

Prof.dr. Virgil Baran

D0.204.1 Computational methods in modern physics

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Computational methods in modern physics							
2.2. Teacher	Assoc. Prof. Alexandru Nicolin / Lect. Dr. Roxana Zus							
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)	Dr. Mihai Marciu							
2.5. Year of study	2	2.6. Semester	1	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1]	**DA**
							Type[2]	**DO**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homework	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Programming languages, Linear algebra, Analytical mechanics, Electrodynamics, Quantum Mechanics,Thermodynamics and Statistical Physics
4.2. competences	Working with software packages which do not require a license for data analysis and data processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	• Understanding how to solve differential equations with Hamiltonian structure using the leapfrog method and related methods. Understanding time-reversibility and energy conservation. • Understanding finite difference methods and their use in numerical study of the Schrödinger equation. Understanding the conservation of the norm of the wave function and the emergence of numerical instabilities. • Understanding the use of finite difference methods for numerically solving Maxwell equations. • Understanding the dynamics of electrically charged particles moving in an electromagnetic through the numerical solution of the Vlasov equation using the test particle method. • Understanding *particle-in-cell* equations and self-consistent solution of field equations and those describing particle dynamics. Understanding the Boris algorithm for particle propagation over time and the Courant stability condition.
Transversal competences	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Presentation of computational methods in modern physics
7.2. Specific objectives	Study of leapfrog method and related methods for solving differential equations of Hamiltonian structure Study of finite-difference methods for solving the Schrödinger equation and Maxwell equations Study of the test particle method used to numerically solve the Vlasov equation Study of particle-in-cell equations that describe the dynamics of electrically charged particles in an electromagnetic field The study of the interaction of laser pulses with metal clusters

8. Contents

8.1. Lecture	Teaching techniques	Observations/ hours
Simplectic and near-simplectic methods for numerical solving of differential equations with Hamiltonian structure. Energy and volume conservation in the phase space.	Systematic exposition - lecture. Examples	2 hours
Finite-difference methods for the three-dimensional Schrödinger equation (especially for periodic and harmonic potential). Conservation of the norm. Stability conditions. Numerical instabilities. Border conditions. Analytical calculations for calibrating the accuracy of numerical schemes.	Systematic exposition - lecture. Examples	4 hours
Finite difference methods for Maxwell equations. Border conditions. Numerical instabilities.	Systematic exposition - lecture. Examples	6 hours
The Vlasov equation and the test particle method. Derivation of particle-in-cell equations. Study of shape functions.	Systematic exposition - lecture. Examples	4 hours
Self-consistent solving of field equations and those describing particle dynamics. Boris algorithm for particle propagation over time. Courant stability	Systematic exposition - lecture. Examples	4 hours

condition.		
Interaction of laser pulses with metal clusters	Systematic exposition - lecture. Examples	4 hours
Comparative presentation of particle-in-cell codes available for solving equations.	Systematic exposition - lecture. Examples	4 hours
Bibliography: 1. B. Leimkuhler și S. Reich, *Simulating Hamiltonian dynamics*, Cambridge University Press, 2004. 2. D.F. Griffiths, J.W. Dold și D.J. Silvester, *Essential partial differential equations. Analytical and computational aspects*, Springer, 2015. 3. S. Mazumder, *Numerical methods for partial differential equations. Finite difference and finite volume methods*, Academic Press, 2016. 4. S.E. Koonin și D.C. Meredith, *Computational physics. Fortran versions*, Perseus Books, 1998. 5. P. Mulser și D. Bauer, *High power laser-matter interaction*, Springer, 2010. 6. P.G. Reinhard și E. Suraud, *Introduction to cluster dynamics*, Wiley-VCH, 2004. 7. K. Langanke, J.A. Maruhn și S.E. Koonin, Eds., *Computational Nuclear Physics 2. Nuclear Reactions*, Springer, 1993. 8. T.D. Arber *et al.*, *Contemporary particle-in-cell approach to laser-plasma modelling*, Plasma Phys. Control. Fusion **57**, 113001 (2015)		
8.2. Tutorials	Teaching and learning techniques	Observations
Solving the three-dimensional Schrödinger equation for a harmonic (radial) and periodic (transverse) potential. Variational determination of the solution of the Schrödinger equation with cubic nonlinearities.	Lecture. Problem solving	4 hours
The analytical solution of Maxwell equations in a two- and three-dimensional numerical setup, in homogeneous environments.	Lecture. Problem solving	4 hours
Bibliography: 1. G.L. Squires, *Problems in quantum mechanics with solutions*, Cambridge University Press, 1995. 2. Y.-K. Lim, *Problems and solutions on electromagnetism*, World Scientific, 1993		
8.3 Laboratory	Teaching and learning techniques	Observations
Numerical solution of differential equations with Hamiltonian structure by simplectic and quasi-simplectic methods. Code in Octave/python/C/C ++	Supervised practical activity	4 hours
The numerical solution of the Schrödinger equation. Code in Octave/python/C/C ++	Supervised practical activity	4 hours
Numerical solution of Maxwell equations. Code in Octave/python/C/C++	Supervised practical activity	4 hours
Numerical solution of particle-in-cell equations. Observation of ultra-intense laser pulse interaction with gaseous and solid targets, wakefield acceleration. Use of EPOCH PIC code	Supervised practical activity	6 hours
Numerical solution of the Vlasov equation. Use of existing FORTRAN programs	Supervised practical activity	2 hours
Bibliography: 1. B. Leimkuhler și S. Reich, *Simulating Hamiltonian dynamics*, Cambridge University Press, 2004. 2. K.W. Morton și D.F. Mayers, *Numerical solution of partial differential equations*, Cambridge University Press, 2005. 3. Yu.N. Grigoryev *et al.*, *Numerical particle-in-cell methods: Theory and applications*, de Gruyter, 2002.		

8.4 Project	Teaching and learning techniques	Observations
Bibliography:		

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

In order to sketch the contents, to choose the teaching/learning methods, the coordinator of the course consulted the content of similar disciplines taught at Romanian universities and abroad. The content of the discipline is according to the requirements of employment in research institutes in physics and materials science, as well as in education (according to the law).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem-solving methods	Homework	10%
10.5.2 Laboratory	- Ability to use specific problem-solving methods	Homework	30%
10.5.3 Project			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date 10.06.2019	Teacher’s name and signature Assoc. Prof. Alexandru Nicolin, Lect. Dr. Roxana Zus	Practicals/Tutorials instructor(s) name(s) and signature(s) Dr. Mihai Marciu,

Date of approval

Head of Department

Prof. Virgil Băran

D0.204.2 Theory of intense laser radiation interaction with atomic and nuclear systems

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course title	Theory of intense laser radiation interaction with atomic and nuclear systems							
2.2. Teacher				Assoc. Prof. Mădălina Boca, Assoc. Prof. Alexandru Nicolin				
2.3. Tutorials instructor(s)								
2.4. Practicals instructor(s)				Assoc. Prof. Alexandru Nicolin				
2.5. Year of study	2	2.6. Semester	1	2.7. Type of evaluation	E	2.8. Type of course unit	Content[1)]	**DA**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**2**
3.2. Total hours per semester	**56**	Lecture	**28**	Practicals/Tutorials	**28**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**30**
3.2.2. Research in library, study of electronic resources, field research	**30**
3.2.3. Preparation for practicals/tutorials/projects/reports/homework	**30**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**90**
3.4. Total hours per semester	**150**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Programing languages, Quantum mechanics, Nuclear physics
4.2. competences	Working with software packages which do not require a license for data analysis and data processing

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Videoprojector
5.2. for practicals/tutorials	Scientific computing laboratory

6. Specific competences acquired

Professional competences	• Understanding the Boltzmann-Vlasov transport formalism. Understanding the test particle method which is used for the numerical solution of the Boltzmann-Vlasov equations. • Understanding the dynamics of electrically charged particles moving in an electromagnetic field from the numerical solution of transport equations • Understanding particle-in-cell methods and the self-consistent numerical treatment of field equations and those describing particle dynamics. • Understanding the numerical treatment of ordinary differential equations with Hamiltonian structure using leapfrog and related methods. Understanding time-reversibility and energy conservation.
Transversal competences	• Efficient use of scientific information resources and of communication and of resources for professional formation in English. • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Presentation of a large class of computational methods used to study the interaction of laser pulses with atomic and nuclear systems
7.2. Specific objectives	Study the general properties of atomic and nuclear systems Numerical study of the Boltzmann-Vlasov transport equations using the test particle method Numerical study of transport equations that describe the dynamics of electrically charged particles moving in an electromagnetic field Study of particle-in-cell methods that describe the dynamics of electrically charged particles in electromagnetic fields Study collective modes in atomic nuclei Study the interaction of laser pulses with metal clusters

8. Contents

8.1. Lecture	Teaching techniques	Observations/ hours
Fundamentals of atomic and nuclear systems	Systematic exposition - lecture. Examples	2 hours
Boltzmann-Vlasov and Boltzmann-Maxwell transport equations	Systematic exposition - lecture. Examples	4 hours
Test particle method for the numerical treatment of Vlasov-type equations. Derivation of particle-in-cell equations.	Systematic exposition - lecture. Examples	4 hours
Self-consistent numerical treatment of field equations and equations describing particle dynamics. Stability conditions.	Systematic exposition - lecture. Examples	4 hours
Numerical methods for equations which describe particle dynamics. Energy and phase-space volume conservation. Symplecticness.	Systematic exposition - lecture. Examples	4 hours
The interaction of intense laser radiation with atomic nuclei and metal clusters. Experimental and theoretical results.	Systematic exposition - lecture. Examples	8 hours
Presentation of future experiments at the European research infrastructure Extreme Light Infrastructure.	Systematic exposition - lecture. Examples	4 hours
Bibliography:		

1. P.M. Bellan, *Fundamentals of plasma physics*, Cambridge University Press, 2008.
2. P. Mulser și D. Bauer, *High power laser-matter interaction*, Springer, 2010.
3. B. Leimkuhler și S. Reich, *Simulating Hamiltonian dynamics*, Cambridge University Press, 2004.
4. P.G. Reinhard și E. Suraud, *Introduction to cluster dynamics*, Wiley-VCH, 2004.
5. K. Langanke, J.A. Maruhn și S.E. Koonin, Eds., *Computational Nuclear Physics 2. Nuclear Reactions*, Springer, 1993.
6. G.A. Mourou, G. Korn, W. Sandner și J.L. Collier, Eds., *ELI – Extreme Light Infrastructure. Whitebook. Science and technology with ultra-intense lasers*, 2011
7. F. Negoita *et al.*, *Laser driven nuclear physics at ELI-NP*, Rom. Rep. Phys. **68**, S37 (2016).
8. K. Homma *et al.*, *Combined laser gamma experiments at ELI-NP*, Rom. Rep. Phys. **68**, S233 (2016).

8.2. Tutorials	Teaching and learning techniques	Observations
Particular properties and solutions of the Boltzmann equation. Analytical calculations.	Lecture. Problem solving	6 hours
Particular properties and solutions of the Vlasov equation. Analytical calculations.	Lecture. Problem solving	8 hours

Bibliography:

1. G.M. Kremer, *An introduction to the Boltzmann equation and transport processes in gases*, Springer, 2010.
2. C. Cercignani, *The Boltzmann equation and its applications*, Springer, 1988.
3. P.M. Bellan, *Fundamentals of plasma physics*, Cambridge University Press, 2008.

8.3 Laboratory	Teaching and learning techniques	Observations
Numerical solution of differential equations with Hamiltonian structure by explicit, semi-implicit and implicit methods. Runge-Kutta methods. The leapfrog method. Time reversibility. Code in Octave/python/C/C++.	Supervised practical activity	6 hours
Numerical solution of Vlasov-type equations. Numerical determination of collective modes (especially pygmy dipole resonance and giant dipole resonance) in different atomic species and the numerical study of the interaction of laser pulses with metallic clusters. Use of existing numerical codes developed within the Department of Theoretical Physics and Mathematics, Optics, Plasma, Lasers.	Supervised practical activity	8 hours

Bibliography:

1. E. Hairer *et al.*, *Solving ordinary differential equations II. Stiff and differential-algebraic problems*, Springer, 1996.
2. P.G. Reinhard și E. Suraud, *Introduction to cluster dynamics*, Wiley-VCH, 2004.
3. K. Langanke, J.A. Maruhn și S.E. Koonin, Eds., *Computational Nuclear Physics 2. Nuclear Reactions*, Springer, 1993.

8.4 Project	Teaching and learning techniques	Observations

Bibliography:

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

In order to sketch the contents, to choose the teaching/learning methods, the coordinator of the course consulted the content of similar disciplines taught at Romanian universities and abroad. The content of the discipline is according to the requirements of employment in research institutes in physics and materials science, as well as in education (according to the law).

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test/oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem-solving methods	Homework	10%
10.5.2 Laboratory	- Ability to use specific problem-solving methods	Homework	30%
10.5.3 Project			
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
15.06.2019	Assoc. Prof. Alexandru Nicolin, Assoc. Prof. Mădălina Boca	Assoc. Prof. Alexandru Nicolin,

Date of approval

Head of Department

Prof. Virgil Băran

DO.207.1 Non-abelian gauge theories and standard model of elementary particles

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Non-abelian gauge theories and standard model of elementary particles							
2.2. Teacher				Prof. Dr. Virgil Baran/ Lecturer dr. Roxana Zus				
2.3. Tutorials/Practicals instructor(s)				Lecturer dr. Roxana Zus				
2.4. Year of study	II	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1)]	**DA**
							Type[2)]	**DO**

[1)] deepening (DA), speciality/fundamental (DS);
[2)] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**1/1**
3.2. Total hours per semester	**40**	Lecture	**20**	Practicals/Tutorials	**10/10**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one’s own course notes, manuals, lecture notes, bibliography	**25**
3.2.2. Research in library, study of electronic resources, field research	**25**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**31**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**81**
3.4. Total hours per semester	**125**
3.5. ECTS	**5**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum field theory, Electrodynamics, Theory of relativity, Nuclear physics
4.2. competences	Knowledge about: mechanics, algebra, quantum mechanics

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of the standard model • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum field theory, concepts, notions and problems in the area of theoretical particle physics and their interactions • Ability to use this knowledge in interpretation of experimental result and understand experiments at CERN; acquire the appropriate understanding of studied fundamental mechanisms
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding the foundations of structure of the matter: fundamental constituents and interactions between them; Understanding the structure of unified theory of interactions
7.2. Specific objectives	Acquire the skills to describe and calculate the physical properties of elementary particles and their interactions. Understanding the non-perturbative features of symmetry breaking in different situations.

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
Symmetries, interactions, local gauge transformations: SU(2) and SU(3) gauge group. Yang-Mills gauge theories.	Systematic exposition - lecture. Examples	2 hours
Weak interaction phenomenology	Systematic exposition - lecture. Examples	2 hours
The standard model of electro-weak interaction. Higgs boson.	Systematic exposition - lecture. Examples	6 hours
Fundamentals on quantum chromodynamics.	Systematic exposition - lecture. Examples	6 hours
Neutrino masses and neutrino oscillations.	Systematic exposition - lecture. Examples	4 hours
Bibliography: 1. M. Maggiore, *A modern introduction to Quantum Field Theory*, Oxford University Press, 2005. 2. M.E. Peskin, D.V. Schroeder *An Introduction to Quantum Field Theory*, Advanced Book Program, Addison-Wesley Publishing Company, 1995. 3. S. Weinberg, *The quantum theory of fields*, Vol. I and Vol. II Cambridge University Press, 2005. 4. F. Halzen, A. Martin, Quarks and Leptons, *An Introductory course in modern particle physics*		

John Wiley & Sons Inc., 1984

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
Path integrals in quantum mechanics and quantum field stheory	Problem solving	4 hours
Yang-Mills fields: path integral quantization	Problem solving	4 hours
Properties of Salam-Weinberg theory of leptons	Problem solving	4 hours
Ground state of QCD. QCD models.	Problem solving	4 hours
Grand unified theories	Problem solving	4 hours

Bibliography: 1. Voja Radovanovich, *Problem book in quantum field theory*, Springer, 2005
2.W. Greiner, B. Müller, *Gauge Theory of Weak Interactions*, Springer, 2009
3.W. Greiner, S. Schramm , E. Stein, *Quantum Chromodynamics*, Springer, 2007

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date 10.06.2019	Teacher's name and signature Prof. dr. Virgil Baran Lecturer dr. Roxana Zus	Practicals/Tutorials instructor(s) name(s) and signature(s) Lecturer dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran

DO.207.2 Theory of hadronic matter in extreme conditions and quark-gluon plasma

1. Study program

1.1. University	University of Bucharest
1.2. Faculty	Faculty of Physics
1.3. Department	Department of Theoretical Physics, Mathematics, Optics, Plasma and Lasers
1.4. Field of study	Physics
1.5. Course of study	Master of Science
1.6. Study program	Theoretical and Computational Physics (in English)
1.7. Study mode	Full-time study

2. Course unit

2.1. Course unit title	Theory of hadronic matter in extreme conditions and quark-gluon plasma							
2.2. Teacher				Prof. Dr. Virgil Baran/ Lecturer dr. Roxana Zus				
2.3. Tutorials/Practicals instructor(s)				Lecturer dr. Roxana Zus				
2.4. Year of study	II	2.5. Semester	2	2.6. Type of evaluation	E	2.7. Type of course unit	Content[1]	**DA**
							Type[2]	**DO**

[1] deepening (DA), speciality/fundamental (DS);
[2] compulsory (DI), elective (DO), optional (DFac)

3. Total estimated time (hours/semester)

3.1. Hours per week in curriculum	**4**	distribution: Lecture	**2**	Practicals/Tutorials	**1/1**
3.2. Total hours per semester	**40**	Lecture	**20**	Practicals/Tutorials	**10/10**

Distribution of estimated time for study	**hours**
3.2.1. Learning by using one's own course notes, manuals, lecture notes, bibliography	**25**
3.2.2. Research in library, study of electronic resources, field research	**25**
3.2.3. Preparation for practicals/tutorials/projects/reports/homeworks	**31**
3.2.4. Preparation for exam	**4**
3.2.5. Other activities	**0**

3.3. Total hours of individual study	**81**
3.4. Total hours per semester	**125**
3.5. ECTS	**6**

4. Prerequisites (if necessary)

4.1. curriculum	Quantum field theory, Statistical mechanics, Theory of relativity, Nuclear physics
4.2. competences	Knowledge about: electrodynamics, quantum mechanics

5. Conditions/Infrastructure (if necessary)

5.1. for lecture	Video projector
5.2. for practicals/tutorials	

6. Specific competences acquired

Professional competences	• Identify and proper use of the main physical laws and principles in a given context: the use of the concepts of the nuclear matter and quark-gluon plasma • Solving problems of physics under given conditions • Use of the physical principles and laws for solving theoretical or practical problems with qualified tutoring • Rigorous knowledge of quantum field theory, concepts, notions and problems in the area of particle physics • Ability to use this knowledge in interpretation of experimental result and understand experiments at CERN; acquire the appropriate understanding of studied fundamental mechanisms
Transversal competences	• Efficient use of sources of information and communication resources and training assistance in a foreign language • Efficient and responsible implementation of professional tasks, with observance of the laws, ethics and deontology.

7. Course objectives

7.1. General objective	Understanding the foundations of structure of the matter: fundamental constituents and interactions between them; Understanding the phase transitions of strongly interacting matter;
7.2. Specific objectives	Acquire the skills to describe and calculate the physical properties of quantum fields and their interactions. Understanding the transport phenomena in the presence of a spontaneously broken chiral symmetry and deconfinment mechanism. Development of the skill to apply mathematical models and numerical method for modelling various physical processes

8. Contents

8.1. Lecture [chapters]	Teaching techniques	Observations/ hours
The phase diagram of nuclear matter The properties of nuclear matter at finite temperature.	Systematic exposition - lecture. Examples	2 hours
The evolution of reaction mechanisms with the energy and centrality in heavy ions collisions.	Systematic exposition - lecture. Examples	2 hours
Nuclear multifragmentation and liquid-gas phase transitions in binary systems.	Systematic exposition - lecture. Examples	2 hours
The transition from hadronic matter to quark-gluon plasma.The quarks and irreducible representations of the SU(3) group. Classification of elementary particles in strong interaction	Systematic exposition - lecture. Examples	4 hours
Non-perturbative features of strongly interacting matter: deconfinement and spontaneous breaking of chiral symmetry. Order parameters for chiral phase transition and deconfinement phase transition. The vacuum structure.	Systematic exposition - lecture. Examples	4 hours
Analogies and differences between electromagnetic	Systematic exposition -	4 hours

and quark-gluon plasmas. Experimental signatures of transition to quark-gluon plasma at RHIC and LHC.	lecture. Examples	

Bibliography:

1. M. Maggiore, *A modern introduction to Quantum Field Theory*, Oxford University Press, 2005.
2. M.E. Peskin, D.V. Schroeder *An Introduction to Quantum Field Theory*, Advanced Book Program, Addison-Wesley Publishing Company, 1995.
3. N.N. Bogoliubov, D.V. Shirkov, *Introduction to The Theory of Quantized Fields*, John Wiley and Sons, 1980.
4. S. Weinberg, *The quantum theory of fields*, Vol. I and Vol. II Cambridge University Press, 2005.
5. V.B. Berestetskii, E.M. Lifshitz , L.P. Pitaevskii , *Quantum Electrodynamics*, Perg. Press, 1989.
6. T.D. Lee, *Particle Physics and Introduction to Field Theory*, Hardwood Academic, 1981.
7. A. Zee, *Quantum Field Theory in a Nutshell*, Princeton University Press,2003.

8.2. Tutorials [main themes]	Teaching and learning techniques	Observations/hours
The study of instabilities in asymmetric nuclear matter. The sigma-omega model of nuclear matter.	Problem solving	4 hours
Phenomenological models of the nucleon.	Problem solving	4 hours
Nambu-Jona-Lasinio model.	Problem solving	4 hours
The equation of state for quarks and gluons systems at finite density and temperature.	Problem solving	4 hours
The dynamics of quark-gluon plasma in transport models.	Problem solving	4 hours

Bibliography:

1. Voja Radovanovich, *Problem book in quantum field theory*, Springer, 2005
2. C. Itzykson and J.B. Zuber, *Quantum Field Theory*, McGraw-Hill, New York, 1980
3. M. Kaku, *Quantum Field Theory: A Modern Introduction*, Oxford University Press, 1993
4. F. Mandl and G. Show, *Quantum Field Theory*, New York, 1999

9. Compatibility of the course unit contents with the expectations of the representatives of epistemic communities, professional associations and employers (in the field of the study program)

This course unit develops some theoretical competences, which are fundamental for a Master student in the field of modern physics, corresponding to national and international standards. The contents is in line with the requirement of the main employers of research institutes and universities.

10. Assessment

Activity type	10.1. Assessment criteria	10.2. Assessment methods	10.3. Weight in final mark
10.4. Lecture	- Clarity and coherence of exposition - Correct use of the methods/ physical models - The ability to give specific examples	Written test and oral examination	60%
10.5.1. Tutorials	- Ability to use specific problem solving methods	Homeworks	40%
10.6. Minimal requirements for passing the exam			
Requirements for mark 5 (10 points scale) At least 50% of exam score and of homeworks.			

Date	Teacher's name and signature	Practicals/Tutorials instructor(s) name(s) and signature(s)
10.06.2019	Prof. dr. Virgil Baran Lecturer dr. Roxana Zus	Lecturer dr. Roxana Zus

Date of approval

Head of Department

Prof.dr. Virgil Baran