University of Debrecen
Faculty of Science and Technology
Institute of Chemistry

PHYSICIST MSC PROGRAM

2021

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DEAN`S WELCOME

Welcome to the Faculty of Science and Technology!

This is an exciting time for you, and I encourage you to take advantage of all that the Faculty of Science and Technology UD offers you during your bachelor's or master's studies. I hope that your time here will be both academically productive and personally rewarding

Being a regional centre for research, development and innovation, our Faculty has always regarded training highly qualified professionals as a priority. Since the establishment of the Faculty in 1949, we have traditionally been teaching and working in all aspects of Science and have been preparing students for the challenges of teaching. Our internationally renowned research teams guarantee that all students gain a high quality of expertise and knowledge. Students can also take part in research and development work, guided by professors with vast international experience.

While proud of our traditions, we seek continuous improvement, keeping in tune with the challenges of the modern age. To meet our region's demand for professionals, we offer engineering courses with a strong scientific basis, thus expanding our training spectrum in the field of technology. Recently, we successfully re-introduced dual training programmes in our constantly evolving engineering courses.

We are committed to providing our students with valuable knowledge and professional work experience, so that they can enter the job market with competitive degrees. To ensure this, we maintain a close relationship with the most important companies in our extended region. The basis for our network of industrial relationships are in our off-site departments at various different companies, through which market participants - future employers - are also included in the development and training of our students.

Prof. dr. Ferenc Kun
Dean

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UNIVERSITY OF DEBRECEN

Date of foundation: 1912 Hungarian Royal University of Sciences, 2000 University of Debrecen

Legal predecessors: Debrecen University of Agricultural Sciences; Debrecen Medical University; Wargha István College of Education, Hajdúböszörmény; Kossuth Lajos University of Arts and Sciences

Number of Faculties at the University of Debrecen: 14

Faculty of Agricultural and Food Sciences and Environmental Management

Faculty of Child and Special Needs Education

Faculty of Dentistry

Faculty of Economics and Business

Faculty of Engineering

Faculty of Health

Faculty of Humanities

Faculty of Informatics

Faculty of Law

Faculty of Medicine

Faculty of Music

Faculty of Pharmacy

Faculty of Public Health

Faculty of Science and Technology

Number of students at the University of Debrecen: 29,045

Full time teachers of the University of Debrecen: 1,541

200 full university professors and 1,205 lecturers with a PhD.

FACULTY OF SCIENCE AND TECHNOLOGY

The Faculty of Science and Technology is currently one of the largest faculties of the University of Debrecen with about 3000 students and more than 200 staff members. The Faculty has got 6 institutes: Institute of Biology and Ecology, Institute of Biotechnology, Institute of Chemistry, Institute of Earth Sciences, Institute of Physics and Institute of Mathematics. The Faculty has a very wide scope of education dominated by science and technology (10 Bachelor programs and 12 Master programs), additionally it has a significant variety of teachers' training programs. Our teaching activities are based on a strong academic and industrial background, where highly qualified teachers with a scientific degree involve student in research and development projects as part of their curriculum. We are proud of our scientific excellence and of the application-oriented teaching programs with a strong industrial support. The number of international students of our faculty is continuously growing (currently 649 students). The attractiveness of our education is indicated by the popularity of the Faculty in terms of incoming Erasmus students, as well.

THE ORGANIZATIONAL STRUCTURE OF THE FACULTY

Dean: Prof. Dr. Ferenc Kun, Full Professor
E-mail: ttkdekan@science.unideb.hu

Vice Dean for Educational Affairs: Prof. Dr. Gábor Kozma, Full Professor
E-mail: kozma.gabor@science.unideb.hu

Vice Dean for Scientific Affairs: Prof. Dr. Sándor Kéki, Full Professor
E-mail: keki.sandor@science.unideb.hu

Consultant on External Relationships: Prof. Dr. Attila Bérczes, Full Professor
E-mail: berczesa@science.unideb.hu

Dean's Office
Head of Dean's Office: Ms. Katalin Tóth
E-mail: toth.katalin@science.unideb.hu

English Program Officer: Mr. Imre Varga – Applied Mathematics (MSc), Chemical Engineering (BSc/MSc), Chemistry (BSc/MSc), Earth Sciences (BSc), Electrical Engineering (BSc), Geography (BSc/MSc), Mathematics (BSc), Physics (BSc), Physicist (MSc), International Foundation Year, Intensive Foundation Semester
Address: 4032 Egyetem tér 1., Chemistry Building, A/101
E-mail: vargaimre@unideb.hu

English Program Officer: Mrs. Szilvia Gyulainé Szemerédi – Biochemical Engineering (BSc), Biology (BSc/MSc), Envirionmental Science (MSc), Hidrobiology Water Quality Management (MSc)
Address: 4032 Egyetem tér 1., Chemistry Building, A/104
E-mail: szemeredi.szilvia@science.unideb.hu

DEPARTMENTS OF INSTITUTE OF PHYSICS

Department of Experimental Physics (home page: http://indykfi.phys.klte.hu/kisfiz/)
4026 Debrecen, Bem tér 18/a,

Name	Position	E-mail	room
Mr. Prof. Dr. Zoltán Trócsányi, PhD, habil, DSc, Member of HAS	University Professor, Head of Department	zoltan.trocsanyi@science.unideb.hu	F21
Mr. Dr. István Nándori, PhD, habil	Associate Professor	nandori.istvan@science.unideb.hu	F11
Mr. Dr. Gyula Zilizi, PhD, habil	Associate Professor	zilizi@science.unideb.hu	E207
Mr. Dr. István Csarnovics, PhD	Assistant Professor	csarnovics.istvan@science.unideb.hu	E214
Ms. Dr. Judit Darai, PhD, habil	Associate Professor	darai@science.unideb.hu	E116
Mr. Dr. Sándor Egri, PhD	Assistant Professor	egris@science.unideb.hu	E209
Mr. Dr. László Oláh, PhD	Assistant Professor	olah.laszlo@science.unideb.hu	E115
Mr. Dr. Balázs Ujvári, PhD	Assistant Professor	balazs.ujvari@science.unideb.hu	E209
Mr. Bence Godó	Assistant Lecturer	godo.bence@science.unideb.hu	E201

Department of Theoretical Physics (home page: http://www.phys.unideb.hu/dtp/)
4026 Debrecen, Bem tér 18/b

Name	Position	E-mail	room
Ms. Prof. Dr. Ágnes Vibók, PhD, habil, DSc	University Professor, Head of Department	vibok.agnes@science.unideb.hu	E2
Mr. Prof. Dr. Ferenc Kun, PhD, habil, DSc, Member of HAS	University Professor	ferenc.kun@science.unideb.hu	E1
Mr. Dr. Sándor Nagy, PhD, habil	Associate Professor	sandor.nagy@science.unideb.hu	E3
Mr. Dr. András Csehi, PhD	Assistant Professor	csehi.andras@science.unideb.hu	F10
Mr. Prof. Zsolt Gulácsi, PhD, habil, DSc	University Professor	zsolt.gulacsi@science.unideb.hu	E9
Mr. Dr. Zsolt Schram, PhD habil	Associate Professor,	schram@unideb.hu	E4
Mr. Dr. Gergő Pál, PhD	Assistant Professor	gergo.pal@phys.unideb.hu	
Mr. Dr. Péter Badankó, PhD	Research Assistant	badanko.peter@gmail.com	

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4026 Debrecen, Bem tér 18/b

Name	Position	E-mail	room
Mr. Prof. Dr. Zoltán Erdélyi, PhD, habil, DSc	University Professor, Head of Department	zoltan.erdelyi@science.unideb.hu	E8
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Mr. Dr. Gábor Katona, PhD	Assistant Professor	gabor.katona@science.unideb.hu	F2
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Mr. János Tomán,	Assistant Lecturer	janos.toman@science.unideb.hu	F10
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Mr. Dr. István Szabó, PhD, habil	Associate Professor, Head of the Institute	istvan.szabo@science.unideb.hu	F20
Mr. László Tóth,	Assistant Lecturer		F2
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Mr. Lajos Harasztosi	Teacher of engineering	lajos.harasztosi@science.unideb.hu	F9

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Mr. Dr. János Kósa, PhD	Assistant Professor	kosa.janosarpad@science.unideb.hu	U5/A
Mr. Dr. Sándor Misák, PhD	College Associate Professor	misak@science.unideb.hu	E214
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Mr. András Mucsi	Teacher of engineering	mucsi.andras@science.unideb.hu	
Mr. Zsolt Szabó	Teacher of engineering	szabo.zsolt@science.unideb.hu	

Department of Enviromental Physics (home page: http://w3.atomki.hu/deat/)
4026 Debrecen, Bem tér 18/c

Name	Position	E-mail	room
Dr. István Csige, PhD, habil	Associate Professor head of department	csige@science.unideb.hu	
Dr. Eszter Baradács, PhD	Assistant Professor	baradacs@science.unideb.hu	
Dr. Zoltán Papp, PhD, habil	Associate Professor	zpapp@science.unideb.hu	

ACADEMIC CALENDAR

General structure of the academic semester (2 semesters/year):

Study period	1st week	Registration*	1 week
	2nd – 15th week	Teaching period	14 weeks
Exam period	directly after the study period	Exams	7 weeks

*Usually, registration is scheduled for the first week of September in the fall semester, and for the first week of February in the spring semester.

For further information please check the following link:

https://www.edu.unideb.hu/tartalom/downloads/University_Calendars_2021_22/University_calendar_2021-2022-Faculty_of_Science_and_Technology.pdf?_ga=2.196279020.1315409739.1629100510-488342717.1574682820

THE PHYSICIST MASTER PROGRAM

Information about the Program

Name of MSc Program:	Physicist MSc Program
Specialization available:	
Field, branch:	Science
Qualification:	Physicist
Mode of attendance:	Full-time
Faculty, Institute:	Faculty of Science and Technology Institute of Physics
Program coordinator:	Prof. Dr. Ágnes Vibók, University Professor
Duration:	4 semesters
ECTS Credits:	120

Objectives of the MSc program:

The objective of the programme is to train physicist, who is able to realize physical principles in natural phenomena, to perform their experimental investigation according to scientific standards, and to obtain the theoretical understanding. The training enables her/him to develop and operate industrial, IT, and measuring systems related to physical laws and high technology processes. The student is able to continuously broaden her/his knowledge and has the aptitude for continuing her/his studies in the framework of doctoral studies.

Professional competences to be acquired

A Physicist:

a) Knowledge:

- Is familiar with the theoretical and practical knowledge of the major topics of physics in the context and in the system level.
- Knowledge in field, laboratory and technical materials, instruments and methods of physics for high level practical work.
- Being familiar with high-level methods of scientific research, self-education and communication.
- Acquainted with the limitations and possible research directions in modern physics.
- Having a high level of knowledge of natural sciences and the elements of the practice that builds on it, and can systematize them.
- Knows the field, the laboratory, and the practical tools and methods related to physics, that enables him/her to perform a professional level work.

- Has a deep and thorough professional knowledge, which needs to solve problems related to natural processes, to natural resources, and to live and inanimate systems.
- Knows in its context the scientific problems, and the projects and systems, that can be treated.
- Familiar with the concepts and the terminology of modern physics and understands recent articles in the literature.

b) Abilities:

- Is able to realize physical principles in natural phenomena, to perform their experimental investigation according to scientific standards, and to obtain theoretical understanding.
- Is able to join research groups to perform both basic and applied physics research.
- Is able to develop and operate industrial, IT, and measuring systems related to physical laws and high technology processes.
- Is able to use information technology in physics.
- With regular professional self-education, he/she is able to elaborate the new scientific results of physics, and apply them creatively in his/her research.
- Is able to test the projects and systems, that can be treated in his/her research field, with such methods that are accepted in phyics.
- Ability for planning, implementation and evaluation of experiments based on comprehensíve knowledge attained in physics.
- Is able to ask questions about physics and related topics.
- Is able to continuously broaden her/his knowledge and has the aptitude for continuing her/his studies in the framework of doctoral studies.
- His/her knowledge and problem solving skills acquired during his/her education make him/her capable of doing independent and leader works in further fields, that use the scientific results and methods of physics (administration, environmental protection, etc.).

c) Attitude:

- Basic gained properties are creativity, flexibility, problems recognizing and solving ability, intuition, systematic data processing ability.
- Seeks to familiarize herself/himself with new developments of modern physics and pursues the application of those developments in broad contexts.
- Able to distinguish well-established science from statements unsupported scientifically.
- He/she is characterized by the sensitivity to the environment, the positive attitude for the vocational training, and commitment for the quality work.
- Has ability for initiation, decision-making, and personal responsibility.
- Actively collaborates with his/her colleagues, contributes to teamwork in a constructive way, is able to assume leadership duties with sufficient experience.
- Able to explain the open questions of his field to experts as well as laymen.
- Constantly striving to expand his/her knowledge and acquire new skills.

d) Autonomy and responsibility:

- Shows a large degree of independence in formulating his/her professional views on both broad and specialized topics of modern physics, as well as in the justification and representation of his/her professional views.

- Awares and takes responsibility for the scientific worldview.
- Based on his/her high level knowledge of physics, and on his/her critical and system level way of thinking, he/she can cooperate with the representatives of his/her own or other scientific areas in a responsible way.
- He/she is environmentally conscious during field and laboratory activities.
- Performs scientific research with the highest level of ethical standards.
- Forms his/her opinion awaring of the importance of the scientific thinking and conceptualization.

Completion of the MSc Program

The Credit System

Majors in the Hungarian Education System have generally been instituted and ruled by the Act of Parliament under the Higher Education Act. The higher education system meets the qualifications of the Bologna Process that defines the qualifications in terms of learning outcomes: statements of what students know and can do on completing their degrees. In describing the cycles, the framework uses the European Credit Transfer and Accumulation System (ECTS).

ECTS was developed as an instrument of improving academic recognition throughout the European Universities by means of effective and general mechanisms. ECTS serves as a model of academic recognition, as it provides greater transparency of study programs and student achievement. ECTS in no way regulates the content, structure and/or equivalence of study programs.

Regarding each major the Higher Education Act prescribes which professional fields define a certain training program. It contains the proportion of the subject groups: natural sciences, economics and humanities, subject-related subjects and differentiated field-specific subjects.

During the program students have to complete a total amount of 120 credit points. It means approximately 30 credits per semester. The curriculum contains the list of subjects (with credit points) and the recommended order of completing subjects which takes into account the prerequisite(s) of each subject. You can find the recommended list of subjects/semesters in chapter "Model Curriculum of Environmental Science MSc Program".

Requirements

The unit of measurement of academic requirements is the academic point (credit). Credits are used for evaluating the performance of education duties of students in programme. Students shall complete a total of at least 120 credits during the entire programme.

Precondition for taking the state exam for MSc students is to prepare the thesis which is the creative elaboration of a research task in written form as defined in the requirements of the training program. Students will finish their studies in the Physicist MSc program by taking the state exam which consists of two parts. On the one hand students have to present the most important elements of their thesis and have to defend it in the form of answering the questions of the state exam board. On the other hand, they have to take the oral exam on the same day.

Professional features

Students have to take 120 credits:

- 4-16 credits of general knowledge from the fields of mathematics, informatics;
- 20-30 credits of general knowledge in the fields of modern physics (6 credits maximum from atomic and molecular physics, condensed matter physics, statistical physics, 9 credits maximum form nuclear and particle physics, 8 credits maximum from advanced laboratory courses);
- 30-60 credits of specialized knowledge in modern physics;
- 30 credits of thesis;
- 6 credits of optional subjects of the faculty;
- the compulsory vocational courses are divided into four blocks of 15-15 credits each.

Model curriculum of Physicist MSc

Knowledge elements, lectures and lecturers	semesters				ECTS credit points	evaluation
	1.	2.	3.	4.		
	contact hours, types of teaching (l – lecture, s – seminar, p – practice, c – consultation, lab – laboratory)					
Basic knowledge elements						
Quantum mechanics – Statistical physics – Particle physics knowledge elements						
1. Quantum mechanics 2. Dr. Sándor Nagy	28l, 14p/4cr				4	exam
2. Statistical physics 2. Dr. Ferenc Kun	28l, 14p/4cr				4	exam
3. Particle physics 1. Dr. Zoltán Trócsányi	28l, 14p/4cr				4	exam
Environmental Physics – Atomic and molecular physics – Condensed matter knowledge elements						
1. Laboratory of environmental physics Dr. Zoltán Papp	42lab/4cr				4	mid-semester grade
2. Atomic and molecular physics I Dr. András Csehi	28l, 14p/4cr				4	exam
3. Condensed matter 3. Dr. Erdélyi Zoltán	28l, 14p/4cr				4	exam

Knowledge elements of the modules						
Fundamental interactions (Dr. Zoltán Trócsányi)						
1. Theory of relativity Dr. Zsolt Schram		28l, 14p/5cr			5	exam
2. Quantum field theory Dr. Gábor Somogyi		28l, 14p/6cr			6	exam
3. Particle physics 2. Dr. Zoltán Trócsányi			28l, 14p/4cr		4	exam
4. Standard model Dr. Zoltán Trócsányi			28l, 14p/4cr		4	exam
Atomic and molecular physics and és quantum informatics (Dr. Ágnes Vibók)						
1. Electronic structure methods and quantum dynamics Dr. Ágnes Vibók		28l, 14p/5cr			5	exam
2. Atoms and molecules in electromagnetic field Dr. Ágnes Vibók			28l, 14p/5cr		5	exam
3. Quantum Informatics Dr. Sándor Nagy			28l, 14p/5cr		5	exam

4. Quantum computers and algorithms Dr. Zsolt Gulácsi				28l, 14p/5cr	5	exam
5. Atomic and molecular physics II Dr. András Csehi		28l, 14p/5cr			5	exam
Complex systems and statistical physics (Dr. Ferenc Kun)						
1. Physics of complex systems Dr. Ferenc Kun			28l, 14p/5cr		5	exam
2. Computer modelling Dr. Ferenc Kun		28l, 14p/5cr			5	exam
3. Phase transitions and critical phenomena 1. Dr. Zsolt Gulácsi		28l, 14p/5cr			5	exam
4. Complex networks and applications Dr. Sándor Nagy		28l, 14p/5cr			5	exam
Condensed matter (Dr. Zoltán Erdélyi)						
1. Nanodiffusion and segregation Dr. Zoltán Erdélyi		28ea/3cr			3	exam
2. Computer simulation Dr. Zoltán Erdélyi			14l, 42lab/5cr		5	mid-semester grade
3. Magnetism and nanomagnetism KV Dr. Lajos Daróczi				28l,14p, 14 lab/5cr	5	exam
4. Measurement of materials properties Dr. Csaba Cserháti		28lab/2cr			2	mid-semester grade
5. Transmission and analytical electronmicroscopy Dr. Csaba Cserháti			28l,14p, 14lab/5cr		5	exam
Environmental Physics (Dr. István Csige)						
1. Environmental Physics 3. Dr. Erdélyiné Dr. Eszter Baradács			28l, 14p/4cr		4	exam
2. Simulation of environmental processes Dr. Erdélyiné Dr. Eszter Baradács			28l, 14p/4cr		4	exam
3. Radiation Protection and Dosimetry Dr. Zoltán Papp		28l, 14lab/4cr			4	exam

4. Physics of the atmosphere Dr. István Csige		28ea/3cr			3	exam
5. Measurements in Environmental Physics Dr. Zoltán Papp		28lab/2cr			2	mid-semester grade
6. Nuclear analytical methods in environmental research Dr. Mihály Molnár			28ea/3cr		3	exam
Nuclear physics (Dr. Judit Darai)						
1. Advanced Nuclear Physics Dr. Judit Darai			28l, 14p/4cr		4	exam
2. Nuclear Technology Dr. László Oláh			28l, 14p/4cr		4	exam
3. Nuclear Astrophysics Dr. Zsolt Fülöp		28ea/3cr			3	exam
4. Nuclear physics laboratory Dr. Balázs Ujvári		56lab/4cr			4	mid-semester grade
5. Insight into the present day nuclear research Dr. Judit Darai			28l, 14p/4cr		4	exam
Quantum mechanical many-body systems (Dr. Zsolt Gulácsi)						
1. Quasiparticles in solid state phyiscs Dr. István Nándori		28l, 14p, 14lab/5cr			5	exam
2. Condensed matter physics 4. Dr. Zsolt Gulácsi		28l, 14p/5cr			5	exam
3. Quantum mechanical many-body physics I Dr. Gulácsi Zsolt			28l, 14p/5cr		5	exam
4. Basics of Functional Renormalization Group Method Dr. István Nándori				28l, 14p/5cr	5	exam

Diploma work			15p/10 cr	30p/20cr	30	mid-semester grade

Work and Fire Safety Course

According to the Rules and Regulations of University of Debrecen a student has to complete the online course for work and fire safety. Registration for the course and completion are necessary for graduation.
Registration in the Neptun system by the subject: MUNKAVEDELEM
Students have to read an online material until the end to get the signature on Neptun for the completion of the course. The link of the online course is available on webpage of the Faculty.

Physical Education

According to the Rules and Regulations of University of Debrecen a student has to complete Physical Education courses at least in one semester during his/her Master's training. Our University offers a wide range of facilities to complete them.

Pre-degree Certification

A pre-degree certificate is issued by the Faculty after completion of the master's (MSc) program. The pre-degree certificate can be issued if the student has successfully completed the study and exam requirements as set out in the curriculum, the requirements relating to Physical Education as set out in Section 10 in Rules and Regulations, internship (mandatory) – with the exception of preparing thesis – and gained the necessary credit points (120). The pre-degree certificate verifies (without any mention of assessment or grades) that the student has fulfilled all the necessary study and exam requirements defined in the curriculum and the requirements for Physical Education. Students who obtained the pre-degree certificate can submit the thesis and take the final exam.

Final exam

Objectives*:*
The professional competencies and knowledge of the student is evaluated. The graduate needs to demonstrate proficiency in physics and the ability to perform high level problems in physics independently. The preparedness for professional debates also needs to be shown.

Requirements*:*
In order to participate in the final exam, the student needs to satisfy all formal and informal requirements. Thus, a minimum of 120 credits need to be earned. Further requirement is the submission of a thesis covering the diploma work of the graduate well before the final exam.

The diploma work
It is based on the independent research activity of the student under the guidance of the supervisor. Students have to choose a topic for their diploma work in the 2nd semester. They have to write it in two semesters. The thesis should be more than 25 pages. The cover page has to contain the name of the institute, the title of the thesis, the name and the degree program of the student, the name and the

university rank of the supervisor. Besides the detailed discussion of the topic, the thesis should contain an introduction, a table of contents and a bibliography. The thesis has to be defended in the final exam.

The final exam

The final exam has two parts. First, the thesis based on the diploma work is presented in front of the examining committee. The graduating student gives a lecture, answers the remarks of the reviewer and the questions of the committee and the audience. In the second part, the student must demonstrate her/his knowledge in physics at the masters level. There are the following groups of questions:

A: fundamental topics
B: module topics

Final Exam Board

Board chair and its members are selected from the acknowledged internal and external experts of the professional field. Traditionally, it is the chair and in case of his/her absence or indisposition the vice-chair who will be called upon, as well. The board consists of – besides the chair – at least two members (one of them is an external expert), and questioners as required. The mandate of a Final Examination Board lasts for one year.

Repeating a failed Final Exam

If any part of the final exam is failed it can be repeated according to the rules and regulations. A final exam can be retaken in the forthcoming final exam period. If the Board qualified the Thesis unsatisfactory a student cannot take the final exam and he has to make a new thesis. A repeated final exam can be taken twice on each subject.

Diploma

The diploma is an official document decorated with the coat of arms of Hungary which verifies the successful completion of studies in the Physicist Master Program. It contains the following data: name of HEI (higher education institution); institutional identification number; serial number of diploma; name of diploma holder; date and place of his/her birth; level of qualification; training program; specialization; mode of attendance; place, day, month and year issued. Furthermore, it has to contain the rector's (or vice-rector's) original signature and the seal of HEI. The University keeps a record of the diplomas issued.

In the Physicist Master Program the diploma grade is calculated as the average grade of the results of the followings:

- Weighted average of the overall studies at the program (A)
- Average of grades of the thesis and its defense given by the Final Exam Board (B)
- Average of the grades received at the Final Exam for the two subjects (C)

Diploma grade = (A + B + C)/3

Classification of the award on the bases of the calculated average:

Excellent	4.81 – 5.00
Very good	4.51 – 4.80
Good	3.51 – 4.50
Satisfactory	2.51 – 3.50
Pass	2.00 – 2.50

Course Descriptions of Physicist MSc Program

Title of course: Quantum Mechanics 2 **Code**: TTFME0102	**ECTS Credit points:** 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Addition of angular momenta. Quantum statistical mechanics. Classical limit, WKB approximation. Time-independent perturbation theory, nondegenerate and degenerate cases. Variational methods. Time-dependent perturbation theory. The Lippmann-Schwinger equation, Born approximation, optical theorem. Resonance scattering. Discrete and continuous symmetries, identical particles. Propagators, transition amplitude. Path integral in quantum mechanics. Relativistic quantum mechanics, Dirac equation, Lorentz symmetry. The solution of the Dirac equation for free particles.

Literature

Compulsory:
J. J. Sakurai, Modern Quantum Mechanics (Addison-Wesley, 2011)
Recommended:
James D. Björken, Sidney D. Drell, Relativistic Quantum Mechanics (McGraw-Hill, 1964)

Schedule:

1st week

Addition of angular momenta, the Clebsch-Gordan coefficients.

2nd week

Quantum statistical mechanics, canonical and grand canonical ensembles.

3rd week

Interpretations of the wave function, classical limit, semiclassical (WKB) approximation.

4th week

Time-independent perturbation theory, nondegenerate case. Wave function renormalization.

5th week

Time-independent perturbation theory, degenerate case. Variational methods.

6th week

Time-dependent perturbation theory, interaction picture, Dyson series. Transition probability, Fermi's golden rule.

7th week

The Lippmann-Schwinger equation, Born approximation, optical theorem.

8th week

Method of partial waves. Resonance scattering.

9th week

Discrete symmetries: parity, time-reversal symmetry. Continuous symmetries, conservation laws.

10th week

Propagators, transition amplitude.

11th week

Feynman's path integrals in quantum mechanics.

12th week

Potentials and gauge transformations, Aharonov-Bohm effect, gravity in quantum mechanics.

13th week

Relativistic quantum mechanics. Dirac equation, Lorentz symmetry.

14th week

The solution of the Dirac equation for free particles. Non-relativistic limit, Foldy-Wouthuysen transformation.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Sándor Nagy, associate professor, PhD

Lecturer: Dr. Sándor Nagy, associate professor, PhD

Title of course: Statistical physics 2
Code: TTFME0103

ECTS Credit points: 4

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Fluctuations in thermal equilibrium. Time dependent fluctuations, correlation functions, spatial correlation of fluctuations. Spectral decomposition, the spectral density. Wiener-Hinchin theorem.

Correlations and response functions. The generalized susceptibility and its relation to equilibrium fluctuations. Fluctuation-dissipation theorem. The theory of linear response.

Linear transport, transport coefficients, entropy production. Electric and heat conduction, Fick laws. Cross effects, Seebeck- and Peltier-effects, the Thomson relation. Onsager's regression hypothesis, microscopic reversibility, Onsager's reciprocity relations.

Brownian motion, random walk. Einstein-model. Smoluchowski description. Diffusion, Fick's laws. Conduction phenomena in terms of Brownian motion, Nyquist-noise.

Diffusion processes, Fokker–Planck-equation. Langevin-equation, Ornstein–Uhlenbeck-process. Fluctuation-dissipation theorem and its physical consequences.

Master equation, stationary solutions. Relation of the Master equation to Monte Carlo simulations methods.

Boltzmann transport equation, collision integral. Electric conduction in classical ideal gases.

Literature

Compulsory:
Sailer Kornél, Statisztikus fizika 2. (egyetemi jegyzet, Debreceni Egyetem).
R. Kubo, M. Toda, and N. Hashitsume, Statistical Physics II – Nonequilibrium Statistical Mechanics (Springer Verlag, Heidelberg, 1985).
P.L. Krapivsky, S. Redner, and E. Ben-Naim, A Kinetic View of Statistical Physics (Cambridge University Press, 2010).

Schedule:

1st week

Basics of equilibrium statistical physics. Ensembles, statistical averages. Fluctuation of the energy, size dependence of fluctuations. Equivalence of ensembles.

2nd week

Spectral decomposition of fluctuations, power spectrum and the spectral density. The Wiener-Hinchin-theorem.

3rd week

Correlations and response functions. Generalized susceptibility. Fluctuation-dissipation theorem.

4th week

Theory of linear response. Linear transport, transport coefficients. Electric and heat conduction, Fick laws. Cross effects, Seebeck- and Peltier-effects, Thomson relation.

5th week

Onsager's regression hypothesis, microscopic reversibility, Onsager's reciprocity law.

6th week

Brownian motion, Einstein-model. Diffusion. Smoluchowski description. Conduction phenomena in terms of Brownian motion, Nyquist-noise.

7th week

Generalized random walks, Levy flights. Anomalous diffusion.

8th week

Diffusion processes, Fokker–Planck-equation, Wiener-process, Gaussian white noise.

9th week

Langevin-equation and its solutions, equivalent Fokker–Planck-equation. Ornstein–Uhlenbeck-process.

10th week

Fluctuation-dissipation theorem and its consequences. Applications of the Langevine equation.

11th week

Master equation, stationary solutions. Relation of the Master equation to Monte Carlo simulations methods.

12th week

Applications of the Master equation. Aggregation phenomena, gelation. Fragmentation processes. Growing complex networks. Time evolution and stationary solutions.

13th week

Boltzmann-transport equation, collisional integral. Electric conduction of the classical ideal gas. H-theorem and its relation to the entropy.

14th week

Applications of the Boltzmann-equation for simple problems: Dissipative gases of granular materials, inelastic collapse, driven dissipative gases. Ballistic agglomeration. Single lane traffic problems, emergence of traffic jams on highways.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful completion of all the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Ferenc Kun, professor, PhD

Lecturer: Dr. Ferenc Kun, professor, PhD

Title of course: Particle Physics 1
Code: TTFME0104

ECTS Credit points: 4

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Symmetries and particles. Static quark model. Free fermion. Experimental verification of quark model. Particle accelerators. Particle detectors. Event registration. Basic experiments (parity violation, anomalous magnetic moment). CP, CPT and kaons. Neutrino experiments. Medical applications. Basics of cosmology.

Literature

Compulsory:
Dezső Horváth and Zoltán Trócsányi: Intorduction to Particle Physics, Cambridge Scholars Publishing, 2019.
Recommended:
Donald H. Perkins: Introduction to High Energy Physics, Addison-Wesley, Menlo Park, USA

Francis Halzen and Alan D.~Martin: Quarks and Leptons. An Introductory Course in Modern Particle Physics, John Wiley and Sons, New York.

Schedule:

1st week

Structure and details of the course, recommended literature and the available information on the web.

2nd week

Fermions and bosons, leptons and hadrons. Interactions and medating bosons. Symmetries and conserved quantities, Noether's theorems. Particle reactions and Feynman diagrams. Spin, isospin and SU(2) symmetry. Strangeness, SU(3) and the first three quarks.

3rd week

Coloured quarks. SU(3) algebra. Basics of quantum colour dynamics (QCD). Hadrons, mesons and baryons. Quark multiplets and excited states.

4th week

Covariant formalism. Dirac equation and Lagrange functions. U(1) invariance, fermion current and continuity. Nucleon as quark atom. Magnetic moment of the neutron.

5th week

Cross section, resonance. Invariant mass. Width of the Z boson and the three fermion families. The fractional charge and colours of quarks. Overview of the quark model.

6th week

Accelerator types. Storage rings, beam cooling. CERN's accelerator complex. Penetration of charged particles in matter.

7th week

Multiwire chambers, scintillator and Cherenkov detectors. Transition radiation. Overview and comparison of the detector types. Structure of the CMS detector at the LHC.

8th week

Particle identification. Detector calibration. Event registration and trigger logic. OPAL detector and characteristic event types at LEP. Collider Detector at Fermilab and its strange events. LHC: Observation of the Higgs boson.

9th week

Mirror symmetries. Discovery of parity violation. Muon spin resonance and its applications. Renormalisation of electromagnetic charge. Anomalous magnetic moment of the muon. Measuring $(g - 2)_\mu$: CERN → BNL → FNAL.

10th week

CP and CPT . Kaon regeneration, strangeness oscillation. Indirect and direct CP violation. Tests of CPT invariance.

11th week

Neutrino production. The Reines-Cowan experiment. Neutrino oscillation. Modern experiments: Super-kamiokande, SNO, Ice Cube, Daya Bay. The LSND mystery. Long distance experiments. How many neutrinos? Neutrino problems and mysteries.

12th week

Particle physics applications: basic research vs. applications. Medical diagnostics using particle accelerators. Isotope therapy and diagnosis. Accelerator therapy, hadron therapy.

13th week

Expanding universe, cosmologic principle. Big bang and inflation. Cosmic background radiation. Satellite observatories: COBE, WMAP, Planck and Hubble telescope. Dark matter and dark energy. Gravitational waves. Big bang and religion.

14th week

Overview, discussion session.

Requirements:
- for a signature
Attendance at **lectures** is recommended, but not compulsory.
Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.
During the semester there are practical home works. The requirement for a signature is a successful (> 50%) completion of the home works.
- for a grade
The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature. The examination starts with a quiz: 8-12 questions with multiple choice answers. The students should be able to explain the chosen answers.
Scoring above 50%: *satisfactory,*
above 75%: *average,*
in addition, the explanations are correct as well: *good*,
in addition, the interpretation of the knowledge is correct: *excellent*.

Person responsible for course: Dr. Zoltán Trócsányi, professor, PhD

Lecturer: Dr. Dezső Horváth, professor, PhD

Title of course: Laboratory of Environmental Physics
Code: TTFML0106

ECTS Credit points: 4

Type of teaching, contact hours
- lecture: -
- practice: -
- laboratory: 4 hours/week

Evaluation: grade for written laboratory record

Workload (estimated), divided into contact hours:
- lecture: -
- practice: -
- laboratory: 56 hours
- home assignment: 28 hours
- preparation for the exam: -

Total: 84 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Determination of gamma-emitting radionuclides in soil (3x4 hours). Measurement of ambient alpha radioactivity by solid state nuclear track detector (2x4 hours). Measurement of tritium concentration of environmental water samples by 3He method (3x4 hours). Radiocarbon dating and environmental research (2x4 hours). Sampling and analysis by PIXE method of atmospheric aerosols (2x4 hours). Measurement of stable isotope ratios by mass spectrometric method (2x4 hours). K-Ar dating (2x4 hours). X-ray fluorescence analysis of environmental samples (2x4 hours). Determination of the airborne concentrations of radon and radon progeny in different environments (2x4 hours).

The content of the course in the given academic year is determined and announced by the responsible instructor based on the above offering, after negotiations with the practical tutors on the current availability of the tutors and the material conditions.

Literature

Compulsory:
Mandatory data sources for each practice required by the tutors in the given academic year.
Recommended:
For each practice, the data sources recommended by the tutors in the given academic year.

Schedule:

The themes cannot be recorded weekly in advance for each student because the individual exercises are done by students in pairs, the same week the different student pairs perform different exercises and the order of the exercises will be different for different student pairs. At the beginning of the term of the semester, a schedule is drawn up that determines which week the exercises are performed for each student pairs.

1st exercise

Determination of gamma-emitting radionuclides in soil (3x4 hours). During the course, students will learn about the operation and use of semiconductor detector gamma spectrometers by determining the content of gamma-emitting radionuclides in environmental samples, mainly in soil. For the first occupation, students should bring 150-200 g of raw soil samples per person, which comes from their living environment. During the first two sessions, students prepare their soil samples for measurement (drying, peeling, sifting) and, on the other hand, they gain insight into the physical background of the operation of the spectrometer determining the full energy peak efficiency vs. gamma energy curve for the geometry used to measure soil samples. On the third session they evaluate the gamma spectra taken for the soil samples and interpret the results obtained.

2nd exercise

Measurement of environmental alpha radioactivity by means of a solid state nuclear track detector (2x4 hours). The student will be informed of the method used to determine the activity concentration of the alpha-decaying radon and thoron gases in the environment by using solid state nuclear track detector. In the first session, the student produces 3 pairs of Radamon type measuring instruments, which include cutting off the track detector disks and assembling the measuring devices. Then installs the gauges to measure the radon and thoron content of the soil gas in situ. In the second session, the collected detectors are processed by etching, tracks are counted using an optical microscope, and the densities and average Rn and Tn activity concentrations are determined.

3rd exercise

Measurement of the tritium concentration of environmental water samples by using 3He method (3x4 hours). The amount to be measured is now between 0 and 20 TU. The detection limit of conventional liquid scintillation measurement technology (currently 4 TU) can be improved by electrolytic enrichment but does not reach 0.4 TU. The method used in the practice determines the amount of tritium not by its radioactive decay, but by the production of the daughter of 3H, the 3He. The water sample is first distilled off, so water is purified from most pollutants and dissolved salts. The water samples are then filled into stainless steel tanks and then vacuumed with high vacuum pumps to remove the air in the container and the gases dissolved in the water. So the water will be completely helium-free. The containers are then sealed. The water sample is only consumed in a few weeks/months, during which time part of the tritium is decays and becomes helium-3. After storage, 3He from the tritium decay in the container is deposited in a special noble gas mass spectrometer and its quantity is determined. Based on the known water mass, the storage time and the volume of the measured 3He, the tritium concentration of water can be calculated. The exercise consists of 3 parts: 1. sampling, distilling, removal of gases; 2. mass spectrometer measurements; 3. evaluation, applications.

4th exercise

Radiocarbon dating and environmental research (2x4 hours).

5th exercise

Sampling and analysis by PIXE method of atmospheric aerosol (2x4 hours). The student learns about the methods of sampling of atmospheric aerosol, concentration determination and nuclear analysis techniques, and gains experience in carrying out measurements based on particle accelerator. Tasks: (1) taking atmospheric aerosol samples with a personal or portable sampler; (2) measuring the mass of the aerosol sample collected onto the filters, calculating the atmospheric aerosol concentration; (3) determination of the element composition of the atmospheric aerosol sample by particle-induced X-ray emission analytical method. Evaluation of spectra by suitable software, computation of concentration, separation of anthropogenic and natural components.

6th exercise

Measurement of stable isotope ratios by mass spectrometric method (2x4 hours).

7th exercise

K-Ar dating (2x4 hours). Students will become familiar with the theoretical and practical back-grounds of K-Ar and Ar-Ar radiometric dating methods, the limitations and possibilities of the methods, the measureable samples and their properties. They look at the wet-chemical laboratory, where sample preparation and K-measurement are underway, and get acquainted with the construction and operation of noble gas mass spectrometers. They determine the age of a selected and prepared sample.

8th exercise

X-ray fluorescence analysis of environmental samples (2x4 hours). Students learn about the theoretical basics and the practical background of the x-ray fluorescence analytical method based on X-ray excitation and X-ray spectrometry by Si (Li) detector. As an example, some elemental concentrations are measured in metal alloys and other samples of environmental origin and conclusions are drawn from the results deduced.

9th exercise

Investigation of the airborne concentration of radon and radon decay products in the laboratory, indoors and outdoors, estimation of radon dose. Devices used: compact portable radon monitors; a filter and filter head for filtering aerosols from the air; gas volume meter; manometer; vacuum cleaner; desktop beta counter; desktop computer with suitable software. The student measures the radon gas activity concentration in the 2nd floor laboratory room with compact radon monitors, takes a sample of the aerosol content of the laboratory air by filtration, measures the beta radiation of the aerosol sample as a function of time under well-defined conditions and determines the equilibrium equivalent activity concentration of the radon decay products. From the results, he calculates the equilibrium factor and estimates the annual value of the radon dose. The student performs measurements on the ground floor corridor of the laboratory building and then outdoors near the building also. The equilibrium factor is determined at both sites and an estimate of the annual value of the radon dose is provided. The results obtained at different sites are compared and conclusions are drawn based on this comparison.

Requirements:

- for a signature

Participation at laboratory sessions is compulsory. A student must attend all the four sessions. In case a student doesn’t so, the course will not be signed and the student must repeat it. Attendance at laboratory sessions will be recorded by the session leader. Being late is equivalent with an absence. Students are required to bring drawing instruments to each sessions. Active participation is evaluated by the teacher. If a student’s behavior or conduct doesn’t meet the requirements of active participation, the teacher may evaluate his/her participation as an absence.

- for a grade

The student will obtain grades for all the exercises one by one. The grades go from fail (1) to excellent (5) according to the following table:

Score	Grade
0-40	fail (1)
41-55	pass (2)
56-70	satisfactory (3)
71-85	good (4)
86-100	excellent (5)

The grade of the course will be the arithmetic mean of the grades obtained for each exercises rounded to the full, provided that the student has completed all the exercises with a grade better than fail (1). If the latter condition is not met then the grade of the course is fail (1) and the student must repeat the course in conformity with the EDUCATION AND EXAMINATION RULES AND REGULATIONS.

Person responsible for course: Dr. Zoltán Papp, associate professor, PhD

Responsible instructor: Dr. Zoltán Papp, associate professor, PhD

Title of course: Atomic and molecular physics I.
Code: TTFME0101

ECTS Credit points: 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): Quantum Mechanics

Further courses built on it: -

Topics of course

Electronic structure of one-electron atoms. Fine- and hyperfine structure, relativistic and spin-orbit corrections. Alkali metals, many-electron atoms and multiplicity. LS- and jj-couplings. Stark-effect and Zeeman-effect. Time-dependent Schrödinger equation in the presence of periodic external fields. Molecular Schrödinger equation, Born-Oppenheimer approximation. Spectra of diatomics: rotational, rovibrational and electronic transitions. Selection rules. Electronic structure of diatomics, the H2+ molecular ion, molecular orbitals. Aspect of polyatomic molecules. Molecular symmetry.

Literature

Compulsory:

B. H. Bransden, C. J. Joachain: Physics of atoms and molecules, Longman Scientific & Technical

D. J. Griffiths: Introduction to Quantum Mechanics, Prentice-Hall: New Jersey

Recommended:

I. N. Levine: Quantum Chemistry, Prentice Hall, 5 edition

Schedule:

1st week

Electronic structure of one-electron atoms. Energy levels, wave functions, quantum numbers, relation to the Bohr-model. Rydberg atoms.

2nd week

Fine- and hyperfine structure of one-electron atoms: relativistic and spin-orbit corrections; isotope effect and nuclear spin. Lamb-shift.

3rd week

Electronic structure of alkali metals. Doublet structure of atomic sodium, multiplicity. Angular momentum and magnetic moment. The Landé factor.

4th week

Electronic structure of many-electron atoms. Central field approximation, LS- and jj coupling schemes. The He atom.

5th week

Stationary electric field as a perturbation: linear and quadratic Stark effect; dipole moment and polarizability.

6th week

Stationary magnetic field as a perturbation: weak and strong field, normal and anomalous Zeeman effect.

7th week

Time-dependent Schrödinger equation of charged particles in external electromagnetic fields. Transition probabilities.

8th week

Schrödinger equation of molecular systems: separability of the nuclear and electronic motions. The Born-Oppenheimer approximation and its validity.

9th week

Spectra of diatomics: rotational transitions, rovibrational spectral lines, electronic transitions. Selection rules. The impact of translation.

10th week

Electronic structure of diatomics. The example of the H2+ molecule: atomic- and molecular orbitals, electron densities, formation of the chemical bond.

11th week

Higher excited states of the H2+ molecule. Bonding and antibonding orbitals. Hibridization, properties of molecular orbitals. Aspect of polyatomic systems.

12th week

Symmetry properties of molecules: symmetry elements, symmetry operations. Point groups. Symmetry of molecular orbitals.

13th week

Summary and consultation.

14th week

End-term test.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. András Csehi, assistant professor, PhD

Lecturer: Dr. András Csehi, assistant professor, PhD

Title of course: Condensed matter III **Code**: TTFME0105	**ECTS Credit points: 3**

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: TTFME0141, TTFML0144

Topics of course

Phase Diagrams: Thermodynamic descriptions of binary systems, understanding the basic concept of the Calphad method; Diffusion under external driving forces: Nernst-Einstein equation, thermodynamic driving force, intrinsic diffusion coefficient; Phase transformations: spinodal decomposition, phase separation, order-disordered transformation, nucleation, martensitic transformations; Segregation: the driving force of segregation, isotherms; Interfaces, grain boundaries; Grain-boundary diffusion: Harrison's classification; Diffraction, reflectometry: diffraction theory of one-dimensional periodic structures in direct and reciprocal space, neutron and X-ray diffraction / reflectometry; Domain magnetism.

Literature

C.Kittel: Introduction to Solid State Physics
William D. Callister, Jr. David G. Rethwisch Materials Science and Engineering, An Introduction, Willey
M.A. Omar: Elementary Solid State Physics, Priciples and Applications
CALPHAD (Calculation of Phase Diagrams): A Comprehensive Guide, Volume 1, 1st Edition, Editors: N. Saunders A.P. Miodownik

Schedule:

1st week

Information, introduction.

Phase diagrams: Basic thermodynamic description of binary systems

2nd week

Phase Diagrams: Basics of calculations of real phase diagrams, Basics of the Calphad method.

3rd week

Diffusion under external driving forces: Nernst-Einstein equation, thermodynamic driving force, intrinsic diffusion coefficient

4th week

Phase transformations: spinodal decomposition ("up-hill" diffusion), phase separation ("down-hill" diffusion)

5th week

Phase transformations: order-disorder transformation

6th week

Phase transformation: nucleation

7th week

Phase transitions: martensite transformations, shape memory materials

8th week

Segregation: Understanding driving forces of the segregation, segregation isotherms

9th week

Understanding the structure of interfaces and grain boundaries; grain-boundary diffusion: Harrison's classification of grain boundaries.

10th week

Diffraction, reflectometry: diffraction theory of one-dimensional periodic structures in direct and reciprocal space, neutron and X-ray diffraction / reflectometry; Measurements in symmetrical geometry.

11th week

Diffraction, reflectometry: diffraction theory of one-dimensional periodic structures in direct and reciprocal space, neutron and X-ray diffraction / reflectometry;

12th week
Domain magnetism: The basic idea of domain magnetism, domain structure.

13th week
Domain magnetism: Interaction of magnetic domains, domain reordering.

14th week
Summary, consultation

Requirements:
- for a signature
Attendance at **lectures** is recommended, but not compulsory.
Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.
During the semester there are tests. The requirement for a signature is a successful (> 50%) completion of each test.
- for a grade
The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.
The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Prof. Dr. Zoltán Erdélyi, full professor, DSc

Lecturer: Prof. Dr. Zoltán Erdélyi, full professor, DSc

Title of course: Theory of relativity
Code: TTFME114

ECTS Credit points: 5

Type of teaching, contact hours
- lectures: 2 hours/week
- problem classes: 1 + 1 hours/week
- laboratory: -

Evaluation: signature + colloquium

Workload (estimated), divided into contact hours:
- lectures: 28 hours
- problem classes: 14 + 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 136 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Physics and geometry, frames of reference, coordinate systems. Relativity principle in classical mechanics and electrodynamics. Propagation of light. Coordinate transformations, Minkowski space. Tensors. The covariance of physical laws. Covariant formulation of electrodynamics. Relativistic mechanics; relativistic collisions and phase space. Elements of relativistic field theory (the principle of least action, field equations). The electromagnetic field, gauge invariance, charge conservation. Symmetries and conservation laws, stress-energy tensor.

Gravitation, gravitational and inertial mass. The equivalence principle. General coordinate systems, geometric concepts (parallel transport, curvature tensor, etc.). Electrodynamics in curvilinear coordinate systems. Mechanics, inertial forces. Einstein equations, simple solutions (spherically symmetric solution, Schwarzschild metric, black holes). The Robertson-Walker metric and Friedmann cosmological models. Linearization of Einstein equations. Wave solutions, gravitational waves and their detection.

Literature

Compulsory:
Taylor, E.F., Wheeler, J.A.: Spacetime Physics, opensource 1992
Landau, L.D., Lifshitz, E.M.: The Classical Theory of Fields, Pergamon Press 1971
Susskind, L. and Friedman, A.: Special relativity and Classical Field Theory, 2017
Recommended:
R.M. Wald, R.M.: General Relativity, The University of Chicago Press, 1984.
Misner, C.W., Thorne, K.S., Wheeler, J.A.: Gravitation, W. H. Freeman, 1973.
E. Byckling, K. Kajantie: Particle Kinematics, Wiley-Interscience, 1973

Schedule:

1st week

Geometry and coordinate systems. Coordinate transformations, covariant and contravari-ant coordinates. Galilei's principle of relativity (Galilei transformation and Newton axi-oms).

The propagation and speed of light (electrodynamics and Galilei transformation, Michel-son-Morley types of experiments).

2nd week

Basic assumptions of the theory of relativity. Line element, invariant length. Lorentz trans-formation and its consequences (addition of velocities, length contraction, time dilation, experiments).

3rd week

The event space. The geometry of Minkowski space, spacetime diagrams. Tensors. Opera-tions with tensors, tensor analysis. The covariance of physical laws.

4th week

The covariant form of Maxwell equations. Four-potentials, electromagnetic field-strength tensor.

Kinematics of a point particle. Proper time. The twin paradox and its interpretation. Four-velocity and acceleration.

5th week

Fundamentals of the relativistic dynamics a point particle (relativistic momentum, energy, equation of motion). Relativistic collisions, phase space. The variation principle in a co-variant form. Motion of a point mass in a force field (charged particle in electromagnetic field, Lagrangian, Lorentz force).

6th week

Fundamentals of relativistic field theory. Hamilton principle, Euler-Lagrange equations. Applying the general description in the description of electromagnetic fields.

7th week

Space time symmetries in field theory. Stress-energy tensor, conservation laws.

8th week

Basics of the theory of general relativity. Gravitational and inertial mass. The equivalence principle, local inertial systems.

9th week

Curvilinear coordinate systems (tensors, tensor analysis, parallel transport, covariant de-rivative). Christoffel symbols, metric tensor.

10th week

Electrodynamics and mechanics in curvilinear coordinate systems. Geometry of spacetime and inertial forces.

11th week

Curvature tensor, Ricci-tensor. The relationship between geometry and matter, Einstein equations.

12th week

Solving the Einstein equations for simple systems. Gravitational field of a spherically symmetric star. Schwarzschild metric, black holes. Robertson-Walker metric, Friedmann cosmological models.

13th week

The linearized Einstein equations. Wave solutions, gravitational waves and their detection.

14th week

Overview of the semester's material, guidance for further studies, consultation.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **problem classes** is compulsory. A student must attend the problem classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the course, problems given for homework should be evaluated and submitted by a specified deadline. The requirement for a signature is a successful (> 50%) completion of the home assignments.

- for a grade

The course ends in an oral **examination/colloquium**. The requirement for applying for the exam is to have a signature.

The grade of the exam is given as follows.

Knowledge of the laws, theorems and definitions relevant to the subject : pass (2)
-in addition, the ability to prove the most important theorems : satisfactory (3)
-in addition, knowledge of proofs and derivations presented at the lectures : good (4)
-in addition, knowledge of the applications involved in the problem classes : excellent (5)

Person responsible for course: Dr. Schram Zsolt, habil. associate professor, PhD, CSc

Lecturer:

Title of course: Quantum Field Theory **Code**: TTFME0215	**ECTS Credit points:** 6

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): Quantum Mechanics, Relativity theory

Further courses built on it: Standard Model

Topics of course

Attempts at a relativistic quantum mechanics, the Klein-Gordon equation, the Dirac equation, the appearance of quantized fields; classical field theory, canonical quantization of scalar fields; the physical significance and computation of the scattering cross section and the decay rate; the scattering amplitude and the LSZ reduction formula; path integral for free and interacting fields; perturbation theory, Feynman graphs, Feynman rules; Lagrangian density for fermion fields, the canonical quantization of the Dirac field; photons and quantum electrodynamics; calculations of cross sections decay widths for elementary processes.

Literature

Compulsory:
Srednicki, M.: Quantum Field Theory, Cambridge University Press, 2007.
Recommended:
Peskin, M.E., Schroeder, D.V.: An Introduction to Quantum Field Theory, Westview Press, 1995.
Mandl, F., Shaw, G.: Quantum Field Theory, Wiley, 1984.
Weinberg, S.: The Quantum Theory of Fields, Volume I, Cambridge University Press, 1995.

Schedule:

1st week

Attempts at a relativistic quantum mechanics I: the abstract Schrödinger equation; Lorentz transformation; first attempt: the Klein-Gordon equation; second attempt: the Dirac equation.

2nd week

Attempts at a relativistic quantum mechanics II: third attempt: the introduction of fields; rewriting the quantum theory of non-relativistic bosons as a non-relativistic field theory.

3rd week

Canonical quantization of scalar fields: the quantum mechanical Hamiltonian of free, relativistic bosons; Lagrangian for the Klein-Gordon equation, the Hamilton function of a free, classical scalar field; canonical quantization; the quantum mechanical Hamiltonian of free, relativistic bosons = the

Hamiltonian of the free, canonically quantized Klein-Gordon scalar field; the relationship between spin and statistics.

4th week

Scattering theory, LSZ reduction, n-point correlation functions: the cross section and decay rate; ``in'' and ``out'' states, the S-matrix; the LSZ reduction formula; n-point correlation functions; time-ordered product of operators; the normalization of fields.

5th week

Path integral in quantum mechanics: general form of the path integral; the path integral in Lagrangian form; vacuum-to-vacuum transition amplitudes.

6th week

Path integral in quantum field theory I: path integral for free scalar fields; the Feynman-propagator; Wick's theorem.

7th week

Path integral in quantum field theory II: the path integral for interacting fields; Feynman-diagrams, Feynman-rules; counterterms.

8th week

Scattering amplitudes, cross sections, decay rates: the computation of tree-level $2 \to 2$ scattering amplitudes in scalar field theory; Feynman-rules in momentum space; computing cross sections at tree-level; decay rates and the LSZ reduction formula.

9th week

Canonical quantization of the Dirac field: the relativistic properties of the Dirac equation; the plane wave solutions of the Dirac equation; Lagrangian density for the Dirac equation; canonical quantization; the Hamilton function; the relationship of spin and statistics.

10th week

Feynman-rules for fermion fields: correlation functions of fermion fields, spinors; propagator for the Dirac spinor; Yukawa theory, fermion-fermion-scalar vertex.

11th week

Feynman-rules for vector fields: Maxwell's equations; gauge invariance; photon polarization, photon propagator; Feynman-rules for QED; gauge invariance in the language of Feynman-diagrams.

12th week

Elementary processes I: the square of the scattering amplitude; summation for spins and polarizations; spinor and gamma matrix technology; scattering amplitude.

13th week

Elementary processes II: calculation of cross sections and decay rates in QED and Yukawa theory for $2 \to 2$ and $1 \to 3$ processes.

14th week

Review of the topics covered during the semester, guidance for further study, consultation.

Requirements:

- for a signature

Being present on at least 75% of the practicals and correctly solving at least half of the assigned homework problems are prerequisites for taking the final exam.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature. The grade for the examination is given according to the following:

knowledge of the definitions, theorems and laws of the subject matter at the exam: pass (2);

above this the ability to prove the more important theorems: satisfactory (3);

above this the knowledge of proofs and derivations mentioned in the lectures: good (4);

above this the knowledge of the applications studied in the practicals: excellent (5).

Person responsible for course: Dr. Gábor Somogyi, senior scientific associate, PhD

Lecturer: Dr. Gábor Somogyi, senior scientific associate, PhD

Title of course: Particle Physics 2 **Code**: TTFME0112	**ECTS Credit points:** 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): Particle Physics 1 (TFME0104)

Further courses built on it: Quantum Mechanics 2 (TFME0102) Relativity Theory (TFME0114)

Topics of course

Gauge symmetries and interactions: QED, QCD and electroweak interaction. Structure of the Standard Model. Computer analysis of experimental data. Experimental tests of the standard model. Search for and observation of the Higgs boson. Results of LEP, HERA, Tevatron and LHC. Problems and extensions of the Standard Model. Heavy ion physics.

Literature

Compulsory:
Dezső Horváth and Zoltán Trócsányi: Intorduction to Particle Physics, Cambridge Scholars Publishing, 2019.
Recommended:
Donald H. Perkins: Introduction to High Energy Physics, Addison-Wesley, Menlo Park, USA
Francis Halzen and Alan D.~Martin: Quarks and Leptons. An Introductory Course in Modern Particle Physics, John Wiley and Sons, New York.

Schedule:

1st week

Overview of the course Particle Physics 1 and the structure of the present course.

2nd week

Global and local gauge symmetries. Local U(1) symmetry and electromagnetism. Perturbation calculation, scattering of point charges. Photon as gauge boson. Invariant (Mandelstam) variables. Feynman diagrams, photon reactions.

3rd week

Local SU(3) symmetry and strong interaction. Running coupling constants. Quark confinement, asymptotic freedom. Parton model and hadron jets. Event shape quantities: thrust, sphericity, etc. Gluonia: their spin and colour charge.

4th week

Parity violation in beta decay, V-A theory. Local SU(2) symmetry does not yield weak interaction.. Spontaneous symmetry breaking, the Brout-Englert-Higgs mechanism. Weak isospin. Parity violation. Weak current and coupling, neutral current. Weinberg angle.

5th week

Mass production in the BEH mechanism. Weak boson and fermion masses. GIM mechanism. Mixing of quark states. CP violation. Cabibbo-Kobayashi-Maskawa matrix. The Lagrangian of the Standard Model.

6th week

Steps of data analysis. Role of simulations. Covariance, correlation, standard deviation, error propagation. Parameter estimation and its quality, confidence. Trigger logic.

7th week

Linear and nonlinear parameter estimation: ROOT and MINUIT program packages. Statistic and systematic uncertainties. Discovery and exclusion. Estimating upper and lower limits. Rules of thumb.

8th week

Direct and indirect experimental proofs of SM. Parametrization and fitting the SM. Forward-backward and right-left asymmetries. Lepton universality. W physics. Tetra-, penta- and hexa-quarks.

9th week

Basic experiments: Proton-proton collisions, CDF and the top quark. Particle searches with CMS at the LHC.

10th week

Higgs boson of the Standard Model. Its possible production and decay. Higgs search: LEP, Tevatron. Its observation at the LHC. The 2-Higgs-doublet models and its search.

11th week

Problem of the Standard Model. Convergence of gauge couplings. Grand unification. Hierarchy problem and its possible solution.

12th week

Supersymmetry and the Minimal Supersymmetric Standard Model (MSSM). Search for MSSM-particles.

13th week

Quark-gluon plasma and its signals. Heavy ion experiments: SPS NA61/SHINE, RHIC PHENIX and LHC ALICE. Hadron jet quenching. Heavy-ion results at the LHC.

14th week

Overview, discussion session.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature. The examination starts with a quiz: 8-12 questions with multiple choice answers. The students should be able to explain the chosen answers.

Scoring above 50%: *satisfactory*,
above 75%: *average,*
in addition, the explanations are correct as well: *good*,
in addition, the interpretation of the knowledge is correct: *excellent*.

Person responsible for course: Dr. Zoltán Trócsányi, professor, PhD

Lecturer: Dr. Dezső Horváth, professor, PhD

Title of course: The Standard Model of Particle Physics **Code**: TTFME0111	**ECTS Credit points:** 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): Quantum Field Theory (TTFME0113)

Further courses built on it: -

Topics of course

Wigner theorem, Lagrangian for massive and massless spin-1 particles. Generalisation of Lorentz transformations, spinors, Lagrangian for spin-1/2 fermions, Lagrangian of quantum electrodynamics, Feynman rules of QED, Rutherford scattering, muon-pair production in electron-positron annihilation. Spontaneous breaking of discrete, global and local symmetries. Abelian and non-Abelian Higgs models, Electroweak symmetry breaking. The fermion sector, fermion masses and mixing angles.

Literature

Compulsory:
M. Schwartz, Quantum Field Theory and the Standard Model
(Cambridge University Press, 2013)

Schedule:

1st week

Unitary representation of the Poincare group, Wigner theorem, embedding spin-0 particles into fields.

2nd week

Embedding massive and massless spin-1 particles into fields.

3rd week

Covariant derivatives and scalar QED, quantization of massive and massless spin-1 fields and the Ward identity.

4th week

Group theory and group representations of the Lorentz group. Spinor representations of the Lorentz group, Weyl spinors.

5th week

Constructing Lorentz invariants Lagrangians with spinors, gamma matrices, coupling to photons.

6th week

Spinor solutions to the Dirac equations.

7th week

Quantizing spinors, invariance of S-matrix, Feynman propagator for spin-1/2 particles.

8th week

Quantum electrodynamics, Feynman rules, signs, gamma matrix identities.

9th week

Rutherford scattering, muon-pair production.

10th week

Spontaneous breaking of discrete, global and local symmetries. Goldstone bosons and the Goldstone theorem.

11th week

Abelian Higgs model, unitary gauge and Higgs mechanism.

12th week

Electroweak symmetry breaking, masses of vector bosons of the Standard model.

13th week

Fermion sector, mass generation in lepton and quark sectors.

14th week

Fermion masses and mixing angles. Mass and flavor basis, the CKM matrix.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Prof. Zoltán Trócsányi

Lecturer: Dr. Adam Kardos, assistant professor, PhD

Title of course: Electronic structure methods and quantum dynamics
Code: TTFME0121

ECTS Credit points: 5

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Schrödinger equation of atoms and molecules. Center of mass motion. The Born-Oppenheimer and adiabatic approximation. Atomic units. The differential Hellmann-Feynman theorem. The integral Hellmann-Feynman theorem. The virial theorem. The variation principle. Variational methods. The linear variation method (Ritz method). Eckart's inequality. Scaling - a connection with the variation principle. Perturbational methods. Non-degenerate Rayleigh-Schrödinger perturbation theory. Degenerate Rayleigh-Schrödinger perturbation theory. Brillouin-Wigner perturbation theory. Wave functions. Spin orbitals. Antisymmetric wave functions. Singlet and triplet states. Slater determinants.

Determinant wave functions. Matrix elements between determinant wave functions. The Hartree-Fock method. The self consistent field (SCF) approximation. The configuration interaction (CI) method. Koopmans theorem. Singlet and triplet excitations. Electron correlation. The multi reference configuration interaction MRCI and multi reference self-consistent field (MCSCF) approximations. The coupled cluster approach. The Schrödinger equations of the nuclei. Vibrational eigenstates. Time-dependent perturbation theory (first and second order). Time evolution of non-stationary systems. Methods for propagating the nuclear wave packet: finite difference method, split operator technique, the relation between coordinate and momentum representations. Analysis of the time-dependent nuclear wave packet: initial states, autocorrelation functions, populations of electronic states, complex absorbing potentials, dissociation of molecules. Further propagation techniques: time-dependent Hartree and the multiconfigurational time-dependent Hartree methods. Structure of the total wave function, basis functions. Time evolution on multiple electronic states, non-adiabatic processes.

Literature

D. R. Yarkony: Modern Electronic Structure Theory, World Scientific, 1995.
I. Mayer: Simple Theorems, Proofs, and Derivations in Quantum Chemistry, Kluwer Academic, 2003.

Schedule:

1st week

Schrödinger equation of atoms and molecules. Center of mass motion.

2nd week

The Born-Oppenheimer and adiabatic approximation.

3rd week

Atomic units. The differential Hellmann-Feynman theorem. The integral Hellmann-Feynman theorem. The virial theorem.

4th week

The variation principle. Variational methods. The linear variation method (Ritz method).

5th week

Eckart's inequality. Scaling - a connection with the variation principle. Perturbational methods. Non-degenerate Rayleigh-Schrödinger perturbation theory.

6th week

Degenerate Rayleigh-Schrödinger perturbation theory. Brillouin-Wigner perturbation theory.

7th week

Wave functions. Spin orbitals. Antisymmetric wave functions. Singlet and triplet states. Slater determinants.

8th week

Determinant wave functions. Matrix elements between determinant wave functions.

9th week

The Hartree-Fock method. The self consistent field (SCF) approximation. The configuration interaction (CI) method.

10th week

Koopmans theorem. Singlet and triplet excitations. Electron correlation. The multi reference configuration interaction MRCI and multi reference self-consistent field (MCSCF) approximations. The coupled cluster approach.

11th week

The Schrödinger equations of the nuclei. Vibrational eigenstates. Time-dependent perturbation theory (first and second order). Time evolution of non-stationary systems.

12th week

Methods for propagating the nuclear wave packet: finite difference method, split operator technique, the relation between coordinate and momentum representations.

13th week

Analysis of the time-dependent nuclear wave packet: initial states, autocorrelation functions, populations of electronic states, complex absorbing potentials, dissociation of molecules.

14th week

Further propagation techniques: time-dependent Hartree and the multiconfigurational time-dependent Hartree methods. Structure of the total wave function, basis functions. Time evolution on multiple electronic states, non-adiabatic processes.Addition of angular momenta, the Clebsch-Gordan coefficients.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	**excellent (5)**

Person responsible for course: Prof. Dr. Ágnes Vibók, PhD, habil, DSc

Lecturer: Prof. Dr. Ágnes Vibók, PhD, habil, DSc

Title of course: Atoms and molecules in electromagnetic field
Code: TTFME0122

ECTS Credit points: 5

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Two and three level atoms. Spin matrices. Properties of spin matrices. Ladder operators for two and three level atoms. Linear harmonic oscillator. Algebra of ladder operators. Matrix representation. Introduction to the quantum optics. Quantization of electromagnetic field. Coherent and squeezed states. Angular momentum algebra. Eigenvalues and eigenvectors of angular momentum and spin operators. Composite systems. Two dimensional isotropic oscillator. Algebra of ladder operators. Three dimensional isotropic oscillator. Eigenvectors and eigenvalues. The angular momentum algebra. Clebsch-Gordan coefficients. Triplet and singlet states of spin and their algebra. Isospin and isomultiplets. Time-dependent Hamiltonian. Perturbative series. First and second order corrections. Energy eigenvalues and eigenfunctions. Harmonic and anharmonic perturbations. Perturbed oscillator. Light-matter interaction. Dipole approximation. Non-degenerate first-order perturbation correction. Absorption and emission. Perturbed hydrogen atom. Hydrogen atom in electric field. The linear Stark effect. Hydrogen atom in magnetic field.

The Zeeman effect. Interaction of a two-level atom with radiation. Dipole approximation. Rabi-model. The rotating wave approximation (RWA). The Jaynes-Cummings model. Atom optic. Spontaneous emission.

Literature

V. K. Thankappan: Quantum Mechanics, Wiley Eastern Limited, 1985.

C. C. Gerry, P. L. Knight: Introductory Quantum Optics, Cambridge University press, 2005.

Schedule:

1st week

Two and three level atoms. Spin matrices. Properties of spin matrices. Angular momentum algebra. Ladder operators for two and three level atoms.

2nd week

Linear harmonic oscillator. Algebra of ladder operators. Matrix representation.

3rd week

Introduction to the quantum optics. Quantization of electromagnetic field. Coherent and squeezed states.

4th week

Angular momentum algebra. Eigenvalues and eigenvectors of angular momentum and spin operators.

5th week

Two dimensional isotropic oscillator. Algebra of ladder operators. Three dimensional isotropic oscillator. Eigenvectors and eigenvalues.

6th week

The angular momentum algebra. Clebsch-Gordan coefficients.

7th week

Triplet and singlet states of spin and their algebra. Isospin and isomultiplets.

8th week

Time-dependent Hamiltonian. Perturbative series. First and second order corrections. Energy eigenvalues and eigenfunctions. Harmonic and anharmonic perturbations. Perturbed oscillator.

9th week

Light-matter interaction. Dipole approximation. Non-degenerate first-order perturbation correction.

10th week

Absorption and emission. Perturbed hydrogen atom. Hydrogen atom in electric field. The linear Stark effect.

11th week

Hydrogen atom in magnetic field. The Zeeman effect.

12th week

Interaction of a two-level atom with radiation. Dipole approximation. Rabi-model. The rotating wave approximation (RWA).

13th week

The Jaynes-Cummings model. Atom optic. Spontaneous emission.

14th week

Closed-term exam.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Prof. Dr. Ágnes Vibók, PhD, habil, DSc

Lecturer: Prof. Dr. Ágnes Vibók, PhD, habil, DSc

Title of course: Quantum Informatics **Code**: TTFME0123	**ECTS Credit points:** 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Mathematical tools and postulates of quantum mechanics. The measurement in quantum mechanics, projective and POVM measurements. Composite systems, quantum entanglement, EPR paradox. Density operator, reduced density matrix. Quantum interferometer, no cloning theorem. Quantum logic gates. Superdense coding, quantum teleportation. Quantum parallelism, Deutch and Deutch-Jozsa algorithms. Grover algorithm, Shor algorithm. Quantum fourier transform.

Literature

Compulsory:
Michael A. Nielsen, Isaac L. Chuang, Quantum Computation and Quantum Information (Cambridge, 2010);
R. Horodecki, P. Horodecki, M. Horodecki, and K. Horodecki, Qunatum entanglement, Rev. Mod. Phys. 81, 865 (2009);
Recommended:
V. Scarani, The device-independent outlook on quantum physics (lecture notes on the power of Bell’s theorem), Acta Phys. Slovaca 62, 347 (2012).

Schedule:

1st week

The review of the mathematical tools in quantum mechanics.

2nd week

The postulates of quantum mechanics.

3rd week

The measurement in quantum mechanics, projective and POVM measurements.

4th week

Investigation of composite systems in quantum theory.

5th week

Quantum entanglement, EPR paradox, Bell’s inequality.

6th week

The density operator, the reduced density matrix.

7th week

Quantum interferometer, no cloning theorem.

8th week

Quantum logic gates.

9th week

Superdense coding in quantum informatics.

10th week

Quantum teleportation in quantum informatics.

11th week

Quantum parallelism, Deutch and Deutch-Jozsa algorithms.

12th week

Grover's search algorithm.

13th week

Integer factorization, Shor's algorithm.

14th week

Quantum Fourier transform.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Sándor Nagy, associate professor, PhD

Lecturer: Dr. Sándor Nagy, associate professor, PhD

Title of course: Quantum Computers and Algorithms
Code: TTFME0124

ECTS Credit points: 5

Type of teaching, contact hours

- lecture: 2 hours/week

- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Quantum computing and its importance, quantum measurements, dynamics, information processing and thermodynamics. The Moor's law, Landauer principle, reversibility, Turing machine. The qbit notion and its implementation, qbit registers, one and many qbits quantum gates, Solovay-Kitaev principle, Mach-Zehnder interferometer, quantum logic circuits, the notions of entanglement, cloning, superdense coding, teleportation. Quantum algorithms: Deutsch-Jozsa, Simon, Grover, Shor. Quantum criptography and error correction codes. Decoherence and quantum hardware, D-wave quantum computers and their use.

Literature

Compulsory:

John Preskill: Lecture Notes on Quantum Computation, California Institute of Technology, US, http://theory.caltech.edu/~preskill/ph229/

Recommended:

M. A. Nielsen, I. L. Chuang: Quantum Computation and Quantum Information, Cambridge University Press, 2001

Schedule:

1st week

The necessity of quantum computation. The development of calculation techniques, Turing machine, Church-Turing law, strong Church-Turing law, probabilistic Turing machine, probabilistic Church-Turing law, the notion of the universal quantum computer, Deutsch theorem, calculation complexity, efficient calculation notion, Moore's law, Rock's law, Mchrone's law.

2nd week

The physical aspects of quantum computing: the notion of bit, qbit, Landauer's principle, reversible and irreversible computing, Bonett's theorem, Maxwell's demon and quantum computing, the Wootters - Zurek -Dieks principle, Bell's theorem, Einstein-Podolsky-Rozen statement and its current interpretation, Feynmann's and Benioff's conception about quantum computation..

3*rd week*

Basic notions of quantum gates: definition, basic properties, linearity, unitary nature. Reversible quantum gates, connection to the quantum mechanical evolution in time. Set of universal quantum gates, Solovay-Kitaev theorem, the operators and matrices connected to gates.

4th week

Gates processing 1 qbit: The I,X,Y,Z gates and their properties, Bloch sphere for the representation of quantum states, phase gate, NOT gate, the Hadamard gate and its importance, square root gates, set of base gates for 1 qbit gates. Schematic plot of 1 qbit gates.

5th week

Gates processing 2 qbits: Control-U (CU) gate and its matrix, the CNOT gate (definition, basic principle, schematic plot, the sum effectuation role), the CZ gate, SWAP gate (definition, basic principle, schematic plot), set of universal quantum gates constructed

from CNOT gate, notion of the control qbit, reversed control gate, 2 qbit gates, connection between 2 qbit gates.

6th week

Entanglement: notion of entangled states, definition, importance, EPR (Bell) states and their role in quantum algorithms. No cloning theorem: proof, interpretation, meaning, connection to uncertainty principle, the quantum mechanical point of view in the interpretation.

7th week

Superdens coding: characteristics, properties, realization, used gates, importance, schematic plot. Quantum teleportation: characteristics, properties, realization, used gates, importance, schematic plot, connection to superdens coding.

8th week

Deutsch-Jozsa algorithm for a function of one variable. Definition, characteristics of the algorithm, realization, schematic plot, interpretation, importance, comparison to classical algorithms.

9th week

Deutsch-Jozsa algorithm for a function of n-variables. Definition of the used function, characteristics of the algorithm, importance of the advancement to the n-variables case, realization, schematic plot, interpretation, importance, comparison to classical algorithms.

10th week

Simon's algorithm for a function of n-variables. Definition, characteristics of the algorithm, realization, schematic plot, interpretation, importance, relation to the Deutsch-Jozsa algorithm, comparison to classical algorithms.

11th week

Grover's algorithm: Definition, characteristics of the algorithm, realization, schematic plot, interpretation, importance, comparison to classical algorithms.

12th week

Shor's algorithm: Definition, characteristics of the algorithm, efficient procedure for the deduction of the highest common divisor. Quantum Fourier transformation and the deduction procedure of its coefficients. Realizations, schematic plot, interpretation,

importance, comparison to classical algorithms.

13th week

Quantum error correction codes: classical error correction codes, interpretation of the error notion for a quantum computing process, connection between error corrections and supplementary registers, measurements of supplementary registers containing error correction qbits, exemplification.

14th week

D-wave quantum computers, their use and programming, transcription of the task to be effectuated in Ising language, exemplifications.

Requirements:
- for a signature
Attendance at **lectures** is recommended, but not compulsory.
Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course. During the semester there will be two written examinations (on 6th and 13th week) from lectures and practice as well. The requirement for a signature is a successful (> 20%) completion of each written exam.
- for a grade
The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.
The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Zsolt Gulácsi, professor, DSc

Lecturer: Dr. Zsolt Gulácsi, professor, DSc

Title of course: Atomic and molecular physics II.
Code: TTFME0125

ECTS Credit points: 5

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): Atomic and molecular physics I.

Further courses built on it: -

Topics of course

Statistical description of atoms and molecules. Pure and mixed states. The density matrix. The Liouville-Neumann equation, Liouville operator. Environmental effects, the reduced density matrix. Classical scattering, basic concepts. Atomic collisions, partial waves, radial equations. Green-function. Contour integrals. Born series. Scattering by a complex potential. Electron-atom collisions, static-exchange and close coupling methods. Optical potentials. Atomic excitation by collision. Ionization and resonances. Atom-atom and atom-molecule collisions at low velocities. Electronic excitations and charge transfer.

Literature

Compulsory:
B. H. Bransden, C. J. Joachain: Physics of atoms and molecules, Longman Scientific & Technical
B. W. Shore: The theory of coherent atomic excitation, JOHN WILEY & SONS
Recommended:
D. J. Griffiths: Introduction to Quantum Mechanics, Prentice-Hall: New Jersey

Schedule:

1st week

Statistical description of atomic and molecular systems. Statistical nature of initial states: pure and mixed states. Coherent superposition.

2nd week

Density matrix and its fundamental properties. Operator expectation values for pure and mixed states. Incoherent superposition. Thermal states.

3rd week

The Liouville-Neumann equation. Constants of motion, probability amplitudes, and coherences. The Liouville operator. Applications.

4th week

Atomic and molecular systems interacting with the environment. The reduced density matrix. Relaxations, fluctuations and scattering processes.

5th week

Classical scattering on a central potential, impact parameter, differential and total cross sections. Elastic scattering on a rigid sphere. Coulomb scattering.

6th week

Atomic collisions. Basic concepts and the potential scattering. Types of collisions, channels and thresholds.

7th week

Scattering amplitude, the method of partial waves. Radial equations, Bessel equation. Hankel and Bessel functions. Phase shifts and resonances.

8th week

Integral equation of potential scattering and its solution by Green’s function method. Contour integrals.

9th week

Born series expansion of the scattering amplitude. The first Born approximation for Coulomb potential, relation to the classical results. Absorption and scattering by a complex potential.

10th week

Electron-atom collisions. Nonrelativistic electron scattering on atomic hidrogen. Modelling elastic scattering: static exchange and close coupling methods.

11th week

Excitation of atoms to discrete levels. Ionization and autoionization processes. Resonances. The electron energy loss spectrum.

12th week

Atom-atom collisions. Long-range interaction, classical description. Elastic scattering at low velocities. Electronic excitation and charge exchange. Aspect of molecular collisions.

13th week

Summary and consultation.

14th week

End-term test.

Requirements:

- *for a signature*

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- *for a grade*

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. András Csehi, assistant professor, PhD

Lecturer: Dr. András Csehi, assistant professor, PhD

Title of course: Computer modelling **Code**: TTFME0132	**ECTS Credit points:** 5

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -

- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Advanced methods of random number generation, Gaussian distributed random numbers. Generalization and optimization of the Hit&Miss method.

Numerical integration by means of finite difference methods. Monte Carlo (MC) integration with simple sampling. Error analysis and optimization. MC integration with importance sampling. MC integration with Markov-chain algorithms, Markov-chain in the phase space of physical systems.

Statistical mechanics of finite temperature systems, size dependence of energy fluctuations. MC measurement, Metropolis algorithm, Metropolis and Glauber dynamics.

Ising model in one and two dimensions. Numerical analysis of the Ising model with exact enumeration. Efficient implementation of the Metropolis algorithm for the Ising model. Initial and boundary conditions, optimization of the simulation program. Thermalization and MC measurements. Error analysis of MC simulations.

Monte Carlo simulation in the vicinity of the critical point. Critical slowing down, cluster algorithms, Swendsen-Wang algorithm. Finite size scaling of simulated data, numerical determination of critical exponents.

Histogram methods. Simple histogram method of Ferrenberg. Broad histogram methods.

Lattice gas models, conserved order parameter (COP) Ising model as a lattice gas. Phase diagram of the COP Ising model. Kawasaki dynamics and its efficient implementation.

Metropolis algorithm for gases and liquids. Optimization of the MC simulation program. Measuring thermodynamic quantities of gases and liquids by means of MC simulations.

Kinetic Monte Carlo (KMC) simulation. Poisson statistics of transitions, transition probability and waiting time. Residence time algorithm. Efficient implementation of KMC simulations.

Literature

Compulsory:

Kun Ferenc, Computer modeling and simulation in physics, (electronic script in English, University of Debrecen, 2012).

H. Gould and J. Tobochnik, An introduction to computer simulation methods (Addison-Wesley, 2006).

M. E. J. Newman and G. T. Barkema, Monte Carlo Methods in Statistical Physics (Oxford University Press, 1999).

Schedule:

1st week

Advanced methods of random number generation. Hit&Miss method, error analysis and optimization.

2nd week

Generating Gaussian distributed random numbers, Box-Müller algorithm. Central limit theorem. Algorithms to generate random points on the surface and inside the volume of a sphere. Multi-dimensional random vectors.

3rd week

Numerical integration by means of finite difference methods, error analysis. Monte Carlo integration with simple sampling.

4th week

Error analysis of Monte Carlo integration, optimization of MC integration. Monte Carlo integration with importance sampling, optimal choice of sampling functions.

5th week

Monte Carlo integration with Markov-chain methods. Markov-chain in the phase space. Generating random numbers with Markov-chain algorithm.

6th week

Statistical mechanics of finite temperature systems. Distribution of the energy of a finite temperature system, energy fluctuations and their dependence on the system size.

7th week

Generating sequences of micro-states with Markov-chain algorithms. Condition of detailed balance. Metropolis algorithm, Metropolis and Glauber dynamics.

8th week

Ising model in one and two dimensions. Metropolis algorithm for the Ising model. Initial and boundary conditions, thermalization of the system. Optimization of the simulation program. Measuring thermodynamic quantities by means of Monte Carlo simulations.

9th week

Monte Carlo simulation in the vicinity of the critical point, numerical determination of critical exponents. Finite size scaling.

10th week

Critical slowing down. Cluster algorithms and their efficient implementation in the Ising model. The Swendsen-Wang algorithm.

11th week

Foundation of histogram methods. Ferrenberg’s simple histogram method. Monte Carlo simulation over a broad range of temperature, the broad histogram method.

12th week

Lattice gas models, conserved order parameter (COP) Ising model as a lattice gas. Kawasaki dynamics and its efficient implementation for the COP Ising model.

13th week

Metropolis algorithm for gases and liquids. Optimization of the MC simulation program. Measuring thermodynamic quantities of gases and liquids by means of MC simulations.

14th week

Kinetic Monte Carlo simulation. Poisson statistics of transitions, transition probability and waiting time. Residence time algorithm. Efficient implementation of kinetic Monte Carlo simulations.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful completion of all the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Ferenc Kun, professor, PhD

Lecturer: Dr. Ferenc Kun, professor, PhD

Title of course: Complex networks and their applications
Code: TTFME0134

ECTS Credit points: 5

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Networks in nature and society. Classification of networks.

Network as a graph. The basics of graph theory. Directed and undirected graphs. Node degree, average degree, degree distribution. Adjacency matrix. Weighted networks. Path and distance, shortest path, diameter, average path. Connectivity. Clustering coefficient.

Random networks. The Erdős-Rényi model. Small world networks, six-step theory. Watts-Strogatz rewiring algorithm.

Scale free networks. The Price model, Barabási-Albert model. Growth and preferential attachment. Extensions of the Barabási-Albert model. Universality.

Generating networks with arbitrary degree distribution. The configuration model. The hidden parameter model. Non-linear preferential attachment. Origin of preferential attachment.

Correlated networks. Robustness of networks.

Percolation of networks. Inverse percolation transition. The Molloy-Reed criterion. Robustness against attack. Failure avalanches and their modelling. Model of failure spreading. Designing robust networks.

Communities on networks and their identification. Social and biological networks. Spreading phenomena. Modelling epidemic spreading. Network epidemics. Networks of social contacts. Immunization. Forecasting epidemic outbreaks.

Literature

Compulsory:
Barabási Albert László, Network Science (Cambridge University Press, 2016).
M. E. J. Newman, Networks: An Introduction (Oxford University Press, Oxford, 2010).

Schedule:

1st week

Networks in nature and society, real life examples. The history of network science. Relation of networks to complex systems. The potential of network approach.

2nd week

Basics of graph theory. Directed and undirected networks. Adjacency matrix. Weighted networks. Bipartit networks. The Metcalfe-law.

3rd week

Structural measures of complex networks: path, distance, shortest path, diameter, average path. Connectivity and clustering. The clustering coefficient.

4th week

Random networks: the Erdős-Rényi model. Degree distribution and clustering coefficient. Structural phases of random networks. Comparison to real networks.

5th week

Small world networks, the six-step distance. The Bacon-number. Watts-Strogatz rewiring algorithm and its computer implementation.

6th week

Scale free networks. Network centers (hubs). Ultra-small world property. The degree exponent.

7th week

Generating complex networks with an arbitrary degree distribution. The configuration model. The hidden parameter model. Network diameter and clustering coefficient.

8th week

The Price model and the Barabási-Albert model of scale free networks with directed and undirected links. Growth and preferential attachment. Degree dynamics, dynamic exponent, degree distribution. Diameter and clustering coefficient.

9th week

Measuring the degree of preferential attachment. Non-linear preferential attachment. The origin of preferential attachment. Edge selection model, copying model.

10th week

Evolving networks. The Bianconi-Barabási model. Fitness and fitness distribution. Measuring network fitness. Bose–Einstein-condensation. Extensions of the Barabási-Albert model. Removal of nodes. Accelerated growth and aging.

11th week

Correlation of node degree, the degree correlation matrix. Measuring degree correlations. Degree correlation coefficient. Generation of correlated networks.

12th week

Percolation on networks. Inverse percolation transition. The Molloy-Reed criterion. Robustness against attack. Failure avalanches and their modelling. Branching process, the branching model. Design of robust networks.

13th week

Communities on social and biological networks. Klicks. Weak and strong communities. Decomposition of networks into communities. The Kerninghan-Lin algorithm. Hierarchical clustering. Integrating algorithms. The Ravasz algorithm. Dividing algorithms. The Girvan-Newman algorithm. Klick percolation.

14th week

Spreading phenomena. Modelling epidemic deseases. Network epidemics. Immunization. Forecasting of epidemic outbreaks.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful completion of all the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Ferenc Kun, professor, PhD

Lecturer: Dr. Ferenc Kun, professor, PhD

Title of course: Phase Transitions and Critical Phenomena 1
Code: TTFME0133

ECTS Credit points: 5

Type of teaching, contct hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -

- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Phase notion, order of the transition, continuous transitions, transitions of n-order, Gibbs's phase rule, the effect of the dimensionality, role of fluctuations, effect of correlations, long range order, order parameter, Ginsburg-Landau thermodynamic potential, Kadanoff block construction, generalized homogenity, critical exponents, scaling laws, severe critical exponents and scaling laws, Orstein-Zernike behaviour, Landau theory, mean-field critical exponents, universality classes, critical slowing-down, renormalization group transformation, critical surface, basic elements of the fixpoint theory, the relation between phase transitions and renormalization group, deduction of critical exponents via renormalization group theory.

Literature

Compulsory:

N. Goldenfeld, Lectures on Phase Transitions and the Renormalization Group, Addison-Wesley, 1992.

Recommended:

J.J. Binney, N. J. Dowrick, A. J. Fisher, M. E. J. Newman: The theory of critical phenomena and introduction to renormalization group, Oxford Science Publication, Clarendon Press, Oxford, 1995.

Schedule:

1st week

The phase notion, role of the thermodynamic potential, stable and metastable states, the order of the transition in the Ehrenfest's scheme, examples for 1-4 order transitions, continuous transitions, infinite order transitions, the Gibbs phase rule and its importance in phase diagrams.

2nd week

The emergence possibility of phase transitions in 1D, Landau's deduction, notion of long range order. Essential parameters as: dimensionality, action range of the interactions, thermodynamic limit, number of components of the characteristique dynamical variable, the precence of $T > 0$ value, and their importance in qualitative changes inside the system.

3rd week

The importance of fluctuations, their dimensionality dependence, the average of the square of local fluctuations. Long range order in two dimensions, the Mermin-Wagner theorem and its consequences.

4th week

The common breaking of continuous symmetries and gauge invariance. The average value of the correlations in geometrical space, its dimensionality dependence and its connection to fluctuations. The upper and lower critical dimensions, their meaning and role.

5th week

The connection between continuous transitions and symmetry breaking, deduction of characteristics emerging from this connection. Expansion based on base functions of irreducible representations, critical regions and critical phenomena. The Landau order parameter and its connection to the symmetry breaking.

6th week

The Ginsburg-Landau thermodynamic potential for homogeneous and inhomogeneous systems, basic properties of the Ginsburg-Landau thermodynamic potential, spontaneous and non-spontaneous transitions.Characteristics and properties of the coefficients in the Ginsburg-Landau thermodynamic potential.

7th week

The correlation length and its critical exponent, Kadanoff block construction, block construction notion and characteristics, notion of block variables. Scale invariance and its consequences. Critical exponents, static scaling, generalised homogenity.

8th week

Scaling of the correlation function, scaling laws connected to the thermodinamic potential and to the pair-correlation function, relations between critical exponents. Dimensionality in scaling laws, hyperscaling. Critical exponents and scaling laws in strict sense.

9th week

The Landau theory of phase transitions, the critical exponents of the Landau theory, mean-field critical exponents, universality classes. Evaluation of the Landau theory of phase transitions.

10th week

The Orstein-Zernike correlation behavior, direct short range correlations, entanglement notion and role.

11th week

The renormalization group transformation, effectuation technique and characteristics. Flow in the parameter space of the Hamiltonian. The behavior at the phase transition, the flow far from phase transitions. Connection to universality classes.

12th week

Fixpoints, their characteristics, the notion of the critical surface, the fixpoint notions in view of the renormalization group.

13th week

Effectuation of the renormalization group transformation for different models.

14th week

Proof of the existence of the phase transition via renormalization group transformation. Relevant, irrelevant and marginal parameters.Exemplification of repulsive, attractive and critical fixpoints. Study of the renormalization group equations around a given fixpoint, the deduction technique of critical exponents.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course. During the semester there will be two written examinations (on 6th and 13th week) from lectures and practice as well. The requirement for a signature is a successful (> 20%) completion of each written exam.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Zsolt Gulácsi, professor, DSc

Lecturer: Dr. Zsolt Gulácsi, professor, DSc

Title of course: Nanodiffusion and segregation
Code: TTFME0141

ECTS Credit points: 3

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 0 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 0 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 108 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): TTFME0105

Further courses built on it: TTFME0142

Topics of course

Introduction. Continuum models: Classical diffusion theories: Fick’s I and II equations; analytical solutions of the II equation in simple cases, assuming an independent diffusion coefficient; Boltzmann transformation, parabolic (square root) (scale) law. Drift, external driving forces (Nernst-Einstein equation). Mutual diffusion. Diffusion in multilayers: The work of DuMond and Youtz; the effect of the concentration dependent diffusion coefficient on the development of the concentration profile (diffusion asymmetry, asymmetric concentration profile, sharpening); high concentration gradients (Cahn-Hilliard theory); stress and diffusion (Stephenson model). Atomic models: Diffusion mechanisms: (vacancy, interstitial, direct exchange, ...); Deterministic kinetic description of diffusion: comparison of continuum and atomistic models (diffusion coefficient - jump frequency); atomic meaning of concentration dependence of diffusion coefficient (diffusion asymmetry); the limitations of the continuum description on the nanoscale, the narrowing of the validity limit of the continuum description with increasing diffusion asymmetry; the effect of chemistry on the behavior of binary alloys (complete mixing, phase separation, ordering, solid state reaction). Anomalous kinetics, non-stoichiometric phases, dissolution of ordered phase. Modeling of diffusion with kinetic Monte Carlo method: differences in deterministic and stochastic descriptions, jump probability; the comparison of the deterministic and kinetic Monte Carlo methods. Segregation: the phenomenon of segregation; surface tension, chemistry and size effect, driving forces of segregation; equilibrium and kinetic segregation isotherms (Henry, McLean, Fowler-Guggenheim); surface segregation in deterministic kinetic and kinetic Monte Carlo models, dissolution of thin layers into substrates. Experimental techniques on the nanoscale: X-ray, synchrotron, neutron-based techniques; surface analytical methods, eg. Auger Electron Spectroscopy (AES), X-ray Photoelectron Spectroscopy (XPS), Atomic Probe Microscopy (APM: AFM, STM)

Literature

C.Kittel: Introduction to Solid State Physics
J.Philibert:Atom Movements: Diffusion And Mass Transport In Solids (Monographies De Physique)
Beke DL, Cserháti Cs, Erdélyi Z, Szabó IA, Segregation in nanostructures (Chapter 7) in Nalwa HS (ed.) Nanoclusters and Nanocrystals - Stevenson Ranch: American Scientific Publishers pp. 211-252 (2003)

Schedule:

1st week

Information, introduction.

2nd week

Continuum models

Analytical solutions of Fick’s second equation in simple cases, assuming an independent diffusion coefficient; Boltzmann transformation, parabolic (square root) (scale) law. Drift, external driving forces (Nernst- Einstein equation)

3rd week
Continuity models

Interdiffusion. Diffusion in multilayers: Beginning with the work of DuMond and Youtz;

4th week
Continuity models

The effect of the concentration dependent diffusion coefficient on the development of the concentration profile (diffusion asymmetry, asymmetric concentration profile, sharpening);

5th week
Continuity models

Interdiffusion in high concentration gradients, Cahn-Hilliard theory;

6th week
Continuity models

Stress and diffusion, Stephenson model

7th week
Atomic models
Diffusion mechanisms: (vacancy, interstitial, direct exchange, ...);

Deterministic kinetic description of diffusion: comparison of continuum and atomistic models (diffusion coefficient - jump frequency); the atomic meaning of the concentration dependence of the diffusion coefficient (diffusion asymmetry).

8th week
Atomic models

The limitations of the continuum description on the nanoscale, the narrowing of the validity limit of the continuum description with increasing diffusion asymmetry; the effect of chemistry on the behavior of binary alloys (complete mixing, phase separation, ordering, solid state reaction). Anomalous kinetics, non-stoichiometric phases, dissolution of ordered phases.

9th week
Atomic models

Modeling fs diffusion with kinetic Monte Carlo method: Differences in deterministic and stochastic descriptions, jump probability; the comparison of deterministic and kinetic Monte Carlo methods.

10th week

Segregation: The phenomenon of segregation; surface tension, chemistry and size effect as driving forces of segregation motors; equilibrium and kinetic segregation isotherms (Henry, McLean, Fowler-Guggenheim).

11th week

Segregation: Surface segregation in the deterministic kinetic and kinetic Monte Carlo models, dissolution thin layers into substrates.

12th week
Experimental techniques on the nanoscale

Diffusion: X-ray, synchrotron, neutron-based techniques;

13th week
Test methods on the nanoscale

Segregation: surface analytical techniques, eg. Auger Electron Spectroscopy (AES), X-ray Photoelectron Spectroscopy (XPS), Atomic Probe Microscopy (APM: AFM, STM)

14th week
Summary, consultation

Requirements:
- for a signature

Attendance at **lectures** is recommended, but not compulsory.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Prof. Dr. Zoltán Erdélyi, full professor, DSc

Lecturer: Prof. Dr. Zoltán Erdélyi, full professor, DSc

Title of course: **Magnetism and nanomagnetism** **Code**:	**ECTS Credit points:** 5

Type of teaching, contact hours
- lecture: 2 hours/week

- practice: 1 hours/week
- laboratory: 1 hours/week

Evaluation: practical grade (practice and laboratory), exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: 14
- home assignment: 14 hours
- preparation for the exam: 40 hours

Total: 110 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): - elektromagnetism

Further courses built on it: -

Topics of course

Interactions between materials and magnetic field, the most important parameters of magnetic materials, classification and characterization of magnetic materials. Magnetic moments of atoms, dia, para and ferromagnetism. Measurement methods of magnetic parameters, magnetization curves, magnetic hysteresis, phenomenological model of ferromagnetism, Curie-Weiss law. Exchange interaction, exchange energy, exchange integral, Ising-model. Anisotropies; magnetocrystalline anisotropy, shape anisotropy. Ferromagnetic domains, domain walls; Bloch-wall, Neel-wall, reversible and irreversible motion of domain walls, origin of Barkhausen-noise, detection, analysis and applications of Barkhausen-noise. Experimental methods for observation of ferromagnetic domain structures. Soft magnetic materials; crystalline, amorphous, nanocrystalline metallic materials and ferrites. Properties, fabrication and applications of soft ferromagnets. Hard magnetic materials; traditional alloys, rare-earth magnets, hard ferrites, properties, fabrication and applications. Isolated ferromagnetic nanoparticles, superparamagnetism. Spin-glasses, cluster-glasses, magnetic properties of nanocrystalline materials. Related phenomena; magnetostriction, magnetostrictive materials, magnetic shape memory and applications, magnetic resistance, giant and colossal magnetic resistance, applications

Laboratory practices:

Lab.1. Measurement of ferromagnetic hysteresis loops by induction method.

Lab.2. Measurement of magnetization curves by vibration magnetometer.

Lab.3. Measurement of magnetic field by fluxgate magnetometer

Lab.5. Barkhausen noise and magnetic emission measurements, statistical noise analysis.

Lab.6. Industrial Barkhausen noise measurement, determination of stress fields in steels.

Lab.7. Measurement of magnetostriction and magnetic shape memory effect.

Literature

Slides, tests etc. : moodle.phys.unideb.hu\ magnetism and nanomagnetism

Compulsory:
C. Kittel: Introduction to Solid State Physics
K. Kreher: Solid State Physics

Recommended:

J. Crangle: Solid State Magnetism
F. Fiorillo:Measurement and Characterisation of Magnetic Materials
E. Della Torre: Magnetic Hysteresis
G. Bertotty: Hysteresis in magnetism
S. Tumansky: Handbook of Magnetic Measurements

Schedule:

1st week

Materials in magnetic field, properties, classification and characterisation of magnetic materials.

2nd week

Magnetic moment of an atom

.3rd week

Dia, para and ferromagnetism

4th week

Basics of ferromagnetism, magnetization curve, measurement methods of magnetization curve

5th week

Phenomenological theory of ferromagnetism, Curie-Weiss law

6th week

Exchange interaction, Ising-model

7th week

Anisotropies in ferromagnetic materials, magnetic domains

8th week

Experimental methods for observation of domain structures, origin of Barkhausen-noise, measurement methods and applications of Barkhausen noise.

9th week

Soft magnetic materials, properties and applications

10th week

Hard magnetic materials, properties and applications

11th week

Ferromagnetic nanoparticles (superparamagnetism)

12th week

Spin glasses, cluster glasses, amorphous and nanocrystalline materials

13th week

Related phenomena, magnetostriction, magnetic shape memory, magnetic resistance, giant magnetic resistance (GMR)

14th week

Summary, discussion

Laboratory practices in small groups by individual timetable.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be submitted. The requirement for a signature is a successful (> 50%) completion of the home works.

- *for a grade*

The course ends in an **examination**. The requirement for applying for an exam is to have practical signatures and grades at least 2 (practice and laboratory practice as well).

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Lajos Daróczi, associate professor, PhD

Lecturer: Dr. László Tóth, assistant professor, PhD

Title of course: Measurement of materials properties
Code: TTFML0144

ECTS Credit points: 2

Type of teaching, contact hours
- lecture: 0 hours/week
- practice: 0 hours/week
- laboratory: 2 hours/week

* **Evaluation:** signature + grade for lab.report

Workload (estimated), divided into contact hours:
- lecture:
- practice:
- laboratory: 32
- home assignment: 32 hours
- preparation for the exam:

Total: 64 hours

Year, semester: Condensed Matter course block

Its prerequisite(s): Condensed Matter 3. TTFME0105

Further courses built on it: -

Topics of course

to expand the knowledge about the subject with the help of 8 4-hour measurement exercises taken from the topic of condensed materials..

Literature

Compulsory: The students are provided by 10-20 page measurement instructions prepared by the Institute.
Recommended:

Schedule:

1st week

Information, introduction, accident and safety instruction, discussion of laboratory schedule.

2nd week

Metallographic studies by light microscopy.

3rd week

Examination of surface and composition by scanning electron microscopy.

4th week

Structural examination by transmission electron microscopy.

5th week

Preparation of thin films and depth analysis of the prepared specimens by secondary neutral mass spectrometry

6th week

Structural analysis by X-ray diffraction.

7th week

Investigation of ferromagnetic materials using Barkhausen noise method

8th week

Preparation of alloys by arc melting method

9th week

Surface studies with SPM and AFM equipment.

Requirements:

* • the basic knowledge of the laboratory practice theory, the measurement, the preparation of a measurement report in electronic form: sufficient;
• accurate knowledge of the theory of exercises, carrying out the measurement, making a measurement report in electronic form: medium;
• Basic knowledge of laboratory practice theory, accurate measurement and evaluation of measurements, preparation of measurement report in electronic form: good;
• accurate knowledge of laboratory practice theory, accurate measurement and evaluation of measurements, preparation of measurement report in electronic form: excellent.

Person responsible for course: Dr. Csaba Cserháti, associate professor, PhD

Lecturer: Dr Csaba Cserháti and Dr. Lajos Daróczi, associate professor, PhD

Title of course: Transmission and analytical electronmicroscopy **Code**: TTFME0146	**ECTS Credit points:** 5

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: 1 hours/week

* **Evaluation:** exam

Workload (estimated), divided into contact hours:

- lecture: 28
- practice: 14
- laboratory: 14
- home assignment: 14 hours
- preparation for the exam: 40

Total: 100 hours

Year, semester: Condensed Matter course block

Its prerequisite(s):

Further courses built on it: -

Topics of course

To get acquainted with the most important method used in transmission electron microscopy used in modern materials science, with special regard to structural analysis..

Literature

Compulsory: Williams, David B., Carter, C. Barry: Transmission Electron Microscopy A Textbook for Materials Science
Recommended:

Schedule:

1st week

Information, introduction. The place of microscopy in materials science

2nd week

Presentation of the principles and operating methods of atomic or near-atomic resolution scanning probe microscopes (SPM, AFM, etc.)

3rd week

Structure and operation modes of the transmission electron microscope

4th week

Repetition and extension of the basic crystallological concepts necessary for the discussion of electron diffraction and the reciprocal lattice space.

5th week

Kinematic theory of electron diffraction and its application 1.

6th week

Kinematic theory of electron diffraction and its application 2.

7th week

Dynamatic theory of electron diffraction and its application 1.

8th week

Dynamatic theory of electron diffraction and its application 2.

9th week

Electron diffraction phenomena, Kikuchi lines

10th week

Convergent beam electron diffraction

11th week

Theory of image formation

12th week

X-ray microanalysis in the TEM

13th week

Electron Energy Loss Spectroscopy (EELS) in the TEM

14th week

Summary, consultation

Requirements:

- * • Participation in practical and laboratory activities, the condition for admission to the exam is the successful completion of the related practice and laboratory
- * • Knowledge of the laws, items and definitions related to the topic in the exam: sufficient;
- * • in addition, knowledge of the main steps in deriving the most important theories and regularities: medium;
- * • in addition, deriving the derivations with less help, seeing the connections: good;
- * • in addition, derivation of derivations without help, ability to apply them: remarkable.

Person responsible for course: Dr. Csaba Cserháti, associate professor, PhD

Lecturer: Dr. Lajos Daróczi, associate professor, PhD

Title of course: Environmental Physics 3. **Code**: TTFME0153	**ECTS Credit points: 4**

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: written or oral exam (and Implementation of a project task)

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Environment and risk, Cosmic radiation environment, Radon in the environment, Environmental effects of nuclear reactor accidents, Climate change, Environmental noise, Volcanoes of the Carpathian-Pannonian region, Aerosol pollution in the atmosphere, Extreme aerosol effects, Normal emissions of nuclear power plants; Disposal of radioactive waste, Flows in the environment, water resources and threats, Water infiltration, age determination, Alternative energy sources, Stabil isotope ratio measurements: $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, $\delta^{34}S$, δD

Literature

Compulsory:

Text distributed in Moodle environment

Schedule:

1st week

Environment and risk

2nd week

Cosmic radiation environment

3rd week

Radon in the environment

Lab: Etched track detector measurements

4th week

Environmental effects of nuclear reactor accidents

Lab: Analytics of environmental radioisotopes (gamma spectrometry)

5th week

Climate change

6th week

Environmental noise

7th week

Volcanoes of the Carpathian-Pannonian region

8th week

Aerosol pollution in the atmosphere

9th week

Extreme aerosol effects

Lab: PIXE

10th week

Normal emissions of nuclear power plants; Disposal of radioactive waste

Lab: LSC measurement technique

11th week

Flows in the environment, water resources and threats

12th week

Water infiltration, age determination

Lab: Noble gas mass spectrometry

13th week

Alternative energy sources

14th week

Stabil isotope ratio measurements: $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, $\delta^{34}S$, δD

Lab: MICADAS

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.
During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.
The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Eszter Baradács, assistant professor, PhD

Lecturers:

Dr. Eszter Baradács, assistant professor, PhD; Dr. László Palcsu, senior research associate, PhD, Dr. Zsófia Kertész, senior research associate, , PhD; Dr. Futó István, research associate PhD; Dr. Zsolt Benkó, research associate PhD; Dr. István Csige, senior research associate PhD; Dr. Róbert Janovics, research associate, PhD;

Title of course: Simulation of Environmental Processes

Code: TTFME0154

ECTS Credit points: 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: written or oral exam (and Implementation of a project task)

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 2nd year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

The goal and role of computer simulation in environmental sciences. Advantages, constrains and limitations of computer simulations in problem solving in environmental sciences. Modelling types, model selection. Reliability of modelling, international intercomparison exercises. Analysis of parameter sensitivity and parameter uncertainty. Compartment models.

Behaviour of radionuclides in the environment. Modelling transport of radionuclides in the atmosphere. Subsurface transport. Contamination of the food chain. Groundwater flow and contaminant transport

Literature

Compulsory:

Text distributed in Moodle environment

Recommended:

Schnoor JL (1996) Environmental modeling: fate and transport of pollutants in water, air, and soil. Wiley, New York

Nirmalakhandan N (2002) Modeling tools for environmental engineers and scientists. CRC, Boca Raton, FL

Schedule:

1st week

Introduction. The goal and role of computer simulation in environmental sciences. Constrains and limitations of computer simulation.

2nd week

Introduction to SciLab: SciLab basics, setup of SciLab, SciLab as an advanced calculator, graphing in 2D.

3rd week

Basics of SciLab programming: SciNotes, Definition and use of user functions, cycles, export of data to files

4th week

Behaviour of radionuclides in the environment. The transport equation.

5th week

Modelling transport of radionuclides in the atmosphere

6th week

Modelling transport processes in soil

7th week

Contamination of the food chain

8th week

Pollution of the water environment. Basic equations of water flow and contaminant transport. Theoretical background of modelling.

9th week

Differential equation in SciLab 1.

10th week

Differential equation in SciLab2.

11th week

Differential equation in SciLab 3-4.

12th week

Implementation of a project task

13th week
Implementation of a project task

14th week
Atmospheres of the planets and of some moons of the Solar System.

Requirements:
- for a signature
Attendance at **lectures** is recommended, but not compulsory.
Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.
During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.
- for a grade
The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.
The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Eszter Baradács, assistant professor, PhD

Lecturers:
Dr. Eszter Baradács, assistant professor, PhD

Title of course: Radiation protection and dosimetry
Code: TTFME0151

ECTS Credit points: 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: -
- laboratory: 1 hours/week

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: -
- laboratory: 16 (4x4) hours
- home assignment: 14 hours
- preparation for the exam: 40 hours

Total: 98 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Overview of measuring instruments and methods for measuring and estimating environmental radioactivity, ionizing radiation and radiation dose. The interaction between ionizing radiation and matter. The chemical and biological processes generated by the radiation in the living material and their biological effects. Stochastic and deterministic effects. Dosimetry concepts. Exposure to population due to natural and artificial radiation sources. Principles, methods and tools of radiation protection. Radiation protection norms and legal regulation. Dosimetry measurements in laboratory practice (environmental gamma dose rate measurement, radon dose estimation, scaling of shielding against gamma radiation).

Literature

Compulsory:

ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection

IAEA General Safety Requirements Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards

Recommended:

RADIATION ONCOLOGY PHYSICS: A HANDBOOK FOR TEACHERS AND STUDENTS, IAEA, VIENNA, 2005

Schedule:

1st week

Ionizing and non-ionizing radiations in the environment. Origin and properties of these radiations. Primary cosmic rays and showers of secondary particles generated by the primary ones in the Earth's atmosphere. The origin of the radionuclides present in the environment, their quantitative environmental distribution and the nuclear radiations arising from their radioactive decay. External and internal radiations (from the point of view of the human body).

2nd week

The interaction between radiation and matter. Interaction of the ionizing radiation with the material. Special features of the interaction of alpha, beta, gamma, neutron and X-ray radiation. Changes in the material: ionization, excitation, ionization density, breakdown of chemical bonds, recombination of ions, de-excitation of atoms, growth of internal energy, radiation damage. Changes in radiation characteristics: loss of energy, scattering, absorption, range. The dependence of the former on the type of radiation and the material quality.

3rd week

The concept and types of radiation exposure. Natural, occupational, medical, accidental, potential exposure. Radiation dose, as a measure of the extent of lesions occurring in the ex-posed material. Different dose quantities and their units of measure, the considerations that led to their creation. Kerma, absorbed dose, equivalent dose, effective dose, collective dose. The role of radiation type, the weight factor of radiation. The role of radiation absorbing material (live or inanimate, type of living body tissue), the weight factor of body tissues or organs. The role of time, dose rate. Organ dose and whole body effective dose. The role of the location of the radiation source: external or internal dose. Committed dose.

4th week

Possibilities and limitations of experimental determination of dose. Physical basics of the operation of the experimental tools and methods used to measure dose. Operation of radiation detectors applied to dose measurements. Ionization chamber, proportional counter, Geiger-Müller counter. The proportionality of the counting rate with dose rate. Dosimeters based on thermo-luminescence, photochemical transformation and particle track detection. Proportionality of the measure of luminescence, dimming and track density with dose. Personal dosimeters: film dosimeter, thermosluminescent dosimeter, pen dosimeter, solid state track detector. Problems with the calibration of dosimeters. Determination of internal dose based on measurements using whole body counters.

5th week

Possibilities and limitations of the determination of dose by calculations. Estimation of external dose by calculations. How the amount and internal distribution of the external dose de-pend on the type of radiation? The spatial distribution of dose near point sources of beta and gamma radiation. Production of simple spatial dose distributions for calibration of dosimeters, estimation of corrections by calculations. The spatial distribution of dose from a radiation source that is distributed evenly in half-space. The spatial distribution of dose from a radiation source that is distributed evenly over an endless plane. The assumptions and calculations required to estimate internal dose. Estimate of dose from inhalation (radiation source deposited on the inner surface of the airways). Estimation of dose from ingestion.

6th week

The amount of annual human dose (obtained from ionizing radiation) from different environmental sources. Doses from natural sources. Dose from cosmic rays. Doses from the radiation of radionuclides decaying outside the body and within the body. Doses arising from dietary intake and inhaled radionuclides. World average doses and regional differences. Doses from artificial sources. Doses from medical applications of ionizing radiation and radioisotopes. Doses from artificial radioactivity released into the free environment. War and accident doses. Occupational doses.

7th week

Direct microbiological effects of ionizing radiations. Formation of free radicals. Damage to biomolecules: DNA breaks, membrane injuries. Correcting DNA damage. Cell death. Changes in cell cycle regulation. Physical, chemical and biological factors that modify the microbiological effects of radiation (radiation type, dose rate, temperature, oxygen effect, water content, amount of antioxidants, cell cycle state, age, gender). Radiation sensitivity of the living world.

8th week

Physiological changes, symptoms, illnesses and death caused by ionizing radiations depending on the dose. Increase in the frequency of malignant tumors and mutations in the population due to a moderate extra dose. Randomness and risk of effects. Molecular and cell biology mechanisms of malignant tumor formation. Biological effects of low doses: doubts about the linearity between the dose and the triggered effect (risk).

9th week

Certainly and within a short period of time occurring symptoms and bodily changes in case of large extra doses. Diseases of some organs and their dose thresholds (immune system, gastro-intestinal tract, genitals, skin, vascular system, central nervous system, lens of the eye). Symptoms and clinical course of acute radiation disease. Median lethal and lethal dose. Late residual effects. Local radiation injuries. Radiation accidents involving personal injury and the lessons learned from these cases.

10th week

Environmental quantities, biological effects and dosimetry of non-ionizing electromagnetic radiations. Power density of ultraviolet, visible and infrared radiation from the Sun. The power density of artificial electromagnetic radiations depending on the distance from various electrical equipment. Dosimetry quantities: specific (per mass unit or surface unit) absorbed energy and power. Methods for measuring dosimetric quantities. Absorption ability of human body material as a function of frequency. Free radicals, molecular breakdowns, generation of electricity and heat in the body. Physiological changes, symptoms.

11th week

The concept of radiation protection, regulation of radiation-related activities at a social level to protect human health. Basic principles and basic concepts of radiation protection. Requirement of justification for radiation hazardous activity, principle and practice of optimizing the protection against radiation, application of individual dose limits, exemption. Deriving dose limits from the estimated risks. Intervention to reduce radiation exposure. Radiation protection for radiological sources. Radiation protection of the population. Exemption and intervention levels and dose limits for workers with radiation sources and population.

12th week

Practical methods of protection against ionizing radiation and reducing radiation exposure. Precautionary measures to avoid the occurrence of radiation exposure. Radiation hazardous occupations. Guidelines for the design of radiation hazardous workplaces, work safety regulations. Personal dosimetry. Methods for protection against external radiation. Time protection, distance protection, radiation absorbing protective layers. Shielding alpha, beta, gamma and neutron radiation. Protection against internal radiation. Rules of work with open radioactive preparations. Radiation protection inspections and radiation protection education.

13th week

Possibilities for reducing exposure to the population. Methods to reduce the radon concentration in residential areas. Possibilities and ways of reducing the population exposure to radiations applied in medical interventions. Ways of intervention to protect the population in the event of the use of a nuclear weapon or a nuclear installation accident. Isolation, rescue, iodine prophylaxis, migration, restriction of food consumption, radiological decontamination. Radiation protection control of the natural environment. National control programs. Checking the environment of nuclear facilities. Experience with nuclear accidents and radiation source accidents.

14th week

International and national organizational system of radiation protection. Recommendations from the International Commission on Radiological Protection (ICRP), the role of the International Atomic Energy Agency (IAEA) and other international organizations. The EURATOM Directive. The institutional system of radiation protection in Hungary. The legal regulation of radiation protection activity. The 1996 CXVI. Act on Nuclear Energy and the government decrees on its implementation.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **laboratory sessions** is compulsory. The student must attend all the four sessions. In case the student doesn’t so, the course will not be signed and the student must repeat it. Attendance at laboratory sessions will be recorded by the session leader. Being late is equivalent with an absence. Students are required to bring drawing instruments to each sessions. Active participation is evaluated by the teacher. If a student’s behavior or conduct doesn’t meet the requirements of active participation, the teacher may evaluate his/her participation as an absence.

The student will obtain partial grades for all the four laboratory sessions one by one. The partial grades go from fail (1) to excellent (5) at the discretion of the session leader. For the laboratory signature, the student has to complete all the laboratory sessions with a partial grade better than fail (1). If the latter condition is not met then the student must repeat the laboratory sessions.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a laboratory signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Zoltán Papp, associate professor, PhD

Lecturer: Dr. István Csige, associate professor, PhD

Title of course: Physics of the Atmosphere **Code**: TTFME0155	**ECTS Credit points: 3**

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: -
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: -
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 108 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

The formation and evolution of the atmosphere. Atmospheres of the planets of the Solar System. Composition of Earth's atmosphere (permanent and variable components; origin, point and extended sources; geogases; biogenic and anthropogenic sources). Vertical and horizontal motions in the atmosphere and their effects on the physical-chemical properties of the atmosphere (thermal convection, advection, diffusion). Application of some cosmogenic radioactive isotopes (Be-7, T) in the study of motion and mixing of air masses. Calculation of atmospheric trajectories and of spatial and temporal variations of concentrations.

Literature

Compulsory:
John Houghton: The physics of atmospheres. Cambridge University Press
Recommended:
The Atmosphere. Ed.: R. F. Keeling, Elsevier, 2006.

Schedule:

1st week

The formation and evolution of the atmosphere.

2nd week

Composition of Earth's atmosphere (permanent and variable components; origin, point and extended sources; geogases; biogenic and anthropogenic sources).

3rd week

Thermodynamics. Barometric formula of the atmospheric pressure. Dry adiabatic lapse rate and moist adiabatic lapse rate.

4th week

Vertical and horizontal motions in the atmosphere and their effects on the physical-chemical properties of the atmosphere (thermal convection, advection, diffusion).

5th week

Radiative transfer in the atmosphere

6th week

Sampling of aerosol. Experimental methods to determine mass concentration, size distribution and chemical composition. Optical properties of aerosol (scattering and absorption of light on aerosol).

7th week

Sources and spatial and temporal variations of aerosol, range of concentrations, environmental and health effects.

8th week

Application of some cosmogenic radioactive isotopes (Be-7, T) in the study of motion and mixing of air masses. Calculation of atmospheric trajectories and of spatial and temporal variations of concentrations

9th week

Analytics of carbon dioxide (modern procedures based on sensors). Stable isotope composition of carbon dioxide, carbon and oxygen mass spectrometry.

10th week

Global cycle of carbon. Isotope effects in the global carbon cycle; flux determination from measurements of micrometeorology and isotope ratios.

11th week

Global water cycle. Water in the atmosphere, precipitation, evapotranspiration. Stable isotope composition of water, analytical mass spectrometry.

12th week

Physics of isotopes of water: fractionation processes and their application in paleoclimatology.

13th week

Physical analytics of carbon monoxide and noble gases. Application of tracer gases in the study of transport processes in the atmosphere.

14th week

Atmospheres of the planets and of some moons of the Solar System.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. István Csige, associate professor, PhD

Lecturers:
Dr. István Csige, associate professor, PhD
Dr. Elemér László, associate professor, PhD

Title of course: Measurements in environmental physics
Code: TTFML0156

ECTS Credit points: 2

Type of teaching, contact hours
- lecture: -
- practice: -
- laboratory: 2 hours/week

Evaluation: grade for written laboratory record

Workload (estimated), divided into contact hours:
- lecture: -
- practice: -
- laboratory: 28 (7x4) hours
- home assignment: 14 hours
- preparation for the exam: -

Total: 42 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Study of photovoltaic phenomena. Experiments with microwaves. Solar panels. Learn and use a handheld GPS device. Measurement of ambient noise. Measurement of the density of small particles. Measurement and analysis of weather variables.

Each of the above measurements has duration of 4 hours and the laboratory practice is therefore kept in 4-hour blocks in one half of the semester.

Literature

Compulsory:
Mandatory laboratory syllabuses for each practice required by the laboratory sessions leader.
Recommended:
For each practice, the data sources recommended by the laboratory sessions leader.

Schedule:

The themes cannot be recorded weekly in advance for all of the student because each student does their own practice alone, the same week each student performs different exercise and the order of the exercises will be different for each student. At the beginning of the semester, a schedule will be made as to which week which student will do which exercise.

1st exercise

Measurement of photovoltaic phenomena. Instruments used: mercury vapor discharge tube; semiconductor photodiode; optical devices; voltage amplifier; voltmeter. Students are familiar with the photovoltaic phenomenon, with the experimental tools required to study it and experimentally study the dependence of electric voltage on the photovoltaic phenomenon from the wavelength of the light.

2nd exercise

Studying the properties of microwaves. Tools used: klystron with waveguide tube, horn antenna and power supply (transmitter); dipole antenna with horn antenna (receiver); amplifier and sound generator loudspeaker; optical devices. The student will become familiar with the production of electromagnetic microwaves and their main properties. Studies the microwaves reflection on a metal plate, refraction at the air/paraffin boundary, polarization with grid, diffraction by an obstacle. The student determines the wavelength of the microwaves in a Michelson interferometer arrangement and studies the waveguide ability of the waveguide tube.

3rd exercise

Investigating the operation of solar cells. Tools used: solar cells; incandescent lamp; photo-resistor; multimeters; potentiometer; DC power supply. The student becomes acquainted with the operation of the solar cell and the accompanying devices suitable for studying it. The student is experimentally studying the dependence of the conductivity of the photo-resistor on the intensity of the illumination and the characteristics of the solar cell (how the idle voltage and the short-circuit current depend on the intensity of the illumination).

4th exercise

Learn and use a handheld GPS device. Tools used: handheld GPS device; data processing computer with suitable software; printer. The student becomes acquainted with the principle, implementation and application of the global satellite positioning method and the operation of the device he uses. The student gets acquainted with the need for unobstructed access to the satellites, with the most important settings of the device. Executes waypoints along a route on a map, try the tracking function. The student records a route and navigates through a navigational aid with a pre-recorded route, measures altitude, searches for a previously recorded location, and stores, records, and prints data recorded by the computer.

5th exercise

Measurement of ambient noise. Devices used: handheld noise measuring device; calibration device; computer with suitable software. The student stands out with the concept of noise, the principle of noise measurement, its execution, and the operation of the instrument he uses. The student calibrates the device, then examines the urban traffic noise. In this context the student measures the maximum noise level or makes longer noise recordings at different public areas. The on-site noise recordings are subsequently evaluated in the laboratory by computer soft-ware. Draws conclusions from the measurement results obtained.

6th exercise

Measurement of the density of small particles. Tools used: pycnometer; balance; distilled water flask; ultrasonic thermostat; filter paper; rock granulate of unknown density. The student determines the work volume of the pycnometer. The student pour a suitable amount of rock granulate into the pycnometer and measures the mass of the rock granulate with balance. Then fills the pycnometer with distilled water up to a mark while measuring the water volume. Then calculates the bulk density of the rock granulate from the measured mass and volumes. Repeats the measurement and calculation after ultrasonic ventilation and compares the result to the previous one. Draws conclusions from the results obtained.

7th exercise

Measurement and analysis of weather variables. Tools used: compact automatic weather station; computer with suitable software. The student becomes acquainted with the basic principles of measurement of weather variables, with the necessary tools and the construction and operation of the measuring system he uses. The student reads from the console of the station and records the current values of the weather variables. From the console's memory, the student uploads data from the last one week to the computer and gets acquainted with the weather station software. Using the software gives a textual description about the weather of his/her recent birthday (in Debrecen), calculates the average temperature of the previous day and then calculates the absolute humidity of the air at some different times. Draws conclusions from the results.

Requirements:

- for a signature

Participation at laboratory sessions is compulsory. A student must attend all the seven sessions. In case a student doesn't so, the course will not be signed and the student must repeat it. Attendance at laboratory sessions will be recorded by the session leader. Being late is equivalent with an absence. Students are required to bring drawing instruments to each sessions. Active participation is evaluated by the teacher. If a student's behaviour or conduct doesn't meet the requirements of active participation, the teacher may evaluate his/her participation as an absence.

- for a grade

The student will obtain grades for all the exercises one by one. The grades go from fail (1) to excellent (5) at the discretion of the session leader. The grade of the course will be the arithmetic mean of the grades obtained for each exercises rounded to the full, provided that the student has completed all the exercises with a grade better than fail (1). If the latter condition is not met then the grade of the course is fail (1) and the student must repeat the course in conformity with the EDUCATION AND EXAMINATION RULES AND REGULATIONS.

Person responsible for course: Dr. Zoltán Papp, associate professor, PhD

Responsible instructor: Dr. Eszter Baradács dr. Erdélyiné, assistant professor, PhD

Title of course: Advanced Nuclear Physics **Code**: TTFME0161	**ECTS Credit points:** 4

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Nuclear structure. The basic idea of the shell model, harmonic oscillator, geometric and dynamic symmetry, spin-orbit interaction, magic numbers. Deformed nuclear states, spontaneous symmetry breaking, liquid drop model of vibration and rotation. Elliott model: shell model of collectivity, dynamically breaking symmetry. Wigner's supermultiplets, quartets, nuclear cluster model, spectrum generating and dynamic algebras. Boson model of collectivity, supersymmetry. Phase transitions in nuclei, cold quantum phases, quasi-dynamic symmetry. Microscopic model of collectivity, relationship between shell, collective and cluster model, multichannel symmetry. Ab initio method, the truncated shell model. Other structure models. Nuclear reactions. Compound nucleus model. Direct reactions. Pre-equilibrium model. Nuclear decay, limits of stability. Exotic radioactivity. Spontaneous fission.

Literature

Recommended:
H.J. Lipkin: Lie groups for pedestrians, North-Holland Amsterdam, 1966
S.S.M.Wong: Nuclear Physics, John Wiley & Sons NY, 1998
D.J. Rowe, J.L. Wood: Fundamentals of Nuclear Models, World Scientific New Jersey, 2010
T Dytrich, K. D. Sviratcheva, J. P. Draayer, C. Bahri and J. P. Vary: Ab initio symplectic no-core shell model, TOPICAL REVIEW, J. Phys. G. Nucl. Phys. 35 (2008) 123 101
P. Van Isacker: Symmetries in Nuclei, arXiv:1012.3611v1 [nucl-th]
J. Cseh: Algebraic models for shell-like quarteting of nucleons, Physics Letters B 743 (2015) 213

Schedule:

1st week

Nuclear structure. The basic idea of the shell model, harmonic oscillator, geometric and dynamic symmetry.

2nd week

Spin-orbit interaction, magic numbers.

3rd week

Deformed nuclear states, spontaneous symmetry breaking, liquid drop model of vibration and rotation.

4th week

Elliott model: shell model of collectivity, dynamically breaking symmetry.

5th week

Wigner's supermultiplets, quartets.

6th week

Nuclear cluster model, spectrum generating and dynamic algebras.

7th week

Boson model of collectivity, supersymmetry.

8th week

Phase transitions in nuclei, cold quantum phases, quasi-dynamic symmetry.

9th week

Microscopic model of collectivity, relationship between shell, collective and cluster model, multichannel symmetry.

10th week

Ab initio method, the truncated shell model. Other structure models.

11th week

Nuclear reactions. Compound nucleus model.

12th week

Direct reactions. Pre-equilibrium model.

13th week

Nuclear decay, limits of stability. Exotic radioactivity. Spontaneous fission.

14th week
Consultation.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

During the semester there are practical home works which have to be evaluated and submitted by the end of the 14th week of the semester. The requirement for a signature is a successful (> 50%) completion of the home works.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Judit Darai, associate professor, PhD

Lecturer: Dr. Judit Darai, associate professor, PhD

Title of course: Nuclear technologgy **Code**: TTFME0162	**ECTS Credit points:** 4

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Characterization of nuclear states and processes. Data measurements in nuclear physics. Interaction of radiations with matter: light and heavy charged particles, neutral particles, gamma-radiation. Detection and spectrometry, characteristic parameters of the instruments. Operation basics of radiation detectors: creation of electric charge (gas, semiconductor), light production (scintillation, Cherenkov and transition radiations). Methods of activity measurements in various time domains. Determination of energy, momenta and velocity. Features and devices of gamma-spectrometry; single and correlation measurements. Methods to study the time behavior of nuclear states and interpretation of the results. Visual and electronic position sensitive detection. Particle identification techniques: deflection by electromagnetic fields, energy loss in materials and pulse shape analysis. Principles, construction and operation of high energy particle accelerators. Main ideas of experiments in neutron physics: sources, detectors and methods. Calorimetry in particle physics. Fundamentals of neutrino physics: particle properties, detection techniques, relations to astrophysics, oscillation. Principles and exploitation ways of nuclear energy. Applications of nuclear fission, nuclear safety. Thermonuclear fusion in the cosmos and the Earth: implementations and problems. Expected environmental impacts of the operation and fuel cycle of nuclear energetics. Comparison with other sources of energy.

Literature

Compulsory:
G.F.Knoll: *Radiation Detection and Measurement*. (4th ed. J.Wiley, 2010.)
Recommended:

1) Relevant chapters in *2016 Review of Particle Physics*, *Experimental Methods and Colliders*, http://pdg.lbl.gov/2017/reviews/contents_sports.html
2) Lecture notes and some supplements: http://falcon.phys.unideb.hu/~raics/public/NukTech/English/

Schedule:

1st week

Structure of the matter; interactions. Main physics quantities. Symmetries and conservation laws. General properties of nuclei, scheme of the nuclear interactions, excited states. Reaction kinematics.

2nd week

Measurement procedures: spectroscopy, collisions (scattering), nuclear reactions. Results of the experiments: integral and differential cross sections, excitation function. Summary of the reaction models. Interaction of radiations with matter: detection and destruction.

3rd week

General principles of the measurements. Components and properties of single channel experiments. Multi parameter systems: prompt relations and analysis of event-by-event data collections. Evaluation: decay statistics, error calculations, curve fitting. Counting losses. Sample preparation.

4th week

Detector types and properties. Electronic signal processing. Differential and integral type measurements. Detection of charged particles. Gamma-spectrometry by scintillation and semiconductor detectors. Correlation methods. Activity determination.

5th week

Time measurements; determination of the life time, half life. Electronic solutions for timing. Utilization of the nuclear physics principles (nuclear recoil, Doppler-shift, channeling effect, resonances, Mössbauer-effect).

6th week

Particle identification methods:deflection in electric and magnetic fields, specific energy loss, pulse shape discrimination. Telescope technique. Methods for velocity measurements.

7th week

Visual methods for track detection: cloud and bubble chamber, light phenomena from gas discharge. Electronic methods for real-time processing: multiwire proportional and drift chambers, gas- and semiconductor strip detectors, time projection chamber, mosaic construction scintillation detectors, semiconductor matrix cameras.

8th week

Principles of high energy accelerators, construction and operation. Detection with electromagnetic and hadron calorimeters. System setup, operation, data handling and evaluation of the CERN Large Hadron Collider at its detector systems.

9th week

Instruments of neutron physics: sources, detectors, moderators. Methods of neutron spectrometry:proton scattering, time-of-flight, charged particle nuclear reactions, foil activation, slowing-down time and length.

10th week

Physics of nuclear energetics: decay, fission, fusion. Operation principle, construction, types and generations of nuclear reactors. Implementation of the fuel cycles and extension their sustainability. Handling of nuclear waste and the environment. The Nuclear Power Plant in Paks: its role in the domestic electric energy supply; its further development.

11th week

Nuclear reactons of the fusion process in the stars. Possible realization ways on the Earth with the heavy hydrogen izotopes. Operation principle of the Tokamak systems. Fuel cycle: production of deuterium and tritium. External and internal contamination. Technical problems in the realization of the fusion reactor.

12th week

Role of the neutrinos in the weak ineraction. Indirect demonstration of their existence and the Debrecen experiment. Prompt and delayed methods of the direct demonstration. Diversity of the neutrinos in the Lepton-families. Oscillations.

13th week

Beginning of the neutrino astronomy. Observation of the Solar neutrino anomaly in the experiments and the solution to the problem. Observation of a supernova explosion by neutrinos and photons. Messengers and information of astronomical events by light, neutrinos, and gravitational waves.

14th week

Utilization of nuclear methods in medical biology, agriculture, space technology and other fields. Significance of the nuclear interactions in the quantum physics. Summary and outlook. Consultation.

Requirements:

- for a signature

The lectures are accompanied by students' seminars of general and special subjects. These are connected to the fundemental and applied research as well as to wide variety of technical applications. Students choose subjects at the beginning of the semester, mainly according to their interest.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. László Oláh, assistant professor, PhD

Lecturer: Dr. Péter Raics, associate professor, PhD

Title of course: Nuclear Astrophysics **Code**: TTFME163	**ECTS Credit points:** 3

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: -
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- preparation for the exam: 40 hours

Total: 68 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Elements of astronomy, observation technique, Hertzsprung-Russel diagram. Elements of nuclear physics, mass, binding energy, nucleus models, nuclear reactions. Abundances of elements, isotope anomalies. Nucleosynthesis through the Big Bang and in the early universe. Early stellar stages, hydrogen and helium burning. Solar models, solar neutrinos. Final stages of stellar evolution, supernovae, neutron stars, black holes. Heavy element nucleosynthesis, r-process, s-process, p-process. Nuclear reaction types, reaction networks. Experimental methods to determine reaction cross sections. Low background studies. Exotic nuclear physics. Cosmic rays, dark matter, dark energy. Cosmochronology, galactic chemical evolution.

Literature

C.E. Rolfs, W.S. Rodney: Cauldrons in the Cosmos, University of Chicago Press, 1988.
C. Iliadis: Nuclear Physics of Stars, WILEY-VCH, 2008

Schedule:

1st week
Elements of astronomy, observation technique, Hertzsprung-Russel diagram.

2nd week
Elements of nuclear physics, mass, binding energy, nucleus models, nuclear reactions.

3rd week
Abundances of elements, isotope anomalies.

4th week
Nucleosynthesis through the Big Bang and in the early universe.

5th week
Early stellar stages, hydrogen and helium burning.

6th week
Solar models, solar neutrinos.

7th week
Final stages of stellar evolution, supernovae, neutron stars, black holes.

8th week
Heavy element nucleosynthesis, r-process, s-process, p-process.

9th week
Nuclear reaction types, reaction networks.

10th week
Experimental methods to determine reaction cross sections.

11th week
Low background studies.

12th week
Exotic nuclear physics.

13th week
Cosmic rays, dark matter, dark energy.

14th week
Cosmochronology, galactic chemical evolution.

Requirements:

- for a signature

Attendance at **lectures** is compulsory. A student must attend the lectures and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Zsolt Fülöp, PhD

Lecturer: Zsolt Fülöp, PhD, Gábor Kiss, PhD

Title of course: **Nuclear physics laboratory**
Code: TTFML0164

ECTS Credit points: 4

Type of teaching, contact hours
- lecture: -
- practice: -
- laboratory: 4 hours / week

Evaluation: lab report and oral presentation

Workload (estimated), divided into contact hours:
- lecture: -
- practice: -
- laboratory: 52 hours
- home assignment: 50 hours
- preparation for the exam: 10

Total: 112 hours

Year, semester: 1st year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Target preparation, introduction of the basic ideas and methods of gamma spectrometry measurements performed using HPGe detectors. Study the basic steps of a gamma spectroscopy procedure used for identifying radioisotopes in samples of unknown origin, carry out gamma spectrum measurements and spectrum evaluations. Determination of the gamma photon energy dependence of the detection efficiency of a HPGe detector when simple detection geometry is used (point like sample is counted by the detector, practice the way of measurement and calculation of the gamma activity of a sample of unknown origin.

Literature

György Gyürky – Energy calibration of the accelarator with Al(p,g)Si reaction
András Fenyvesi – Gamma Spectroscopy Measurements with High Purity Germanium Detector System
András Fenyvesi – Measurement of the cross section of the 56Fe(n,p)56Mn reaction at En = 9.9 MeV neutron energy via the activation method

Schedule:

1st week

Al target preparation

2nd week

Preparation of the stack to be irradiated

3rd week

Energy calibtartion of the accelarator by measuring the reaction of 27Al(p,γ) 28Si

4th week

Preparation of the stack to be irradiated

5th week

Activation of samples with quasi-monoenergetic neutrons (irradiation of the prepared aluminum and iron discs).

6th week

Counting of the activated samples with the HPGe spectrometers

7th week

Evaluation of the full energy gamma peaks in the spectra using the programs of the mul-tichannel analyzers (MCAs).

8th week

Calculation of the neutron flux and the cross section

9th week

Comparison of the obtained cross section with data of evaluations. Comparison and dis-cussion of the results of the three groups. Discussing uncertainty and error of the meas-urement.

10th week

Energy calibration of the HPGe detector

11th week

Evaluation of the experimental results and fabrication of the report.

12th week

The presentation of the report of the experimental results.

13th week

Optional consultations

14th week

Catch up laboratory work

Requirements:

- for a signature

Signature requires the attendance at all laboratory works.

- for a grade

Knowledge of definitions, laws and theorems: grade 2;

In addition, knowledge of the proofs of most important theorems: grade 3;

In addition, knowledge of the proofs of theorems: grade 4;
In addition, knowledge of applications: grade 5.

Person responsible for course: Dr. Sándor Nagy, associate professor, PhD

Lecturer: Dr. Balazs Ujvari, assistant professor, PhD

Title of course: **Insight into the Present Day Nuclear Research** **Code**: TTFME0165	**ECTS Credit points:** 4

Type of teaching, contact hours
- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:
- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 2st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Instruments and scientific applications of precision atomic mass measurement. Experimental verification of the constancy of the radioactive decay constant. Nucleon beam and quantum electrodynamics. Current state of energy-producing fusion experiments. The nuclear physics “pandemium” effect and its role in the heat production of nuclear reactors. Radioactive ion beams. Experimental study of exotic nuclei. Measuring the cross section of nuclear reactions through the example of a specific reaction. Nuclear astrophysical experiments in a deep underground laboratory. Special modes of rotation in nuclei. Nuclear power - yesterday, today, tomorrow. Methods of evaluation of gamma spectra. Gamma spectroscopic studies on radioactive beams.

Topics may change depending on new findings in scientific research.

Literature

Depending on the topics covered during the semester, the literature recommended by the speaker.

Schedule:

1st week

Instruments and scientific applications of precision atomic mass measurement. The working principle of the Penning trap. Applications of high precision data. Experimental control of QED (measurement of free and bound electron g-factor). CPT symmetry test (g-factor of electron and positron; measurement of proton-antiproton mass difference). Determination of basic physical constants (fine structure constant; mp/me ratio). Measurement of the 3H-3He mass difference for the KATRIN program to determine the neutrino mass. Experimental verification of the CKM matrix. Preparing for the introduction of a new kilogram standard.

2nd week

Experimental verification of the constancy of the radioactive decay constant. The unprecedented accuracy of the study of the constants of various decomposition processes through the years of precision work organized by a network of large international metrology laboratories. Exclusion of solar gravitational field influence.

3rd week

Nucleon beam and quantum electrodynamics. Search for finite proton size and first experimental proof of QED (Lamb). Questioning the equal QED manageability of electron and muon (Pohl). Current experimental attempts and future plans to solve the “mystery” of the proton and deuteron rays.

4th week

Current state of energy-producing fusion experiments. General overview. JET, the largest tokamak through DT operation. ITER, the first fusion reactor. The future of fusion energy production. A new initiative: the Wendelstein 7-X Stellarator.

5th week

The nuclear physics “pandemium” effect and its role in the heat production of nuclear reactors.

Methods of analysis of the γ-spectrum of fission products; collision of energy resolution and efficiency. A systematic source of error in level construction: the nuclear physics “pandemonium” effect. Corollary: Uncertainty in the calculation of heat of decomposition. Advantages of using a full absorption gamma (TAG) spectrometer.

6th week

Radioactive ion beams. Methods for generating radioactive ion beams used to study the properties of nuclei far from the stability band; the methods for identifying the particles making up the beam, the detectors used in typical measurements and their basic characteristics.

7th week

Experimental study of exotic nuclei. Methods for measuring the special distribution of neutrons and protons in the nucleus. Neutron skin, neutron halo and their astrophysical significance

8th week

Measuring the cross section of nuclear reactions through the example of a specific reaction.

Demonstration of the steps required for the experimental determination of the cross-section of an effect through the example of a specific nuclear reaction, from the characterization of the targets through the irradiations with the accelerator to the detection of the reaction products.

9th week

Nuclear astrophysical experiments in a deep underground laboratory. Special techniques that are required to measure very low impact cross sections. Low background radiation in a deep underground laboratory is advantageous for the measurements. Demonstration of the characteristics of nuclear astrophysical research with an underground accelerator through the example of LUNA's international cooperation, which is unique in the world

10th week

Special modes of rotation in nuclei.

Description of the characteristic collective form of motion of deformed (non-spherical) nuclei, rotation. Special phenomena resulting from the interaction of the internal state and rotation of the nucleus: e.g. chiral rotation, oscillating rotation, closure of rotation bands.

11th week

Nuclear power - yesterday, today, tomorrow.

Energy conditions of nuclear physics processes and possibilities of their use. Nuclear fission as a source of energy. Self-sustaining chain reaction. Internal (physical) and external (technical) security. Reactor types and their development directions. Fuel cycle. Energy from fusion. Hybrid solutions. Radioactive waste. Social attitude, politics. *12th week* Methods of evaluation of gamma spectra. Analysis of multidimensional coincidence gamma matrices. Structure of the system of excited states (level scheme). Determining the multipolarity of gamma transitions using angle correlation analysis; determination of quantum mechanical characteristics (spin and parity values) of excited states based on the obtained multipolarities *13th week* Gamma spectroscopic studies on radioactive beams. Obtaining basic information about the structure of exotic nuclei, the properties of the excited states of nuclei by gamma spectroscopic evaluation of experiments with radioactive beams. Characterization of the latest gamma detectors. *14th week* Consultation.
Requirements: *- for a signature* Attendance at **lectures** and participation at **practice classes** is compulsory. A student must attend the classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course. *-for a grade* Every students have to give two presentations on topics chosen from the material of the semester and to answer to some basic questions. The grade is based on this performance.
Person responsible for course: Dr. Judit Darai, associate professor, PhD
Lecturer: Dr. Judit Darai, associate professor, PhD

Title of course: Condensed Matter Physics 4 **Code**: TTFME0172	**ECTS Credit points: 5**
Type of teaching, contact hours - lecture: 2 hours/week - practice: 1 hours/week - laboratory: -	
Evaluation: exam	
Workload (estimated), divided into contact hours: - lecture: 28 hours - practice: 14 hours - laboratory: - - home assignment: 40 hours - preparation for the exam: 40 hours Total: 122 hours	
Year, semester: 1st year, 1st semester	
Its prerequisite(s): -	
Further courses built on it: -	

Topics of course

Drude model (basic equation of motion, metallic shine, electric and thermal conductivity, Lorentz number, plasma frequency, Hall effect, Seebeck effect, model evaluation based on experimental results); Non-interacting quantum mechanical electron system at T=0 and non-zero temperatures, Fermi surface, compressibility, Sommerfeld model (Sommerfeld expansion, characterization of different physical quantities of interest, study of the specific heat, density of states, effective mass, model evaluation based on experimental data); Phonons, Fermi liquids, non-Fermi liquids, lattice diffraction, Bloch electron. The effect of week periodic potential (non-degenerate and degenerate cases), Tight-binding method, band insulator, Mott insulator, Wigner lattice, semiclassical model, hole notion. Landau levels, quantum Hall effect, topological insulator, spin quantum Hall effect, anomalous quantum Hall effect, heavy-fermion systems, band topology.

Literature

Compulsory:

N. W. Ashcroft, N. D. Mermin: Solid State Physics, Saunders College Publishing, 1976, US

Recommended:

P. W. Anderson: Concepts in Solids, Benjamin/Cummings Publishing Company, London 1982.

Schedule:

1st week

Model starting points for the Drude model, appearance circumstances, the relaxation time notion, treatement of collision process, deduction of the model equation of motion and its interpretation.

2nd week

The results provided by the Drude model in the presence of an external electric field constant in r-space but periodic in time. The electrical conductance of the Drude model and its characteristics. The Drude resistivity in the light of experimental data.

3rd week

The results provided by the Drude model in the presence of an external electric field periodic both in space and time. Metallic shine, plasma frequency and its physical interpretation and measurement. Comparison to experimental data. The introduced concepts seen today: the plasmon notion..

4th week

The Hall effect seen in the frame of the Drude model. Evaluation of the theoretical result and comparison to experimental data. The Hall effect seen today: Landau levels, the quantum-Hall effect, the spin quantum-Hall effect, the anomalous quantum-Hall effect, topological insulators and their importance.

5th week

The thermal conductivity in the frame of the Drude model. Comparison to thermal conductivity deduced for gases. The Lorentz number, the Wiedemann-Franz low, deduction of the Lorentz number in the frame of the Drude model, comparison to experimental data. The importance of the Lorentz number in physical processes today.

6th week

Seebeck effect, thermopower and its deduction in the frame of the Drude model, physical interpretation of the deduced result and comparison to experimental data. Evaluation of the Drude model, failures of the model and limits of the Drude model. Study of the

development possibilities of the model description. The importance of the Seebeck effect in the modern condensed matter physics.

7th week

Quantum mechanic non-interacting electron gas at T=0 temperature. Born-von Karman periodic boundary conditions, possible states in k-space, summation possibilities over the momentum value, the notion of the density of states, its calculation technique, and its expression for non-interacting Fermi gas. Fermi surface, density of states on the Fermi surface, Fermi energy, Fermi velocity, Fermi temperature, comparison to experimental data.

8th week

Ground state energy at T=0, calculation of the internal pressure, deduction of the equation of state, comparison to the properties of the non-interacting classical gas. Deduction of the compressibility, its evaluation, and comparison to experimental data taken in T -> 0 limit.

Role of the Fermi gas compressibility in the rigidity of solid state matter.

9th week

Non-interacting quantum Fermi gas at non-zero temperatures. Partition function, thermodynamic potential, deduction of the relation for internal energy, entropy and total number of particles. The Fermi function and its approximation possibilities. The momentum distribution function and its discussion at current knowledge level: the effect of the interaction, importance of cusp points.

10th week

The Sommerfeld expansion, the Sommerfeld model and its results at low non-zero temperatures. The calculation of the chemical potential, and its relation to the Fermi energy. Calculation of the specific heat, and its connection to the effective mass. Comparison to the results deduced in the Drude model, and experimental data. The evaluation of the Sommerfeld model, its limits, study of the development possibilities of the model description. Importance of the introduced concepts in the current condensed matter physics: Fermi liquid notion, Non-Fermi liquids, known rigorous non-Fermi liquid in 1D: Luttinger liquid, short presentation of heavy fermion systems.

11th week

Point lattice, Bravais lattice, Voronoy construction and polyhedron, Lattice plain families and their characteristics, reciproc lattice and its characteristics in D=1,2,3 dimensions, connection between reciproc lattice vectors and lattice plain families, Miller vectors.

Bravais lattices constructed based on their cells, characteristic cells and their properties, the zone notion, and its properties.Phonons

12th week

Waves propagation in a lattice, diffraction caused by the lattice, Bragg and von Laue treatement of the diffraction, reciproc space, and Brillouin zone notions. Experimental definition of the reciproc lattice and Brillouin zone boundaries. Form factors and their role. Bloch theorem in the light of symmetry properties, Bloch theorem in the light of the Schrödinger equation, the notion of Bloch electron.

13th week

Fourier transformation in the Bravais lattice, Schrödinger equation in the independent electron approximation. The action of a small periodic potential: non-degenerate and degenerate cases. The behavior of the electron in the center of the Brillouin zone and close to the Brillouin zone boundary. The gap caused by the periodic potential, the band notion, movement inside the band, conducting and insulating systems, umklapp processes and their importance, the Johns zone notion and its importance.

14th week

Wannier functions tight binding approximation and the dispersion relation that it provides, Mott insulator, Wigner lattice, the Semiclassical model, its characteristics and limits, the hole notion and its importance. The condensed matter physics seen today, strongly correlated systems.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course. During the semester there will be two written examinations (on 6th and 13th week) from lectures and practice as well. The requirement for a signature is a successful (> 20%) completion of each written exam.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Zsolt Gulácsi, professor, DSc

Lecturer: Dr. Zsolt Gulácsi, professor, DSc

Title of course:Quantum Mechanical Many-Body Physics 1
Code: TTFME0174

ECTS Credit points: 5

Type of teaching, contact hours

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 40 hours
- preparation for the exam: 40 hours

Total: 122 hours

Year, semester: 1st year, 1st semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Second quantization, S matrix, Gell-Mann Low theorem, P and T products, expectation value of time ordered operator products. T=0 description: One particle Green-function, expectation value of different Hamiltonian terms, ground state energy, Gorkov equation, one-particle propagators for non-interacting Fermi and Bose systems, Lehmann representation, spectral functions, Wick theorem and its application, Feynmann diagrams, Dyson equation, self-energy contributions, polarization insertion, two-particle Green function, Vertex function, Bethe-Salpeter equation. Non-zero T description: The Matsubara technique, T > 0 Green functions, summation over Matsubara frequencies in fermionic and bosonic cases, calculation of expectation values at T > 0 in terms of Green-functions, the relation between the thermodynamic potential and T > 0 Green function, Feynman diagram technique at non-zero temperatures.

Literature

Compulsory:
A. L. Fetter, J. D. Walecka: Quantum theory of many particle systems, McGraw-Hill Book Company, New York, 1975
Recommended:
A. A. Abrikosov, L. P. Gorkov, I. Y. Dzyaloshinskii: Quantum Theoretical Methods in statistical Physics, Dover Publication Inc., New York, 1975.

Schedule:

1st week

Second quantization in Fermi and Bose cases, the relation between first and second quantization.

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2nd week

Quantum field theory methods used at T=0 temperature. Quantum mechanical pictures and the connection in between them. S matrix:definition, expression, importance.

3rd week

Adiabatic swithing on, the Gell-Mann Low theorem: deduction, interpretation, importance.

.4th week

T and P products, calculation of expectation values from T products, the use of the S matrix in this process, the propagator notion.

5th week

The one-particle Green function at T=0 temperature. The Gorkov equation, deduction and use.

6th week

Deduction of the expectation values of different operators in terms of the one-particle Green function in the fermionic and bosonic case.

7th week

Analitic properties of one-particle Green functions, spectral functions and Lehmann representation..

8th week

The poles of the Green function, connection between T and P roducts, Wick theorem.

9th week

Feynmann diagrams, diagram expansion of the expression of the one-particle Green function, self energy contribution, Dayson equation and its importance.

10th week

Green functions in k-space, Feynmann diagrams in k-space, notion of the polarization loop.

11th week

Two-particle Green functions, notion of the vertex function, Bethe-Salpeter equation.

12th week

One-particle Green function at non-zero temperatures, and its properties. Feynmann diagrams at non-zero temperatures.

13th week

Matsubara frequencies, the Green function expressed as a sum over Matsubara frequencies, the technique of calculation of the sums over Matsubara frequencies in fermionic and bosonic cases.

14th week

Deduction of the thermodynamic potential from the one-particle Green function at non-zero temperatures, calculation of thermodynamic averages. The calculation of the change in the thermodynamic potential when a new interacting term emerges in the Hamiltonian..

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

Participation at **practice classes** is compulsory. A student must attend the practice classes and may not miss more than three times during the semester. In case a student does so, the subject will not be signed and the student must repeat the course. During the semester there will be two written examinations (on 6th and 13th week) from lectures and practice as well. The requirement for a signature is a successful (> 20%) completion of each written exam.

- for a grade

The course ends in an **examination**. The requirement for applying for an exam is to have a practical signature.

The grade for the examination is given according to the following table:

Score	Grade
0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. Zsolt Gulácsi, professor, DSc

Lecturer: Dr. Zsolt Gulácsi, professor, DSc

Title of course: Basics of Functional Renormalization Group Method **Code**: TTFME0175	**ECTS Credit points:** 5
Type of teaching, contact hours	

- lecture: 2 hours/week
- practice: 1 hours/week
- laboratory: -

Evaluation: exam

Workload (estimated), divided into contact hours:

- lecture: 28 hours
- practice: 14 hours
- laboratory: -
- home assignment: 14 hours
- preparation for the exam: 28 hours

Total: 84 hours

Year, semester: 2nd year, 2nd semester

Its prerequisite(s): -

Further courses built on it: -

Topics of course

Introduction of the sine-Gordon (SG) model as a discrete system of torsional harmonic oscillators. Symmetries and phase structure of SG type models. The bosonisation and SG type models. Topological phase transitions of SG type models. SG models in higher dimensions and their relation to Higgs, inflaton and axion physics. The Kadanoff-Wilson blocking construction. The Wegner-Houghton, the Polchinski and the Wetterich functional renormalization group (FRG) equations. Gradient expansion and regulator dependence. Linearised FRG equations for SG type models in the leading order of the gradient expansion, i.e., in the local potential approximation (LPA). Exact FRG equations for SG type models with a single frequency in LPA. Exact FRG equations for multi-frequency SG type models in LPA. Beyond LPA, the derivation and the solution of the linearised FRG equations for SG type models. Beyond LPA, the derivation and the solution of the exact FRG equations for SG type models with single and multi frequencies.

Literature

Compulsory:
Nándori István, Lecture Note on the Functional Renormalization Group Study of Sine-Gordon Models, electronic lecture note.
Recommended:
Nagy Sándor, Lectures on renormalization and asymptotic safety, Annals Phys. 350 (2014) 310-346,
Sailer Kornél, Renormálási csoport a kvantumtérelméletben, KLTE 1997,
Sailer Kornél, Szimmetriák II., KLTE 1994-2013.

Schedule:

1st week

The classical (relativistic but not quantised) sine-Gordon model is introduced by taking the continuous limit of a discrete system of torsional harmonic oscillators. A brief introductions to QFT, renormalization and renormaliztaion group are also peresented.

2nd week

Periodic (sine-Gordon type) models are overviewed and the consequence of their symmetries on their phase structure is discussed.

3rd week

The bosonisation transformations, i.e., mappings of two-dimensional fermionic and gauge theories such as the multi-color QCD_2, and the multi-flavour QED_2, onto bosonic models are summarised and their connetcions to sine-Gordon type models are given.

4th week

Topological phase transitions are discussed by rewriting the generating functional of sine-Gordon theories onto partition functions while the path-intgeral is performed. Their relation to classical spin models and the O(2) symmetric scalar theory and the vortex dynamics of superconducting and superfluid systems are presented.

5th week

Applications of sine-Gordon models in higher dimensions and in Conformal Field Theory. The relation of sine-Gordon models to Higgs, inflaton and axion physics is discussed.

6th week

The Kadanoff-Wilson blocking construction is discussed which is based on scale-invariance of the system undergoes a second order phase transition. It is shown that the Wegner-Houghton and the Polchinski RG equations can be derived based on the blocking construction by using the idea of Kenneth G. Wilson.

7th week

A brief introduction to the modern form of the FRG apporach, i.e., the derivation of the Wetterich RG equation is presented and its relation to the Wegner-Houghton and Polchinski RG equations is given. Important technical issues, such as gradient expansion, regulator dependence etc. are also discussed.

8th week

The derivation of the linearised FRG equations (for sine-Gordon type models) obtained in the leading order of the gradient expansion (LPA) is presented. Discussion of the phase structure of sine-Gordon type models based on the solution of these RG equations is also given.

9th week

Exact FRG equations for sine-Gordon type models with a single frequency are presented and their solutions are studied.

10th week

The FRG study of multi-frequency sine-Gordon theories are presented in LPA. The connection of the RG results to the requirement of convexity is shown.

11th week

Beyond LPA, the derivation and the solution of the linearised FRG equations for sine-Gordon type models are shown.

12th week

Beyond LPA, the derivation and the solution of the exact FRG equations for sine-Gordon type models with single and multi frequencies are presented.

13th week

Results obtained by the FRG method are summarised.

14th week

Consultation.

Requirements:

- for a signature

Attendance at **lectures** is recommended, but not compulsory.

- for a grade

The course ends in an **examination**.

The grade for the examination is given according to the following table:

Score	Grade

0-49	fail (1)
50-62	pass (2)
63-75	satisfactory (3)
76-88	good (4)
89-100	excellent (5)

Person responsible for course: Dr. István Nándori, associate professor, PhD

Lecturer: Dr. István Nándori, associate professor, PhD