Study plan

Name of study plan: Kvantové technologie

Faculty/Institute/Others:
Department:
Branch of study guaranteed by the department: Welcome page
Garantor of the study branch:
Program of study: Quantum Technologies
Type of study: Follow-up master full-time
Required credits: 0
Elective courses credits: 120
Sum of credits in the plan: 120
Note on the plan:

Name of the block: Compulsory courses in the program
Minimal number of credits of the block: 0
The role of the block: P

Code of the group: NMSPQT1
Name of the group: MDP P_QTN 1st year
Requirement credits in the group:
Requirement courses in the group: In this group you have to complete at least 11 courses
Credits in the group: 0
Note on the group:

Code	Name of the course / Name of the group of courses *(in case of groups of courses the list of codes of their members)* *Tutors,* ***authors*** *and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
02QIC	**Quantum Information and Communication** *Aurél Gábor Gábris* ***Aurél Gábor Gábris*** *Martin Štefaňák (Gar.)*	Z,ZK	4	3P+1C	Z	P
02KO1	**Quantum Optics 1** *Václav Potoček* ***Václav Potoček*** *Igor Jex (Gar.)*	Z,ZK	4	2P+2C	Z	P
02KO2	**Quantum Optics 2** *Václav Potoček* ***Václav Potoček*** *Igor Jex (Gar.)*	Z,ZK	4	2P+2C	L	P
02KTPA1	**Quantum Field Theory 1** *Václav Zatloukal* ***Václav Zatloukal*** *Martin Štefaňák (Gar.)*	Z,ZK	8	4P+2C	Z	P
02KTPA2	**Quantum Field Theory 2** *Petr Jizba* ***Václav Zatloukal*** *Martin Štefaňák (Gar.)*	Z,ZK	8	4P+2C	L	P
12KGOZ1	**Quantum Generators of Optical Radiation 1** *Helena Jelínková, Michal Jelínek, Michal Němec* ***Michal Jelínek*** *Helena Jelínková (Gar.)*	ZK	2	2P	Z	P
12KGOZ2	**Quantum Generators of Optical Radiation 2** *Jan Šulc* ***Jan Šulc*** *Jan Šulc (Gar.)*	Z,ZK	4	2P+2C	L	P
11TPLQ1	**Theory of Solid State 1** *Jaroslav Hamrle, Hanuš Seiner Jaroslav Hamrle (Gar.)*	ZK	4	2P+2C	Z	P
11TPLQ2	**Theory of Solid State 2** *Jaroslav Hamrle, Hanuš Seiner Jaroslav Hamrle (Gar.)*	Z,ZK	4	26P+26C	L	P
02VUQT1	**Research Project 1** ***Martin Štefaňák*** *Martin Štefaňák (Gar.)*	Z	6	0P+6C	Z	P
02VUQT2	**Research Project 2** *Martin Štefaňák* ***Martin Štefaňák*** *Martin Štefaňák (Gar.)*	KZ	8	0P+8C	L	P

Characteristics of the courses of this group of Study Plan: Code=NMSPQT1 Name=MDP P_QTN 1st year

02QIC	Quantum Information and Communication	Z,ZK	4
Quantum theory brought new ideas to the theory of information leading which ultimately lead to the theory of quantum information, computation and communication. The lecture introduces the basic concepts of quantum information e.g. quantum algorithms (Shor's and Grover's), entanglement, quantum teleportation, quantum cryptography and quantum error correction. It also provides an introduction to modern parts of quantum information, e.g. measurement-based and adiabatic quantum computation and quantum walks.			
02KO1	Quantum Optics 1	Z,ZK	4
Building upon classical optics, the course shows the construction of a semiclassical Quantum Optics theory of light and light-matter interaction. The aim of the lecture is to provide a robust theory allowing the qualitative and quantitative description of a broad range of quantum optical phenomena as well as some methods for practical computation.			
02KO2	Quantum Optics 2	Z,ZK	4
This course completes Quantum Optics 1 by teaching the terminology and computational methods related to the reformulation of Quantum Optics in phase space. It also extends the application areas to continuum modes and dissipative processes. A concise survey of modern research topics in both theoretical and practical parts of Quantum Optics as well as its applications in further experimental research is also provided.			

02KTPA1	Quantum Field Theory 1	Z,ZK	8
The lecture aims to introduce the students to both fundamental and applied parts of quantum field theory. The focus is in particular on equations of relativistic quantum mechanics, canonical quantization of scalar and bispinor field, perturbation theory (Feynman's rules) and basics of renormalization. The content of the lecture can serve as a base for further study in fields of exactly solvable models, theory of critical phenomena, molecular chemistry and biochemistry or quantum gravity.			
02KTPA2	Quantum Field Theory 2	Z,ZK	8
The lecture aims at introducing the students to the Feynman's functional integral and its applications. The focus is on broadening the knowledge of modern parts of relativistic and non-relativistic quantum field theory and statistical physics. The content of the lecture can serve as a base for further study in fields of exactly solvable models, theory of critical phenomena, molecular chemistry and biochemistry or quantum gravity.			
12KGOZ1	Quantum Generators of Optical Radiation 1	ZK	2
The aim of the lecture is to introduce the principles and elements of modern quantum generators of optical radiation and their technical solutions.			
12KGOZ2	Quantum Generators of Optical Radiation 2	Z,ZK	4
The course is focused to the description of quantum generator behaviour using the general principles of quantum statistical physics. The aim of the lecture is to introduce the theoretical basis of laser generator function using semi-classical and fully quantum description of interaction between bonded electrons and resonance radiation.			
11TPLQ1	Theory of Solid State 1	ZK	4
The content of the lesson are basic physical properties of crystalline solid state materials. Students will be introduced to band structure of solids and basic materials classification, such as metals, semiconductors and dielectrics. The lesson further focuses on magnetic properties, superconductivity and surface properties, a topic mostly expected to be important in construction of quantum computers.			
11TPLQ2	Theory of Solid State 2	Z,ZK	4
The content of the lesson is based on quantum-mechanical description of crystalline solid state materials, providing a fundamental base of theoretical description of solid state properties.			
02VUQT1	Research Project 1	Z	6
The research project is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the project supervisor during common regular meetings and discussions.			
02VUQT2	Research Project 2	KZ	8
The research project is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the project supervisor during common regular meetings and discussions.			

Code of the group: NMSPQT2
Name of the group: MDP P_QTN 2nd year
Requirement credits in the group:
Requirement courses in the group: In this group you have to complete at least 3 courses
Credits in the group: 0
Note on the group:

Code	Name of the course / Name of the group of courses *(in case of groups of courses the list of codes of their members)* *Tutors,* ***authors*** *and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
02DPQT1	**Diploma Thesis 1** ***Martin Štefaňák*** *Martin Štefaňák (Gar.)*	Z	10	0P+10C	Z	P
02DPQT2	**Diploma Thesis 2** ***Martin Štefaňák*** *Martin Štefaňák (Gar.)*	Z	20	0P+20C	L	P
02KTPA3	**Quantum Field Theory 3** *Petr Jizba* ***Václav Zatloukal*** *Petr Jizba (Gar.)*	Z,ZK	8	4P+2C	Z	P

Characteristics of the courses of this group of Study Plan: Code=NMSPQT2 Name=MDP P_QTN 2nd year

02DPQT1	Diploma Thesis 1	Z	10
The diploma thesis is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the thesis supervisor during common regular meetings and discussions.			
02DPQT2	Diploma Thesis 2	Z	20
The diploma thesis is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the thesis supervisor during common regular meetings and discussions.			
02KTPA3	Quantum Field Theory 3	Z,ZK	8
The lecture aims at advanced parts of Feynman's functional integral. The focus is on broadening the knowledge of modern parts of relativistic and non-relativistic Quantum Field Theory and statistical physics. The content of the lecture can serve as a base for further study in fields of exactly solvable models, theory of critical phenomena, molecular chemistry and biochemistry or quantum gravity.			

Name of the block: Elective courses
Minimal number of credits of the block: 0
The role of the block: V

Code of the group: NMSPQTV
Name of the group: MDP P_QTN Optional courses
Requirement credits in the group:
Requirement courses in the group:
Credits in the group: 0
Note on the group:

Code	Name of the course / Name of the group of courses *(in case of groups of courses the list of codes of their members)* *Tutors,* ***authors*** *and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
12FDD	**Physics of Detection and Detectors of Optical Radiation** *Ladislav Pína* ***Ladislav Pína*** *Ladislav Pína (Gar.)*	ZK	2	2+0	Z	v
02FG	**Physics of graphene described by Dirac equation** *Vít Jakubský* ***Vít Jakubský*** *Vít Jakubský (Gar.)*	Z	2	2P+0C	L	v
11FPOR	**Physics of Surfaces and Interfaces** *Ladislav Kalvoda Ladislav Kalvoda (Gar.)*	ZK	2	2P+0C	Z	v
12UKP	**Ultra-short Pulse Generation** *Václav Kubeček* ***Václav Kubeček*** *Václav Kubeček (Gar.)*	ZK	2	2+0	Z	v
02KCH	**Quantum Chemistry** *Michal Jex* ***Michal Jex*** *Michal Jex (Gar.)*	Z,ZK	3	2P+1C	Z	v
02KVK1	**Quantum Circle 1** ***Martin Štefaňák*** *Pavel Exner (Gar.)*	Z	2	0+2	Z	v
02KVK2	**Quantum Circle 2** ***Martin Štefaňák*** *Pavel Exner (Gar.)*	Z	2	0+2	L	v
18MEMC	**Monte Carlo Method** *František Gašpar, Miroslav Virius* ***Miroslav Virius*** *Miroslav Virius (Gar.)*	Z,ZK	4	2P+2C	Z	v
11MONA	**Molecular Nanosystems** *Irena Kratochvílová* ***Irena Kratochvílová*** *Irena Kratochvílová (Gar.)*	ZK	2	2	Z	v
12NF	**Nanophysics** *Milan Šiňor, Ivan Richter* ***Ivan Richter*** *Milan Šiňor (Gar.)*	ZK	2	2+0	Z	v
11NAMA	**Nanomaterials - Preparation and Characteristics** *Irena Kratochvílová* ***Irena Kratochvílová*** *Irena Kratochvílová (Gar.)*	Z,ZK	2	2+0	L	v
12NOP	**Nonlinear Optics** *Ivan Richter* ***Ivan Richter*** *Ivan Richter (Gar.)*	Z,ZK	4	3+1	L	v
18OOP	**Object Oriented Programming** *Miroslav Virius* ***Miroslav Virius*** *Miroslav Virius (Gar.)*	Z	2	2C	Z	v
11OPTX	**Optical Properties of Solids** *Zdeněk Bryknar Zdeněk Bryknar (Gar.)*	ZK	2	2P+0C	Z	v
02OKS	**Open Quantum Systems** *Jaroslav Novotný* ***Martin Štefaňák*** *Jaroslav Novotný (Gar.)*	Z	2	2+0		v
12OREZ	**Open Resonators** *Václav Kubeček* ***Václav Kubeček*** *Václav Kubeček (Gar.)*	Z,ZK	4	2P+1C	Z	v
11SIKL	**Computer Simulation of Condensed Matter** *Ladislav Kalvoda, Petr Sedlák* ***Ladislav Kalvoda*** *Ladislav Kalvoda (Gar.)*	ZK	4	2+2	Z,L	v
18PCP	**Advanced C++** *Miroslav Virius* ***Miroslav Virius*** *Miroslav Virius (Gar.)*	Z,ZK	4	2P+2C	L	v
02QPRGA	**Quantum Programming** *Aurél Gábor Gábris, Iskender Yalcinkaya* ***Aurél Gábor Gábris*** *Aurél Gábor Gábris (Gar.)*	Z	3	1P+1C	L	v
12RFO	**X-ray Photonics** *Ladislav Pína* ***Ladislav Pína*** *Ladislav Pína (Gar.)*	ZK	2	2+0	Z	v
02REP	**Matrix Lie group representations** *Jiří Hrivnák* ***Jiří Hrivnák*** *Jiří Hrivnák (Gar.)*	Z	2	2+0	Z	v
02SKTP	**Seminar on quantum field theory** *Petr Jizba* ***Václav Zatloukal*** *Petr Jizba (Gar.)*	Z	3	26P+13C	L	v
01SUP	**Start-up Project** *Přemysl Rubeš* ***Přemysl Rubeš*** *Přemysl Rubeš (Gar.)*	KZ	2	2P+0C		v
12SOP	**Statistical Optics** *Ivan Richter* ***Ivan Richter*** *Ivan Richter (Gar.)*	Z,ZK	2	2+0	L	v
02SZD1	**Statistical Data Analysis 1** *Miroslav Myška* ***Miroslav Myška*** *Miroslav Myška (Gar.)*	Z,ZK	4	2P+2C	Z	v
02SZD2	**Statistical Data Analysis 2** *Miroslav Myška* ***Miroslav Myška*** *Miroslav Myška (Gar.)*	Z,ZK	4	2P+2C	L	v
11SUPR	**Superconductivity and Low Temperature** *Zdeněk Janů, Martin Ledinský* ***Martin Ledinský*** *Martin Ledinský (Gar.)*	ZK	4	4	Z	v
01TG	**Graph Theory** *Jan Volec, Petr Ambrož* ***Petr Ambrož*** *Petr Ambrož (Gar.)*	ZK	5	4P+0C		v
01TIN	**Information Theory** *Tomáš Hobza* ***Tomáš Hobza*** *Tomáš Hobza (Gar.)*	ZK	2	2+0	Z	v
02UC1	**Particles Accelerators 1** *Miroslav Krůs* ***Miroslav Krůs*** *Miroslav Krůs (Gar.)*	ZK	2	2P+0C	Z	v
02UC2	**Particle Accelerators 2** *Miroslav Krůs* ***Miroslav Krůs*** *Miroslav Krůs (Gar.)*	ZK	2	2+0		v
12MODO	**Selected Chapters of Modern Optics** *Ivan Richter, Pavel Kwiecien, Lucie Marešová* ***Pavel Kwiecien*** *Ivan Richter (Gar.)*	Z	2	2+0	Z	v
02VPSFA	**Selected Topics in Statistical Physics and Thermodynamics** *Igor Jex* ***Martin Štefaňák*** *Igor Jex (Gar.)*	Z,ZK	7	4P+2C	Z	v
02ZQCD	**Quantum Chromodynamics** *Jana Bielčíková* ***Jan Čepila*** *Jana Bielčíková (Gar.)*	Z,ZK	6	3+2	Z	v
02ZELW	**Introduction to Theory of Electroweak Interactions** *Jana Bielčíková, Boris Tomášik* ***Boris Tomášik*** *Boris Tomášik (Gar.)*	Z,ZK	6	3P+2C	Z	v

Characteristics of the courses of this group of Study Plan: Code=NMSPQTV Name=MDP P_QTN Optional courses

12FDD	Physics of Detection and Detectors of Optical Radiation	ZK	2
Electromagnetic spectrum. Sources of electromagnetic radiation. Radiometric and photometric units. Ideal detector. External and internal photoefect. Quantum fluctuations of radiation. Noise of detector and electronic circuits. Dynamic range. Detectors based on external photoefect. Photocathodes. Electron multipliers. Microchannel plates. Image intensifiers. Detectors based on internal photoefect. Semiconductor detectors. Scintilators. Detectors of IR, VIS and UV radiation. X-ray detectors.. Pyroelectricity and pyrodetectors. Detector electronic circuits. Human eye.			
02FG	Physics of graphene described by Dirac equation	Z	2
General description of crystal. Tight-binding model of graphene and its approximation in terms of Dirac equation.Transport of Dirac fermions in graphene in presence of external fields and related phenomena. Bilayer graphene, its description and properties in the external magnetic field. Carbon nanotubes, their classification. Basic description of graphene nanoribbons,boundary conditions and energy. Dirac fermions in curved space, fullerenes. Other Dirac materials.			
11FPOR	Physics of Surfaces and Interfaces	ZK	2
Description is provided of basic thermodynamic properties, atomary and electronic structure of surfaces and interfaces. The physical models valid for bulk sysstems are juxtaposed with the changes due to introduction of new surface/interface. The theoretical treatment is followed by overview of experimental techniques applied to preparation of surface structures and to study of chemical composition and structural arrangement of the latter. In addition, brief overview is given of simulation approaches suitable for analysis and prediction of properties of selected systems. All the subjects are demonstrated on praktical exaples of case studies.			
12UKP	Ultra-short Pulse Generation	ZK	2
What we mean by ultrashort light pulses (USP) . History of USP generation. Characteristics of USP and their description.Methods of USP generation. Principle of mode-locking in lasers. Methods of mode-locking.Influence of dispersion on propagation and USP generation.Methods of dispersion compensation and its use.Spatio-temporal optics of USP.Methods of measurement USP characteristics. Autocorrelation methods. Spectral phase interferometry and frequency resolved optical gating - SPIDER and FROG. Methods of shaping of USP.Amplification of USP, temporal stretching and compression - chirped pulses amplification CPA.Selected application of USP.			
02KCH	Quantum Chemistry	Z,ZK	3
Introduction to quantum chemistry. Students will acquire theoretical and practical skills to solve basic problems of theoretical quantum chemistry with focus on electronic structure.			
02KVK1	Quantum Circle 1	Z	2
Seminars of the Doppler Institute on topics of mathematical quantum physics for students and PhD. students.			
02KVK2	Quantum Circle 2	Z	2
Seminars of the Doppler Institute on topics of mathematical quantum physics for students and PhD. students.			
18MEMC	Monte Carlo Method	Z,ZK	4
This courseis devoted to the numerical method Monte Carlo and to its selected applications.			
11MONA	Molecular Nanosystems	ZK	2
The main goal of the lecture is to show possibilities to use selected molecules properties in molecular nanodevices.			
12NF	Nanophysics	ZK	2
The lecture offers a deep overview on nanophysics, clarifies the terminology, compares various forms of matter and structures, with the emphasis on nanostructures, and relates electronic and photonic nanostructures. It also reviews terms and methods form solid state physics, and applies them to quantum restricted nanostructures (quantum wells, multiple quantum wells, quantum wires, quantum dots). The attention is further given both to the electrodynamics of metals, its specifics, the lecture discusses and classifies plasmons; it further systematically explains especially the surface plasmons. Next, the lecture covers the photonic nanostructures, their properties, and relation to electronic structures, with the emphasis on photonic crystals, it gives their examples in 1D, 2D and 3D. The final attention is given to novel artificial materials, mainly metamaterials with negative refractive index. The course is concluded with the student presentations on selected given topics.			
11NAMA	Nanomaterials - Preparation and Characteristics	Z,ZK	2
The course describes methods of preparation of nanomaterials, their structure, specific properties and applications. The properties of carbon and silicon nanobodies and layers will be analyzed in detail. The aim of the subject is to explain the relationships between physical / chemical properties of nanoparticulate materials and their main structural features.			
12NOP	Nonlinear Optics	Z,ZK	4
The lecture covers both the basic and advanced topics of nonlinear optics, both from classical and quantum viewpoint, consequentially to the previous courses of Physical optics. From a classical viewpoint, the attention is given to optical processes in dielectric media, macroscopic polarization vector, and microscopic description of polarization vector. Further, it deals with dispersion properties of nonlinear susceptibilities (2nd order nonlinearity for noncentrosymmetric media, 3rd order nonlinearity for centrosymmetric media), and with symmetries of nonlinear susceptibility tensors. From a quantum (poloclassical) viewpoint, the attention is given to derivation of linear, quadratic, and cubic susceptibility, and particularly to the resonant process in two-level media. The processes are classified to nonresonant (parametric) and resonant ones, conservation laws, as well as Manley-Rowe relations, phase matching and synchronisms are discussed. The lecture then separately discusses three-wave mixing (second harmonic generation, sum and difference frequency generation), four wave mixing, optical Kerr effect, third harmonic generation. Concentration is given to light induced refractive index changes, selffocusation and automodulation effects, electrooptical and photorefractive effects, nonlinear light scattering, optical phase conjugation, nonlinear absorption effects, and to nonlinear effects with short pulses. The lecture is conluded with applications of selected nonlinear optical effects.			
18OOP	Object Oriented Programming	Z	2
This course consists of the contributions of students concerning given topics concerned on technologies uded in program development.			
11OPTX	Optical Properties of Solids	ZK	2
This course gives an introductory into the optical properties of solids. The fundamental principles of absorption, reflection, luminescence and light propagation are discussed for a wide range of materials, including crystalline insulators, semiconductors, and metals. Classical and quantum models are used as appropriate, and the observed phenomena are discussed from point of their application.			
02OKS	Open Quantum Systems	Z	2
Quantum description of composite subsystems and their subsystems, density operator. Pure and mixed states, entropy. Quantum correlations, entanglement, its basic properties and possible applications. Introduction to theory of generalized quantum measurement, positive operator-valued measure, physical realizations. Quantum operations, general description of state changes, superoperator theoretical framework, examples of quantum operations. Markovian quantum master equation, quantum dynamical semigroups. Basic models for description of decoherence and thermalization.			
12OREZ	Open Resonators	Z,ZK	4
Electromagnetic field-geometrical optics. Open resonators and transfer matrices.Wave optics. Huygens principle and Kirchhoff integral.Gaussian beams in one dimensional optic systems. Intensity moments for description of beam propagation. Quality of general beams . Additional beam characteristics. Diffraction theory of open resonators. Fabry-Perot interferometer. Optical dielectric layers. Passive open resonators. Stable resonators without apertures. Stable resonators limited by apertures. Resonator detuning sensitivity. Resonators on the stability limits. Unstable resonators.Unstable resonators with with variable reflectivity mirrors. Resonators containing lenses and polarizing elements.Open resonators with active medium with gain. Influence of the gain on mode structure and losses in stable and unstable resonators.			
11SIKL	Computer Simulation of Condensed Matter	ZK	4
Computer simulation in condensed-matter physics is becoming an important tool used by both experimentalist and theorists to develop new materials and technologies. Thus, solution of many practical problems can be transferred from the real to a "virtual" laboratory. During the course, students will be introduced to the theoretical background of basic computation methods and let to test the acquired knowledge in practical exercises. Each lesson is organized as a tutorial where typical problems are solved with detailed explication of the computation methods used. The course is taking place in Computer classroom of the Department of Solid State Physics. Practical demonstration and exercises are using Material Studio simulation environment (Accelrys Software Inc.).			

18PCP	Advanced C++	Z,ZK	4
This lecture covers the virtual inheritance,variadic templetes, template metaprogramming, template libraries design and implementation, tools for data type processing in compile time and for the advanced diagnostic of the templates, concepts, coroutines, modules, ranges, views and other tools introduced in C++ 20, application of the multithreading (execution parallelization).			
02QPRGA	Quantum Programming	Z	3
The goal of the course is to provide the basic skills for programming quantum computers, and to use these skills to develop an understanding of fundamental quantum communication protocols and quantum algorithms. The classes are combinations of lectures that introduce the essential concepts and tools, and interactive tutorials on how these concepts are implemented with Python programming language. Every week the students will be given Jupyter notebooks involving self-study materials and homework. The course is suitable for bachelor and master's students from all years and familiarity with quantum mechanics is not necessary. The classes are held entirely online to get the most out of the learning material and make it internationally accessible. The quantum SDK Qiskit will be used during the course. Use of own laptops with a quantum SDK installed before the course start is required.			
12RFO	X-ray Photonics	ZK	2
More than one hundred years has passed since the discovery of X-ray radiation. X-ray radiation has become intensively studied and used part of the electromagnetic radiation spectrum. Development of photonics in this part of the spectrum is with increasing intensity stimulated by development in the field of astrophysics, hot plasma physics, macromolecular biology, material sciences and nanotechnologies, especially X-ray lithography to enable further development of information technologies. Lectures cover sources of X-ray radiation, X-ray interaction with matter, X-ray optics and detection.			
02REP	Matrix Lie group representations	Z	2
1.Group theory, symmetric group, homomorphism, isomorphism, group action, direct product, semidirect product, normal group, simple and semisimple group, factor group, matrix Lie groups, SO(n), SU(n), Lorentz group, Poincaré group. 2.One-parameter group, Lie algebras, Lie group – Lie algebra correspondence, exponential map. 3.Universal covering group, relation between SO(3) and SU(2). 4.Representation theory, unitary representation, regular representation, equivalent representation, irreducibility, reducibility, Schur`s lemma, Weyl`s theorem. 5.Lie algebra representation and their connection to Lie group representation, projective representation. 6.Irreducible representations of SO(3) and SU(2), raising and lowering operators, spin representation. 7.Finite-dimensional representations of Lorentz group, tensor product of representations. 8.Representations of SU(3), Gell-Mann matrices, weights and roots. 9.Young tableaux.			
02SKTP	Seminar on quantum field theory	Z	3
The lecture aims to introduce the students to advanced topics of quantum field theory. The focus is mainly on quantization with Feynman's functional integral.			
01SUP	Start-up Project	KZ	2
12SOP	Statistical Optics	Z,ZK	2
The lecture covers both the basics and advanced topics in statistical optics, i.e. the classical theory of optical coherence. It reviews the basics of probability theory and statistics, random variables, random stochastic processes, together with the complex analytical and quasimonochromatic signals. It futher systematically discusses especially the statistical properties of radiation, in terms of the classical scalar 2nd order theory of optical coherence, including elementary concepts and definitions, correlation functions and their properties, time domain, interference law, complex degree of coherence, frequency domain, coherence time, area, volume, spectral degree of coherence, and Wiener-Khinchin theorem. It also introduces special types of fields (coherent, cross spectrally pure) and radiation from primary sources (Schell model sources). The attention is further given both to the dynamics of correlation function (Wolf equations, Van Cittert - Zernike theory) and to applications of the coherence theory (Michelson stellar interferometer, correlation spectroscopy). The course is further devoted to vectorial aspects of coherence theory (standard statistical theory of polarization, using either polarization matrices or Stokes parameters), together with the unified treatment of polarization and coherence aspects, and general vectorial correlation matrices and tensors. The final attention is given to higher order correlation functions.			
02SZD1	Statistical Data Analysis 1	Z,ZK	4
The course is primarily focused on practical application of methods of experimental data analysis. Students obtain knowledge of different statistical methods and their usage, fitting methods, and testing of hypothesis. The course quickly recapitulates basis of mathematical probability theory but it is recommended to attend a full course of the mathematical probability.			
02SZD2	Statistical Data Analysis 2	Z,ZK	4
Individual student's work will include implementation and testing of a program for analysis of generated data sample. Background understanding of Monte Carlo generators for hadron collision will be explained. The course covers methods of data smearing and subsequent deconvolution of data. Basics understanding and usage of neural networks and machine learning will be covered.			
11SUPR	Superconductivity and Low Temperature	ZK	4
The subject of course is: low temperature physics, including cooling methods, low temperature technique, and measurement of low temperatures; macroscopic quantum phenomena in quantum fluids (superfluidity and superconductivity), quantum crystals and diffusion, mesoscopic phenomena in electron systems, quantum Hall effects, Coulomb blockade and single electron transistor.			
01TG	Graph Theory	ZK	5
1. Basic notion of graph theory. 2. Edge and vertex connectivity (Menger Theorem). 3. Bipartite graphs. 4. Trees and forests. 5. Spanning trees (Matrix-Tree Theorem). 6. Euler tours and Hamilton cycles. 7. Maximal and perfect matching. 8. Edge coloring. 9. Flows in networks. 10. Vertex coloring. 11. Plannar graphs (Kuratowski theorem), vertex coloring of planar graphs. 12. Spectrum of the adjacency matrix. 13. Extremal graph theory.			
01TIN	Information Theory	ZK	2
Information theory explores the fundamental limits of the representation and transmission of information. We will focus on the definition and implications of (information) entropy, the source coding theorem, and the channel coding theorem. These concepts provide a vital background for researchers in the areas of data compression, signal processing, controls, and pattern recognition.			
02UC1	Particles Accelerators 1	ZK	2
Introduction to physics and technology of classical (electrostatic and radiofrequency) particle accelerators.			
02UC2	Particle Accelerators 2	ZK	2
Introduction to physics and technology of modern and next generation accelerators based on laser and plasma technology.			
12MODO	Selected Chapters of Modern Optics	Z	2
The subject contents selected lectures of different fields of modern optics which are given by both academic and industry experts. The lectures mainly include the fields which are not covered in common courses of optics.			
02VPSFA	Selected Topics in Statistical Physics and Thermodynamics	Z,ZK	7
The course concentrates on some advanced topics of statistical mechanics not discussed in the basic course on thermodynamics and statistical physics. Question concerning density matrices, the behaviours of nonideal gases and its macroscopic description, microscopic description of phase transitions, the role of fluctuations are addressed in detail.			
02ZQCD	Quantum Chromodynamics	Z,ZK	6
The goal of these lectures is to acquire knowledge about basic principles of strong interaction starting from the constituent quark model and SU(3) flavour symmetry, studies of nucleon structure in deep inelastic scattering of leptons on nucleons and parton model to basics of Quantum Chromodynamics and its practical applications in the context of current experiments in high energy physics and physics of ultra-relativistic heavy-ion collisions.			
02ZELW	Introduction to Theory of Electroweak Interactions	Z,ZK	6
The goal of these lectures is to acquire knowledge about theory of weak interaction from Fermi theory of -decay, introduction of charged intermediate vector boson to unification of electromagnetic and weak interaction in the framework of Standard model including Higgs mechanism. Short student presentations dedicated to experimental discoveries related to the topics covered in the lectures (such as first measurements of W and Z gauge bosons, Higgs boson discovery) are envisioned.			

List of courses of this pass:

Code	Name of the course	Completion	Credits
01SUP	Start-up Project	KZ	2
01TG	Graph Theory	ZK	5
1. Basic notion of graph theory. 2. Edge and vertex connectivity (Menger Theorem). 3. Bipartite graphs. 4. Trees and forests. 5. Spanning trees (Matrix-Tree Theorem). 6. Euler tours and Hamilton cycles. 7. Maximal and perfect matching. 8. Edge coloring. 9. Flows in networks. 10. Vertex coloring. 11. Plannar graphs (Kuratowski theorem), vertex coloring of planar graphs. 12. Spectrum of the adjacency matrix. 13. Extremal graph theory.			
01TIN	Information Theory	ZK	2
Information theory explores the fundamental limits of the representation and transmission of information. We will focus on the definition and implications of (information) entropy, the source coding theorem, and the channel coding theorem. These concepts provide a vital background for researchers in the areas of data compression, signal processing, controls, and pattern recognition.			
02DPQT1	Diploma Thesis 1	Z	10
The diploma thesis is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the thesis supervisor during common regular meetings and discussions.			
02DPQT2	Diploma Thesis 2	Z	20
The diploma thesis is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the thesis supervisor during common regular meetings and discussions.			
02FG	Physics of graphene described by Dirac equation	Z	2
General description of crystal. Tight-binding model of graphene and its approximation in terms of Dirac equation.Transport of Dirac fermions in graphene in presence of external fields and related phenomena. Bilayer graphene, its description and properties in the external magnetic field. Carbon nanotubes, their classification. Basic description of graphene nanoribbons,boundary conditions and energy. Dirac fermions in curved space, fullerenes. Other Dirac materials.			
02KCH	Quantum Chemistry	Z,ZK	3
Introduction to quantum chemistry. Students will acquire theoretical and practical skills to solve basic problems of theoretical quantum chemistry with focus on electronic structure.			
02KO1	Quantum Optics 1	Z,ZK	4
Building upon classical optics, the course shows the construction of a semiclassical Quantum Optics theory of light and light-matter interaction. The aim of the lecture is to provide a robust theory allowing the qualitative and quantitative description of a broad range of quantum optical phenomena as well as some methods for practical computation.			
02KO2	Quantum Optics 2	Z,ZK	4
This course completes Quantum Optics 1 by teaching the terminology and computational methods related to the reformulation of Quantum Optics in phase space. It also extends the application areas to continuum modes and dissipative processes. A concise survey of modern research topics in both theoretical and practical parts of Quantum Optics as well as its applications in further experimental research is also provided.			
02KTPA1	Quantum Field Theory 1	Z,ZK	8
The lecture aims to introduce the students to both fundamental and applied parts of quantum field theory. The focus is in particular on equations of relativistic quantum mechanics, canonical quantization of scalar and bispinor field, perturbation theory (Feynman's rules) and basics of renormalization. The content of the lecture can serve as a base for further study in fields of exactly solvable models, theory of critical phenomena, molecular chemistry and biochemistry or quantum gravity.			
02KTPA2	Quantum Field Theory 2	Z,ZK	8
The lecture aims at introducing the students to the Feynman's functional integral and its applications. The focus is on broadening the knowledge of modern parts of relativistic and non-relativistic quantum field theory and statistical physics. The content of the lecture can serve as a base for further study in fields of exactly solvable models, theory of critical phenomena, molecular chemistry and biochemistry or quantum gravity.			
02KTPA3	Quantum Field Theory 3	Z,ZK	8
The lecture aims at advanced parts of Feynman's functional integral. The focus is on broadening the knowledge of modern parts of relativistic and non-relativistic Quantum Field Theory and statistical physics. The content of the lecture can serve as a base for further study in fields of exactly solvable models, theory of critical phenomena, molecular chemistry and biochemistry or quantum gravity.			
02KVK1	Quantum Circle 1	Z	2
Seminars of the Doppler Institute on topics of mathematical quantum physics for students and PhD. students.			
02KVK2	Quantum Circle 2	Z	2
Seminars of the Doppler Institute on topics of mathematical quantum physics for students and PhD. students.			
02OKS	Open Quantum Systems	Z	2
Quantum description of composite subsystems and their subsystems, density operator. Pure and mixed states, entropy. Quantum correlations, entanglement, its basic properties and possible applications. Introduction to theory of generalized quantum measurement, positive operator-valued measure, physical realizations. Quantum operations, general description of state changes, superoperator theoretical framework, examples of quantum operations. Markovian quantum master equation, quantum dynamical semigroups. Basic models for description of decoherence and thermalization.			
02QIC	Quantum Information and Communication	Z,ZK	4
Quantum theory brought new ideas to the theory of information leading which ultimately lead to the theory of quantum information, computation and communication. The lecture introduces the basic concepts of quantum information e.g. quantum algorithms (Shor's and Grover's), entanglement, quantum teleportation, quantum cryptography and quantum error correction. It also provides an introduction to modern parts of quantum information, e.g. measurement-based and adiabatic quantum computation and quantum walks.			
02QPRGA	Quantum Programming	Z	3
The goal of the course is to provide the basic skills for programming quantum computers, and to use these skills to develop an understanding of fundamental quantum communication protocols and quantum algorithms. The classes are combinations of lectures that introduce the essential concepts and tools, and interactive tutorials on how these concepts are implemented with Python programming language. Every week the students will be given Jupyter notebooks involving self-study materials and homework. The course is suitable for bachelor and master's students from all years and familiarity with quantum mechanics is not necessary. The classes are held entirely online to get the most out of the learning material and make it internationally accessible. The quantum SDK Qiskit will be used during the course. Use of own laptops with a quantum SDK installed before the course start is required.			
02REP	Matrix Lie group representations	Z	2
1.Group theory, symmetric group, homomorphism, isomorphism, group action, direct product, semidirect product, normal group, simple and semisimple group, factor group, matrix Lie groups, SO(n), SU(n), Lorentz group, Poincaré group. 2.One-parameter group, Lie algebras, Lie group – Lie algebra correspondence, exponential map. 3.Universal covering group,			

relation between SO(3) and SU(2). 4.Representation theory, unitary representation, regular representation, equivalent representation, irreducibility, reducibility, Schur`s lemma, Weyl`s theorem. 5.Lie algebra representation and their connection to Lie group representation, projective representation. 6.Irreducible representations of SO(3) and SU(2), raising and lowering operators, spin representation. 7.Finite-dimensional representations of Lorentz group, tensor product of representations. 8.Representations of SU(3), Gell-Mann matrices, weights and roots. 9.Young tableaux.

02SKTP	Seminar on quantum field theory	Z	3
The lecture aims to introduce the students to advanced topics of quantum field theory. The focus is mainly on quantization with Feynman's functional integral.			
02SZD1	Statistical Data Analysis 1	Z,ZK	4
The course is primarily focused on practical application of methods of experimental data analysis. Students obtain knowledge of different statistical methods and their usage, fitting methods, and testing of hypothesis. The course quickly recapitulates basis of mathematical probability theory but it is recommended to attend a full course of the mathematical probability.			
02SZD2	Statistical Data Analysis 2	Z,ZK	4
Individual student's work will include implementation and testing of a program for analysis of generated data sample. Background understanding of Monte Carlo generators for hadron collision will be explained. The course covers methods of data smearing and subsequent deconvolution of data. Basics understanding and usage of neural networks and machine learning will be covered.			
02UC1	Particles Accelerators 1	ZK	2
Introduction to physics and technology of classical (electrostatic and radiofrequency) particle accelerators.			
02UC2	Particle Accelerators 2	ZK	2
Introduction to physics and technology of modern and next generation accelerators based on laser and plasma technology.			
02VPSFA	Selected Topics in Statistical Physics and Thermodynamics	Z,ZK	7
The course concentrates on some advanced topics of statistical mechanics not discussed in the basic course on thermodynamics and statistical physics. Question concerning density matrices, the behaviours of nonideal gases and its macroscopic description, microscopic description of phase transitions, the role of fluctuations are addressed in detail.			
02VUQT1	Research Project 1	Z	6
The research project is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the project supervisor during common regular meetings and discussions.			
02VUQT2	Research Project 2	KZ	8
The research project is based on a topic approved by the administrators of the programme, department and by the dean. The student is guided by the project supervisor during common regular meetings and discussions.			
02ZELW	Introduction to Theory of Electroweak Interactions	Z,ZK	6
The goal of these lectures is to acquire knowledge about theory of weak interaction from Fermi theory of -decay, introduction of charged intermediate vector boson to unification of electromagnetic and weak interaction in the framework of Standard model including Higgs mechanism. Short student presentations dedicated to experimental discoveries related to the topics covered in the lectures (such as first measurements of W and Z gauge bosons, Higgs boson discovery) are envisioned.			
02ZQCD	Quantum Chromodynamics	Z,ZK	6
The goal of these lectures is to acquire knowledge about basic principles of strong interaction starting from the constituent quark model and SU(3) flavour symmetry, studies of nucleon structure in deep inelastic scattering of leptons on nucleons and parton model to basics of Quantum Chromodynamics and its practical applications in the context of current experiments in high energy physics and physics of ultra-relativistic heavy-ion collisions.			
11FPOR	Physics of Surfaces and Interfaces	ZK	2
Description is provided of basic thermodynamic properties, atomary and electronic structure of surfaces and interfaces. The physical models valid for bulk sysstems are juxtaposed with the changes due to introduction of new surface/interface. The theoretical treatment is followed by overview of experimental techniques applied to preparation of surface structures and to study of chemical composition and structural arrangement of the latter. In addition, brief overview is given of simulation approaches suitable for analysis and prediction of properties of selected systems. All the subjects are demonstrated on praktical exaples of case studies.			
11MONA	Molecular Nanosystems	ZK	2
The main goal of the lecture is to show possibilities to use selected molecules properties in molecular nanodevices.			
11NAMA	Nanomaterials - Preparation and Characteristics	Z,ZK	2
The course describes methods of preparation of nanomaterials, their structure, specific properties and applications. The properties of carbon and silicon nanobodies and layers will be analyzed in detail. The aim of the subject is to explain the relationships between physical / chemical properties of nanoparticulate materials and their main structural features.			
11OPTX	Optical Properties of Solids	ZK	2
This course gives an introductory into the optical properties of solids. The fundamental principles of absorption, reflection, luminescence and light propagation are discussed for a wide range of materials, including crystalline insulators, semiconductors, and metals. Classical and quantum models are used as appropriate, and the observed phenomena are discussed from point of their application.			
11SIKL	Computer Simulation of Condensed Matter	ZK	4
Computer simulation in condensed-matter physics is becoming an important tool used by both experimentalist and theorists to develop new materials and technologies. Thus, solution of many practical problems can be transferred from the real to a "virtual" laboratory. During the course, students will be introduced to the theoretical background of basic computation methods and let to test the acquired knowledge in practical exercises. Each lesson is organized as a tutorial where typical problems are solved with detailed explication of the computation methods used. The course is taking place in Computer classroom of the Department of Solid State Physics. Practical demonstration and exercises are using Material Studio simulation environment (Accelrys Software Inc.).			
11SUPR	Superconductivity and Low Temperature	ZK	4
The subject of course is: low temperature physics, including cooling methods, low temperature technique, and measurement of low temperatures; macroscopic quantum phenomena in quantum fluids (superfluidity and superconductivity), quantum crystals and diffusion, mesoscopic phenomena in electron systems, quantum Hall effects, Coulomb blockade and single electron transistor.			
11TPLQ1	Theory of Solid State 1	ZK	4
The content of the lesson are basic physical properties of crystalline solid state materials. Students will be introduced to band structure of solids and basic materials classification, such as metals, semiconductors and dielectrics. The lesson further focuses on magnetic properties, superconductivity and surface properties, a topic mostly expected to be important in construction of quantum computers.			
11TPLQ2	Theory of Solid State 2	Z,ZK	4
The content of the lesson is based on quantum-mechanical description of crystalline solid state materials, providing a fundamental base of theoretical description of solid state properties.			
12FDD	Physics of Detection and Detectors of Optical Radiation	ZK	2
Electromagnetic spectrum. Sources of electromagnetic radiation. Radiometric and photometric units. Ideal detector. External and internal photoefect. Quantum fluctuations of radiation. Noise of detector and electronic circuits. Dynamic range. Detectors based on external photoefect. Photocathodes. Electron multipliers. Microchannel plates. Image intensifiers. Detectors based on internal photoefect. Semiconductor detectors. Scintilators. Detectors of IR, VIS and UV radiation. X-ray detectors.. Pyroelectricity and pyrodetectors. Detector electronic circuits. Human eye.			
12KGOZ1	Quantum Generators of Optical Radiation 1	ZK	2
The aim of the lecture is to introduce the principles and elements of modern quantum generators of optical radiation and their technical solutions.			

12KGOZ2	Quantum Generators of Optical Radiation 2	Z,ZK	4
The course is focused to the description of quantum generator behaviour using the general principles of quantum statistical physics. The aim of the lecture is to introduce the theoretical basis of laser generator function using semi-classical and fully quantum description of interaction between bonded electrons and resonance radiation.			
12MODO	Selected Chapters of Modern Optics	Z	2
The subject contents selected lectures of different fields of modern optics which are given by both academic and industry experts. The lectures mainly include the fields which are not covered in common courses of optics.			
12NF	Nanophysics	ZK	2
The lecture offers a deep overview on nanophysics, clarifies the terminology, compares various forms of matter and structures, with the emphasis on nanostructures, and relates electronic and photonic nanostructures. It also reviews terms and methods form solid state physics, and applies them to quantum restricted nanostructures (quantum wells, multiple quantum wells, quantum wires, quantum dots). The attention is further given both to the electrodynamics of metals, its specifics, the lecture discusses and classifies plasmons; it further systematically explains especially the surface plasmons. Next, the lecture covers the photonic nanostructures, their properties, and relation to electronic structures, with the emphasis on photonic crystals, it gives their examples in 1D, 2D and 3D. The final attention is given to novel artificial materials, mainly metamaterials with negative refractive index. The course is concluded with the student presentations on selected given topics.			
12NOP	Nonlinear Optics	Z,ZK	4
The lecture covers both the basic and advanced topics of nonlinear optics, both from classical and quantum viewpoint, consequentially to the previous courses of Physical optics. From a classical viewpoint, the attention is given to optical processes in dielectric media, macroscopic polarization vector, and microscopic description of polarization vector. Further, it deals with dispersion properties of nonlinear susceptibilities (2nd order nonlinearity for noncentrosymmetric media, 3rd order nonlinearity for centrosymmetric media), and with symmetries of nonlinear susceptibility tensors. From a quantum (poloclassical) viewpoint, the attention is given to derivation of linear, quadratic, and cubic susceptibility, and particularly to the resonant process in two-level media. The processes are classified to nonresonant (parametric) and resonant ones, conservation laws, as well as Manley-Rowe relations, phase matching and synchronisms are discussed. The lecture then separately discusses three-wave mixing (second harmonic generation, sum and difference frequency generation), four wave mixing, optical Kerr effect, third harmonic generation. Concentration is given to light induced refractive index changes, selffocusation and automodulation effects, electrooptical and photorefractive effects, nonlinear light scattering, optical phase conjugation, nonlinear absorption effects, and to nonlinear effects with short pulses. The lecture is conluded with applications of selected nonlinear optical effects.			
12OREZ	Open Resonators	Z,ZK	4
Electromagnetic field-geometrical optics. Open resonators and transfer matrices.Wave optics. Huygens principle and Kirchhoff integral.Gaussian beams in one dimensional optic systems. Intensity moments for description of beam propagation. Quality of general beams . Additional beam characteristics. Diffraction theory of open resonators. Fabry-Perot interferometer. Optical dielectric layers. Passive open resonators. Stable resonators without apertures. Stable resonators limited by apertures. Resonator detuning sensitivity. Resonators on the stability limits. Unstable resonators.Unstable resonators with with variable reflectivity mirrors. Resonators containing lenses and polarizing elements.Open resonators with active medium with gain. Influence of the gain on mode structure and losses in stable and unstable resonators.			
12RFO	X-ray Photonics	ZK	2
More than one hundred years has passed since the discovery of X-ray radiation. X-ray radiation has become intensively studied and used part of the electromagnetic radiation spectrum. Development of photonics in this part of the spectrum is with increasing intensity stimulated by development in the field of astrophysics, hot plasma physics, macromolecular biology, material sciences and nanotechnologies, especially X-ray lithography to enable further development of information technologies. Lectures cover sources of X-ray radiation, X-ray interaction with matter, X-ray optics and detection.			
12SOP	Statistical Optics	Z,ZK	2
The lecture covers both the basics and advanced topics in statistical optics, i.e. the classical theory of optical coherence. It reviews the basics of probability theory and statistics, random variables, random stochastic processes, together with the complex analytical and quasimonochromatic signals. It futher systematically discusses especially the statistical properties of radiation, in terms of the classical scalar 2nd order theory of optical coherence, including elementary concepts and definitions, correlation functions and their properties, time domain, interference law, complex degree of coherence, frequency domain, coherence time, area, volume, spectral degree of coherence, and Wiener-Khinchin theorem. It also introduces special types of fields (coherent, cross spectrally pure) and radiation from primary sources (Schell model sources). The attention is further given both to the dynamics of correlation function (Wolf equations, Van Cittert - Zernike theory) and to applications of the coherence theory (Michelson stellar interferometer, correlation spectroscopy). The course is further devoted to vectorial aspects of coherence theory (standard statistical theory of polarization, using either polarization matrices or Stokes parameters), together with the unified treatment of polarization and coherence aspects, and general vectorial correlation matrices and tensors. The final attention is given to higher order correlation functions.			
12UKP	Ultra-short Pulse Generation	ZK	2
What we mean by ultrashort light pulses (USP) . History of USP generation. Characteristics of USP and their description.Methods of USP generation. Principle of mode-locking in lasers. Methods of mode-locking.Influence of dispersion on propagation and USP generation.Methods of dispersion compensation and its use.Spatio-temporal optics of USP.Methods of measurement USP characteristics. Autocorrelation methods. Spectral phase interferometry and frequency resolved optical gating - SPIDER and FROG. Methods of shaping of USP.Amplification of USP, temporal stretching and compression - chirped pulses amplification CPA.Selected application of USP.			
18MEMC	Monte Carlo Method	Z,ZK	4
This courseis devoted to the numerical method Monte Carlo and to its selected applications.			
18OOP	Object Oriented Programming	Z	2
This course consists of the contributions of students concerning given topics concerned on technologies uded in program development.			
18PCP	Advanced C++	Z,ZK	4
This lecture covers the virtual inheritance,variadic templetes, template metaprogramming, template libraries design and implementation, tools for data type processing in compile time and for the advanced diagnostic of the templates, concepts, coroutines, modules, ranges, views and other tools introduced in C++ 20, application of the multithreading (execution parallelization).			

For updated information see http://bilakniha.cvut.cz/en/FF.html
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