

**Quantum Physics**  
**Module of courses for international exchange students**  
**Department of Optics, Faculty of Science, Palacký University in Olomouc**

**Quantum information theory**

Lecturer: Jaromír Fiurášek

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 4

Physical aspects of information processing; Quantum theory, quantum states, quantum operations, quantum measurements, quantum entanglement; Quantum computer, quantum logic gates, quantum Fourier transform, Shor's algorithm, quantum search algorithms; Physical implementations of quantum computers; Quantum communication, quantum channels, quantum error correction; Quantum teleportation, entanglement swapping; Quantum cryptography, quantum communication networks, quantum repeaters.

**Quantum Communication and Information Processing 1**

Lecturer: Radim Filip

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 2

This course gives basic and intermediate understanding of quantum information processing with continuous variables and hybrid information processing combining this with qubits. It contains quantum description using both Heisenberg picture and Wigner function formalism applied to measurement-induced quantum gates, quantum teleportation, quantum distillation and purification, quantum memory and quantum key distribution.

**Quantum communication and information processing 2**

Lecturers: Jaromír Fiurášek, Radim Filip

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 2

Quantum description of electromagnetic field, creation and annihilation operators, photon number operator, Fock states, coherent states. Sources of correlated photon pairs, spontaneous parametric down-conversion, polarization entangled photons, time-bin entanglement. Quantum description of linear optical interferometers, beam splitters, wave-plates. Single-photon and multi-photon interference, Hong-Ou-Mandel dip. Quantum teleportation of polarization states of single photons, dense coding. Optimal cloning of quantum states of single photons. Distillation and concentration of entangled photon pairs. Measurement induced optical nonlinearity, linear optical quantum gates, nonlinear sign gate, C-NOT gate, multi-qubit gates.

### **Conceptual Issues of Quantum Theory**

Lecturer: Miloslav Dušek

Lecture: 2 hrs per week

Credits: 3

Quantum interference, Superposition principle, Quantum measurement; State preparations and quantum tests, Projection operators, Density matrix, POVM; Interaction-free measurement, Quantum Zeno effect; Wave-function collapse, Decoherence; Interpretations of quantum theory; Indistinguishable particles; EPR paradox, Hidden variables, Bell's inequalities, Quantum correlations and non-locality, Entanglement, Impossibility of instantaneous information transfer; Parametric down-conversion, Interferometric test of Bell's inequalities and other interesting quantum optical experiments; Quantum teleportation, Quantum cryptography, Quantum computing.

### **Coherence and statistical optics**

Lecturer: Jaromír Fiurášek

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 5

Light as a stochastic process, stationary processes, ergodic processes, complex analytical signal Temporal coherence, temporal coherence function, coherence time Power spectral density, Wiener-Khinchin theorem, Fourier spectroscopy Spatial coherence, mutual coherence function, propagation of partially coherent light spatially incoherent light sources, van Cittert-Zernike theorem, Michelson stellar interferometer Imaging with partially coherent light, imaging with fully coherent and incoherent light, optical transfer function Statistical properties of thermal light, intensity correlations, intensity probability distributions Mandel-Rice formula, Mandel photodetection equation Partially polarized light, coherence matrix, degree of polarization

### **Thermodynamics and Statistical Physics**

Lecturer: Tomáš Opatrný

Lecture: 3 hrs + Exercise: 1hr per week

Credits: 5

Thermodynamics: Thermodynamic state and quantities, the laws of thermodynamics: the zeroth, first, second and third law of thermodynamics. Heat engines. Entropy and the arrow of time, Maxwell demon and its relation to the information theory, seeming violations of the second law. Thermodynamic potentials, Maxwell relations, thermodynamic stability.

Statistical physics: Microstate and macrostate in classical and quantum physics, phase space, ergodic hypothesis, statistical definition of entropy. Statistical ensembles, microcanonical, canonical, and grand canonical ensemble, partition function and its relation to thermodynamic variables. Two-level systems, harmonic oscillators and ideal gases, theory of heat capacities, Planck law. Quantum statistics of ideal gases, Bose-Einstein condensation, Fermi gas.

### **Quantum electrodynamics**

Lecturer: Zdeněk Hradil

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 3

Interaction of electromagnetic field with charged particles, time dependent perturbation theory, emission and absorption of photons, Feynmann diagrams, lifetime of excited atom, cross section of photoeffect, Compton scattering, Cherenkov radiation, single photon and two photon processes, natural linewidth and self-energy, second quantization of Schroedinger equation, spin-statistics theorem, relationship between second quantization and quantum mechanics, electromagnetic interaction, non relativistic Bremsstrahlung, Rutherford scattering, Renormalization in quantum electrodynamics, Casimir effect, renormalization of the mass of the electron, Lamb shift, correlations between fermions and photons, Hanbury-Brown Twiss experiment, quantum optics, interference and correlations of photons, nonclassical effects.

[Greiner W.: *Quantum Mechanics - Special Chapters*. Springer, 1998]

### **Quantum field theory**

Lecturer: Zdeněk Hradil

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 3

Introduction to physics of elementary particles, Lorentz transformation and special theory of relativity, Klein-Gordon equation, spinor representation of Lorentz group, Dirac equation and its interpretation, vacuum and antiparticles, Gamma matrices, Maxwell equations in a covariant form, variational principle and symmetries, Noether theorem and conservation laws, scalar complex and electromagnetic field, Bohm-Ahronov effect, canonical quantization of scalar Klein-Gordon field, Dirac field and anti commutators, canonical quantization of electromagnetic field, gauge fields, radiation and Lorentz gauge, Feynmann path integral.

[Ryder, L.H.: *Quantum Field Theory*. Cambridge University Press, Cambridge, U.K., 1997]

### **Fundamentals of Laser Physics**

Lecturer: Radim Filip

Lecture: 2 hrs + Exercise: 1hr per week

Credits: 6

This course gives basic and intermediate understanding of principals of light-matter interaction in lasers and masers using population dynamics, semi-classical and quantum description. It describes in detail amplification and saturation effects, nonlinear dynamics and stability problems, photon statistics, atomic-coherence effects and some quantum optical effects in lasers and masers. Further, it contains basic principles of experimental determination of quantum properties of laser beam.

### **Selected Chapters from Laser Physics**

Lecturer: Radim Filip

Lecture: 3 hrs + Exercise: 1hr per week

Credits: 5

This course gives upper-intermediate understanding of quantum description of light-matter interaction. It also reviews applications of lasers in metrology, spectroscopy, interferometry, optical communication, quantum and nonlinear optics and quantum information. It is finished by practical exercise on the laser-kit system demonstrating lasing and its properties.

### **Nonlinear Dynamics, Chaos, and Synergetics**

Lecturer: Radim Filip

Lecture: 3 hrs + Exercise: 1hr per week

Credits: 5

This course gives basic and intermediate understanding of principles of nonlinear dynamics, chaos and synergetic and its behavior under influence of noise. It contains simulations and applications of logistic equations, population dynamics, stochastic equations, Fokker-Planck equations in different branches of physics and science. It is finished by a project on numerical simulation of nonlinear dynamics and its evaluation.