

The Curriculum of the Doctoral School of Physics
University of Pécs



Pécs, 2023.

1 Study Requirements in the Doctoral School of Physics, Faculty of Science, University of Pécs

The system of study requirements and the order of administration are regulated by the Rules of the Doctoral School of Physics, Faculty of Science, University of Pécs (PTE TTK), in accordance with university regulations.

A brief summary is given below:

1. The duration of the doctoral training is 8 semesters.
2. The doctoral training consists of two phases:
 - i) The first is a “*training and research phase*” lasting four semesters.
 - ii) The second is a “*research and dissertation phase*”, also lasting four semesters.
3. The total number of credits to be earned during the doctoral training is $120 + 120 = 240$ credits.
4. Credits in the doctoral training can be obtained through various forms of activity:
 - i) participation in training (“study credits”),
 - ii) teaching,
 - iii) research work,
 - iv) processing of scientific literature,
 - v) publication of research results,
 - vi) written reports summarizing the doctoral student’s activities.
5. Compulsory courses in the doctoral training:

Quantum Optics and Quantum Information	Laser Physics, Nonlinear Optics and Spectroscopy	Physics of Many-Particle Systems	Scientist–Teacher Training
Processing and Presentation of Scientific Papers (János Hebling)			
Quantum Optics I. (János Bergou, Péter Ádám)	Optics (János Hebling)	Mathematical Methods in the Description of Many-Particle Systems (Tamás Gál)	Teaching Physics I. (Classical Physics) (László Pálfalvi)
Quantum Information I. (János Bergou, Péter Ádám)	Laser Physics (János Hebling)	Physics of Many-Particle Systems (Tamás Gál)	Teaching Physics II. (Modern Physics) (László Pálfalvi)

6. Comprehensive examination subjects:

Training Program	Quantum Optics and Quantum Information	Laser Physics, Nonlinear Optics and Spectroscopy	Physics of Many-Particle Systems	Scientist–Teacher Training
Exam Subject I.	Quantum Mechanics	Optics	Physics of Many-Particle Systems	Teaching Physics I.
Exam Subject II.	Quantum Information	Laser Physics	Mathematical Methods in the Description of Many-Particle Systems	Teaching Physics II.

7. Regulations for Credits Obtainable from Different Types of Activities

i) Semesters 1–4:

Total required credits: 120

Type of Activity	Min	Max	Remarks	Verification Method
Study	30	48	For courses completed upon the supervisor's recommendation, one weekly class hour per semester equals 2 credits. Credits may also be obtained through courses offered by other programs or universities, with the supervisor's and program leader's approval.	Certified by the course instructor.
Teaching	8	32	One weekly class hour per semester equals 2 credits.	Certified by the educational coordinator of the Institute of Physics.
Processing of Scientific Literature	0	24	Literature designated by the supervisor; 0, 2, 4, or 6 credits per semester.	Certified by the supervisor.
Research	6	32	0, 2, 4, 6, or 8 credits per semester.	Certified by the supervisor.
Report concluding the first two semesters	3	12	For the presentation or written report (maximum 15 pages) summarizing the student's activities so far; 3, 6, 9, or 12 credits may be granted upon the supervisor's recommendation.	Certified by the supervisor.

ii) Semesters 5–8:

Total required credits: 120

Type of Activity	Min	Max	Remarks	Verification Method
Study	0	16	For courses completed upon the supervisor's recommendation, one weekly class hour per semester equals 2 credits. Credits may also be obtained through courses offered by other programs or universities, with the supervisor's and program leader's approval.	Certified by the course instructor.
Teaching	0	24	One weekly class hour per semester equals 2 credits.	Certified by the educational coordinator of the Institute of Physics.
Processing of Scientific Literature	0	12	Literature designated by the supervisor; 0, 2, 4, or 6 credits per semester.	Certified by the supervisor.
Research	0	16	0, 2, 4, 6, or 8 credits per semester.	Certified by the supervisor.
Publication	72	96	A publication in an international peer-reviewed journal may yield up to 30 credits; an oral presentation at an international conference up to 20; a poster presentation up to 15; and other types of publications up to 10 credits. These credits may be validated in any semester following acceptance of the publication.	Certified by the program leader each semester upon the supervisor's recommendation.

2 Programs and Research Areas of the Doctoral School

This chapter lists the programs of the Doctoral School and their characteristic research topics.

The current doctoral research topics are available at <http://www.doktori.hu>.

The task of the **Council of the Doctoral School of Physics (FizDIT)** is to monitor, improve, and expand the quality of research topic proposals.

2.1 Quantum Optics and Quantum Information Program

Head: Prof. János Bergou, University Professor

2.1.1 Quantum Optics

- Application of quantum trajectory methods for the description of quantum optical systems
- Coherent control in atomic systems
- Coherent control and manipulation of quantum systems using phase-modulated laser pulses
- Slowing down of light using frequency-modulated laser pulses: Applications in quantum information and resonant nonlinear optics
- Collective optical excitations in ultracold atomic gases
- Investigation of light–trapped ion interactions
- Propagation of electromagnetic fields in photonic crystal optical fibers
- Analog Hawking radiation in moving Bose–Einstein condensates
- Properties and role of quantum random walks in quantum information systems and their optical implementations
- Multiphoton scattering of electrons
- Dependence of interactions with few-cycle femtosecond light pulses on absolute phase
- Gauge-invariant Wigner functions of charged particles
- Wigner functions of s-waves in arbitrarily high dimensions

2.1.2 Quantum Information

- Behavior of entanglement in various physical systems and processes (e.g. quantum optical setups, solid-state systems, etc.)
- Realization of quantum computers; quantum optical aspects of various physical implementations (optical, atomic, ionic, etc.)
- Fundamental questions of quantum mechanics from the perspective of information theory: measurement theory, nonlocality, Bell inequalities, interpretations
- Strongly correlated electron systems in two dimensions
- Fractional quantum Hall effect
- Use of decohered quantum systems in quantum information processing
- Practical applications of nonclassical light
- Investigation of error-free capacities of quantum channels

2.2 Laser Physics, Nonlinear Optics, and Spectroscopy Program

Head: Prof. János Hebling, University Professor, DSc, Doctor of the Hungarian Academy of Sciences

- Molecular dynamics studies using time-resolved spectroscopic methods in the fs–ns time domain
- Development and application of integrating spheres for studying transitions with small cross-sections
- Investigation of LiTaO₃ crystals with high optical damage thresholds using the Z-scan method
- Development and critical evaluation of Z-scan measurement theories
- Generation of high-power, ultrashort THz pulses via optical rectification

- Transient dynamics in semiconductors induced by terahertz pulses
- Pump–probe measurements with terahertz pulses
- Physical properties of graphene
- Investigation of nonlinear photonic crystals
- High-resolution spectroscopy of rare-earth-doped optical crystals
- Development of optical and optoelectronic devices based on periodically poled LiNbO₃ crystals
- Development of ultrashort pulse optical parametric oscillators (OPOs) and amplifiers (OPAs)
- Modeling of interactions between intense electromagnetic fields and charged particles using PIC (Particle-in-Cell) methods
- Role of hydroxide ions in nonlinear optical crystals
- Thermal recording of holograms in photorefractive crystals
- ESR observation of transition metal dopants in LiNbO₃ and modification of incorporation by heat treatment
- Experimental and theoretical studies of capillary z-pinch soft X-ray lasers
- Experimental and theoretical investigations of capillary z-pinch optical waveguides
- Nonlinear optics with soft X-ray lasers
- Laser measurement techniques for aerosols: determination of particle size and concentration
- Investigation of the biological effects of aerosols
- Energy transfer and fluorescence quenching in cavitand host–guest complexes
- Surface characterization using interferometric methods
- Modeling and design of particle counters
- Application of laser-based methods in the determination of atmospheric parameters

2.3 Physics of Many-Particle Systems Program

Head: Dr. habil. Tamás Gál, Associate Professor

- The Heisenberg model as a quantum field theory
- Fusion rules and the pentagon equation
- Properties of mesons and baryons in the nuclear medium
- Spectroscopy of exotic hadrons
- Topological excitations in QCD
- Experimental investigation of low-pressure gas discharges
- Development of modeling methods for low-pressure gas discharges
- Particle-based simulations of electron kinetics
- Simulation of strongly coupled plasma many-particle systems
- Electron microscopy of wide-bandgap semiconductors (SiC and GaN)
- Ion-beam synthesis of new phases, such as the creation of oriented diamond grains in SiC single crystals by high-temperature carbon ion implantation
- Preparation and microscopy of new multicomponent nanocomposite layers

2.4 Scientist–Teacher Training Program

Head: Prof. László Pálfalvi, University Professor

- Educational videos in physics teaching
- Competence-oriented knowledge assessment in secondary school physics education
- Use of microcontrollers in physics education
- Application of simulations in electromagnetism for experiment preparation
- Electromagnetic fields and radio-frequency waves in secondary school physics teaching
- Methods and effects of science popularization in science education

- Environmental physics in physics education
- Interpretation of measurement results and data-driven decision-making; use of probability and statistics in secondary school physics education
- Role and development of non-subject-specific cognitive skills in university (and secondary school) physics education
- Analogies in physics
- Talent development and physics competitions
- Integration of advanced physics and mathematics knowledge in competition problems
- Extremum problems in physics exercises
- Complex, selected (education-related) problems from the field of classical physics
- *Ball model reloaded*: computer-based molecular modeling
- Abandoned attempts in the history of physics
- The development of physics as the interplay of chance and necessity

3 Courses of the Doctoral School

This chapter lists the courses offered by the Doctoral School, grouped according to the thematic programs.

Based on the recommendations of the program leaders, the **Council of the Doctoral School of Physics (FizDIT)** determines the courses offered each semester.

The Council is also responsible for monitoring, improving, and expanding the quality of the course list.

Doctoral students enrolled in a specific program may, according to their particular research interests and topics, also take courses offered by other programs.

According to the regulations of the Doctoral School of Physics, doctoral students “*may earn study credits by attending courses organized in other programs or at other universities, upon the recommendation of their supervisor.*”

3.1 Quantum Optics and Quantum Information Program

3.1.1 Quantum Optics I. (*Péter Ádám*)

- Quantized electromagnetic field, modes
- Density operator and phase space
- Operator ordering and operator functions
- Wigner function, characteristic function, quasiprobability distribution functions
- Quantum states of the EM field: thermal, coherent, and squeezed states
- The phenomenon of entanglement, Einstein–Podolsky–Rosen pairs

Recommended literature:

- A. Yariv: *Quantum Electronics* (John Wiley, New York, 1988)
- W. H. Louisell: *Quantum Statistical Properties of Radiation* (John Wiley, New York, 1990)
- S. M. Barnett, P. M. Radmore: *Methods in Theoretical Quantum Optics* (Clarendon Press, 1997)
- M. O. Scully, M. S. Zubairy: *Quantum Optics* (Cambridge University Press, 1997)

3.1.2 Quantum Optics II. (*Péter Ádám*)

- Passive optical elements: beam splitters, phase shifters, multiports
- Theory of photodetection and photon counting
- Homodyne and heterodyne detection
- Statistical and quantum theory of coherence
- Nonlinear optical processes
- Active optical elements: amplification, parametric oscillators
- Description of losses, noise, and damping in quantum optics

Recommended literature:

- L. Mandel & E. Wolf: *Optical Coherence and Quantum Optics* (Cambridge University Press, 1995)
- S. M. Barnett & P. M. Radmore: *Methods in Theoretical Quantum Optics* (Clarendon Press, 1997)
- U. Leonhardt: *Measuring the Quantum State of Light* (Cambridge University Press, 1997)

3.1.3 Quantum Optical Experiments (*Tamás Kiss*)

- Generation and detection of nonclassical light
- Reconstruction of quantum states, quantum tomography
- Verification of quantum mechanical models in optics
- Quantum state teleportation
- Atom trapping and atom optics

Recommended literature:

- Hans-A. Bachor & T. C. Ralph: *A Guide to Experiments in Quantum Optics*

3.1.4 Quantum Information I: Theory (Péter Ádám)

- Classical and quantum information theory (Shannon and von Neumann entropy, channel capacity)
- Dynamics of qubits (unitary evolution, quantum operations, von Neumann and POVM measurements, quantum logic networks)
- Theory of entanglement (typical entangled states such as EPR, GHZ, W, Werner, etc.; entanglement measures; entanglement witnesses in general and for specific classes of states; multipartite entanglement)
- Quantum communication protocols (teleportation, cloning, superdense coding, cryptography)
- Quantum algorithms (Shor's, Grover's, quantum random walk, error-correcting codes)

Recommended literature:

- M. A. Nielsen & I. L. Chuang: *Quantum Computation and Quantum Information* (Cambridge University Press, 2000)

3.1.5 Quantum Information II: Experimental Aspects and Applications (Mátyás Koniorczyk)

- Models of the general quantum computer; quantum simulations
- Decoherence, operational conditions of quantum computers, “fault-tolerant quantum computing”
- Ion-trap quantum computers
- Quantum simulators and computers based on cold trapped atoms
- Photonic quantum computers and quantum communication (polarization qubits, coherent-state qubits, Gaussian states)
- NMR quantum computers and quantum dots
- Applications of quantum information theory in other fields of physics (e.g. DMRG as a variational method in the context of quantum information, phase transitions and quantum information)

Recommended literature:

- M. A. Nielsen & I. L. Chuang: *Quantum Computation and Quantum Information* (Cambridge University Press, 2000)

3.1.6 Computational Methods in Quantum Information (Mátyás Koniorczyk)

- Pure and mixed states of qubits and qudits
- Unitary time evolution and projective measurement
- Multipartite quantum systems: tensor product, partial trace
- General quantum mechanical evolution: completely positive (CP) maps, POVM measurements
- Schmidt decomposition, entanglement, EPR, GHZ, W states

- Bound entanglement, PPT and NPT states
- Quantum mechanical entropies
- Bipartite entanglement and concurrence
- Monogamy of entanglement, tangle, CKW inequalities
- Localizable entanglement, cluster states

Recommended literature:

- John Preskill: *Lecture Notes for Physics 229: Quantum Information and Computation* (California Institute of Technology, 1998)
- Michał Horodecki, Paweł Horodecki, and Ryszard Horodecki: *Mixed State Entanglement and Quantum Communication*, in *Quantum Information: An Introduction to Basic Theoretical Concepts and Experiments* (Springer-Verlag, 2001)
- M. Hein, W. Dür, J. Eisert, R. Raussendorf, M. Van den Nest, H.-J. Briegel: *Entanglement in Graph States and Its Applications* (arXiv:quant-ph/0602096)

3.1.7 Quantum Mechanical Paradoxes (Mátyás Koniorczyk)

- Einstein–Podolsky–Rosen paradox
- Nonlocality and Bell inequalities
- Greenberger–Horne–Zeilinger (GHZ) correlations
- Correlations and entangled states of the electromagnetic field
- Single-photon interferometry, complementarity, duality
- Two-photon interferometry, quantum eraser
- Quantum nondemolition measurements
- Pre- and post-selected quantum mechanics

Recommended literature:

- J. S. Bell: *Speakable and Unspeakable in Quantum Mechanics*
- H. Paul & I. Jex: *Introduction to Quantum Optics: From Light Quanta to Quantum Teleportation*

3.1.8 Fundamentals of Quantum Electrodynamics (QED) (Sándor Varró)

- Classical field theory, conservation laws
- Fields and particles, creation and annihilation operators
- Canonical quantization
- Perturbation theory, Wick’s theorem, Feynman diagrams
- Quantization of gauge theories: electrodynamics
- Spontaneous emission, Lamb shift, Casimir effect, multiphoton absorption

Recommended literature:

- P. W. Milonni: *The Quantum Vacuum: An Introduction to Quantum Electrodynamics*
- C. Cohen-Tannoudji, J. Dupont-Roc, and G. Grynberg: *Photons and Atoms – Introduction to Quantum Electrodynamics* (Wiley, New York, 1989)

3.1.9 Resonant Light–Matter Interaction (Péter Ádám)

- Light scattering on atoms, spontaneous emission
- Semiclassical theory and coupled Maxwell–Bloch equations
- Propagation of coherent pulses
- Resonance fluorescence

- Electrodynamics in cavities
- The Jaynes–Cummings model
- The micromaser
- Quantum theory of lasers

Recommended literature:

- L. Allen & J. H. Eberly: *Optical Resonance and Two-Level Atoms* (Dover Publications, 1987)
- C. Cohen-Tannoudji, J. Dupont-Roc, G. Grynberg: *Photons and Atoms – Introduction to Quantum Electrodynamics*
- M. O. Scully, M. S. Zubairy: *Quantum Optics* (Cambridge University Press, 1997)
- *Fundamentals of Quantum Electronics*, ed. Sándor Varró, Lecture Notes

3.1.10 Quantum Statistics of Open Systems (Péter Domokos)

- Density matrix, von Neumann equation and measurement, entropy
- Quantum system in a heat bath, Markov approximation
- Master equation, quantum regression theorem
- Zwanzig projector-operator method
- Phase-space methods, Wigner function, Fokker–Planck equation
- Heat bath in a non-thermal state
- Quantum Langevin equations, generalized Einstein relations
- Stochastic differential equations: Itô and Stratonovich interpretations
- Theory of photodetection
- Monte Carlo wave-function method for describing the time evolution of open systems
- Applications in quantum optics

Recommended literature:

C. W. Gardiner: *Handbook of Stochastic Methods* (Springer-Verlag, 2004)

H. Carmichael: *An Open Systems Approach to Quantum Optics* (Springer-Verlag, 1993)

3.1.11 Laser Cooling and Trapping of Atoms (Péter Domokos)

- Mechanical effects of light on neutral particles; historical overview
- Characteristic time scales, separation of internal and external degrees of freedom, foundations of the semiclassical theory
- Mechanical effect of a laser on a stationary atom: radiation pressure and dipole force
- Work done by the radiation field, energy balance
- Fluctuations of the electromagnetic field, diffusion in atomic motion
- Mechanical effect of a laser on a moving atom, Doppler cooling
- Optical molasses, introduction of Langevin equations and the concept of temperature
- Mechanical effects of lasers on multilevel atoms
- Magneto-optical trap
- Polarization-gradient cooling, Sisyphus effect
- Quantized motion of atoms, velocity-selective coherent population trapping
- Sideband cooling of trapped atoms

Recommended literature:

H. J. Metcalf & P. van der Straten: *Laser Cooling and Trapping* (Springer-Verlag, 1999)

C. Cohen-Tannoudji, J. Dupont-Roc & G. Grynberg: *Photons and Atoms – Introduction to Quantum Electrodynamics* (Wiley, New York, 1989)

3.1.12 Bose–Einstein Condensation in Dilute Gases (Tamás Kiss)

- Ideal (non-interacting) Bose gas: phase transition, critical temperature, condensed fraction
- Trapping: quadrupole, TOP, Ioffe–Pritchard, optical and magneto-optical traps
- Cooling: Doppler, Sisyphus, and evaporative cooling
- Interacting gases: scattering, scattering length
- Gross–Pitaevskii equation, Thomas–Fermi approximation, healing length
- Hydrodynamic approximation
- Elementary excitations, Bogoliubov transformation
- Finite temperature, Hartree–Fock approximation
- Correlations, coherence, atom laser

Recommended literature:

C. J. Pethick & H. Smith: *Bose–Einstein Condensation in Dilute Gases* (Cambridge University Press, 2002)

L. P. Pitaevskii & S. Stringari: *Bose–Einstein Condensation* (Oxford University Press, 2003)

H. J. Metcalf & P. van der Straten: *Laser Cooling and Trapping* (Springer-Verlag, 1999)

3.1.13 Coherent Control (Zsolt Kiss)

- Interaction of the electromagnetic field with idealized two-level atoms
- Control of atomic electronic states, Bloch equations
- Adiabatic control of electronic states in two-level systems
- Dissipative processes; the role of dissipation in the controllability of atomic levels
- Interaction of three-level systems with coherent electromagnetic fields
- Stimulated Raman adiabatic passage (STIRAP) in three-level systems
- Interaction of degenerate atomic systems with electromagnetic fields; selection rules
- STIRAP in degenerate three-level systems
- Applications in atomic physics
- Interaction of molecular electron shells with electromagnetic fields
- Control of vibrational wave packets in diatomic molecules
- Femtochemistry: influencing chemical reactions with femtosecond laser pulses

Recommended literature:

R. Loudon: *The Quantum Theory of Light* (Oxford University Press, 2000)

C. Cohen-Tannoudji, J. Dupont-Roc & G. Grynberg: *Photons and Atoms – Introduction to Quantum Electrodynamics* (Wiley, New York, 1989)

M. O. Scully & M. S. Zubairy: *Quantum Optics* (Cambridge University Press, 1997)

P. W. Brumer & M. Shapiro: *Principles of the Quantum Control of Molecular Processes* (Wiley, 2003)

3.1.14 Coherent Interaction of Short Laser Pulses with Resonant Atoms (Gagik Dzsofjan)

- Vector model of the interaction of a laser pulse with a two-level atom
- Lasing without population inversion and other atomic coherence and interference phenomena
- Coherent manipulation of atoms: deflection and beam splitting
- Adiabatic passage induced by stimulated Raman scattering in multilevel quantum systems
- Adiabatic passage induced by frequency-modulated (chirped) laser pulses
- Self-induced transparency, solitons
- Electromagnetically induced transparency
- Lossless propagation of chirped laser pulses in media consisting of multilevel atoms

Recommended literature:

C. Cohen-Tannoudji, J. Dupont-Roc & G. Grynberg: *Photons and Atoms – Introduction to Quantum Electrodynamics* (Wiley, New York, 1989)

M. O. Scully & M. S. Zubairy: *Quantum Optics* (Cambridge University Press, 1997)

3.2 Laser Physics, Nonlinear Optics and Spectroscopy Program

3.2.1 Fluorescence Spectroscopy (*János Erostyák*)

- Basic concepts of fluorescence spectroscopy
- Measurement methods and instrumentation: direct methods, sampling techniques, time-correlated single-photon counting, pump–probe methods, phase fluorimetry
- Fluorescence polarization
- Fluorescence quenching
- Energy transfer
- Reversible two-state reactions
- Evaluation methods in fluorescence spectroscopy

Recommended literature:

J. R. Lakowicz: *Principles of Fluorescence Spectroscopy* (Plenum Press, New York, 1983)

L. Szalay & S. Damjanovich (eds.): *Luminescence in Biology and Medicine* (Akadémiai Kiadó, Budapest, 1983)

J. R. Lakowicz (ed.): *Topics in Fluorescence Spectroscopy, Vols. 1–3* (Plenum Press, New York, 1991)

B. Valeur & J.-C. Brochon (eds.): *New Trends in Fluorescence Spectroscopy: Applications to Chemical and Life Sciences* (Springer, Berlin, 2001)

3.2.2 Determination of Nonlinear Optical Parameters by the Z-scan Method (*László Pálfalvi*)

- Description of light propagation using matrix optics
- Diffraction, Gaussian beams
- Elements of nonlinear optics and crystal optics; third-order optical nonlinearity
- Z-scan theory for thin samples; possibilities for determining the nonlinear refractive index and nonlinear absorption
- Extension of the Z-scan method to thick samples; limitations of the various theories
- Application of the Z-scan method to light pulses; time-resolved Z-scan measurements
- Simplified model of photorefraction
- Thermo-optical nonlinearity
- Investigation of LiNbO₃ by the Z-scan method

Recommended literature:

R. L. Sutherland: *Handbook of Nonlinear Optics* (Marcel Dekker, 1996)

M. G. Kuzyk & C. W. Dirk: *Characterization Techniques and Tabulations for Organic Nonlinear Materials* (Marcel Dekker, 1998), pp. 655–692

R. Guenther: *Modern Optics* (John Wiley & Sons, 1990)

3.2.3 Introduction to Laser Physics (*Gábor Almási*)

- Absorption and emission of light; conditions for gain
- Bandwidth, line shape, properties of saturation
- Matrix optics; geometrical description of resonators
- Wave theory of resonators; Gaussian beams
- Transient phenomena in resonators
- Rate-equation model of lasers
- Gas, dye, semiconductor, and solid-state lasers
- Devices for light detection
- Generation and measurement of ultrashort laser pulses
- Industrial applications of lasers
- Medical and biological applications of lasers

Recommended literature:

P. W. Milonni & J. H. Eberly: *Lasers* (John Wiley, 1988)

M. Sargent, M. O. Scully & W. E. Lamb: *Laser Physics* (Addison–Wesley, 1974)

B. E. A. Saleh & M. C. Teich: *Fundamentals of Photonics* (Wiley-Interscience, 1991)

3.2.4 Ultrashort-Pulse Lasers (János Hebling)

- Description of ultrashort light pulses
- Group delay, group-delay dispersion
- Pulse stretchers and compressors (prism pair, grating pair, chirped mirrors)
- Principle of mode locking
- Methods of mode locking (Kerr-lens effect, synchronous pumping)
- Special resonators; astigmatism compensation
- Modeling of Kerr-lens mode locking
- Ultrashort-pulse fiber lasers

Recommended literature:

W. Kaiser (ed.): *Ultrashort Laser Pulses and Applications* (Topics in Applied Physics, 1988)

J. C. Diels & W. Rudolph: *Ultrashort Laser Pulse Phenomena*, 2nd ed. (Academic Press, 2006)

3.2.5 X-ray Lasers (Szergej Kuhlevszkij)

- Basic physical processes in lasers
- Laser gain coefficient
- Highly ionized ions as active laser media
- Ionization and recombination in plasma
- Energy levels in ions and their population inversion
- Magnetohydrodynamic description of plasma
- Recombination-pumped laser schemes
- Applications

Recommended literature:

R. C. Elton: *X-Ray Lasers* (Academic Press, San Diego, 1990)

J. A. R. Samson & D. L. Ederer (eds.): *Vacuum Ultraviolet Spectroscopy* (Academic Press, New York, 1998)

D. Attwood: *Soft X-Rays and Extreme Ultraviolet Radiation* (Cambridge University Press, 2000)

3.2.6 Nonlinear Optical Frequency-Conversion Devices (János Hebling)

- Nonlinear optical susceptibility
- Wave propagation in nonlinear optical media
- Frequency-conversion processes (sum- and difference-frequency generation, parametric amplification)
- Phase-matching methods (collinear and noncollinear; birefringence- and temperature-based; noncritical phase matching)
- Quasi-phase matching
- Optical parametric amplifier and oscillator
- Optical rectification

Recommended literature:

R. W. Boyd: *Nonlinear Optics* (Academic Press, 1992)

R. L. Sutherland: *Handbook of Nonlinear Optics* (Marcel Dekker, 2003)

2.2.7 Optical Spectroscopic Instruments (János Hebling)

- The concept of a spectrum
- General description, construction, and figures of merit of angular-dispersion instruments
- Fabry–Pérot interferometers
- Fourier-transform spectrometers
- Crystal-optical devices (polarizers, $\lambda/2$ and $\lambda/4$ plates)
- Types of detectors
- Characteristics of detectors

Recommended literature:

F. A. Jenkins & H. E. White: *Fundamentals of Optics* (McGraw-Hill, 1957)
 W. Demtröder: *Laser Spectroscopy: Basic Concepts and Instrumentation* (Springer, 1981)
 György Ábrahám: *Optics* (Panem Kft., 1997)
 R. W. Boyd: *Nonlinear Optics* (Academic Press, 1992)
 R. L. Sutherland: *Handbook of Nonlinear Optics* (Marcel Dekker, 2003)

3.2.8 Infrared and Raman Spectroscopy of Nonlinear Optical Crystals (*László Kovács*)

- Fundamentals of vibrational spectroscopy
- Fourier-transform infrared and Raman spectrometers
- Theory of normal modes, symmetries, selection rules
- Optical properties of crystals
- Infrared and Raman spectra of optical crystals
- Spectroscopy of localized vibrations
- Vibrations of hydroxide ions and oxygen tetrahedra in oxide crystals

Recommended literature:

G. Turrell: *Infrared and Raman Spectra of Crystals* (Academic Press, 1972)
 K. Nakamoto: *Infrared and Raman Spectra of Inorganic and Coordination Compounds* (Wiley, 1963)
 B. C. Smith: *Fundamentals of Fourier Transform Infrared Spectroscopy* (CRC Press, 1996)
 D. C. Harris & M. D. Bertolucci: *Symmetry and Spectroscopy: An Introduction to Vibrational and Electronic Spectroscopy* (Oxford University Press, 1978)

3.2.9 Magnetic Resonance, EXAFS and Other Spectroscopies (*Gábor Corradi*)

- Spin-relaxation effects; basics of electron spin resonance (ESR) and nuclear magnetic resonance (NMR) spectroscopy
- Combination of electron and nuclear resonances (ENDOR and ENDOR-induced ESR); optically detected ESR and ENDOR
- Applications to point defects in solids, biological objects and nanoparticles, and to medical diagnostic imaging
- Information obtainable from X-ray absorption fine structure (XAFS/EXAFS) and its application to determining atomic environments
- Overview of surface-analysis methods

Recommended literature:

J. E. Wertz & J. E. Bolton: *Electron Spin Resonance* (McGraw-Hill, 1972)
 A. Abragam & B. Bleaney: *Electron Paramagnetic Resonance of Transition Ions* (Clarendon Press, 1970)
 C. P. Slichter: *Principles of Magnetic Resonance* (Springer; 2nd rev. ed. 1978; corrected ed. 1980; enlarged 3rd printing 1989/1990)
 J.-M. Spaeth, J. R. Niklas & R. H. Bartram: *Structural Analysis of Point Defects in Solids* (Springer, 1992)
 H. Kuzmany: *Solid-State Spectroscopy: An Introduction* (Springer, 1998)

3.2.10 Physics of Gas Discharges (*Zoltán Donkó*)

- Basic phenomena of low-pressure gas discharges: generation of charge carriers, drift and diffusion, elementary collision processes
- Self-sustained gas discharges: gas breakdown, glow discharges, cathode processes and the cathode fall region, positive column
- Radio-frequency gas discharges
- Modeling of gas discharges: fluid models, particle-simulation models
- Diagnostics of gas-discharge plasmas: electrical probes, conventional and laser spectroscopy
- Applications of gas discharges: gas lasers; spectroscopic and other light sources; plasma chemistry; plasma-based surface modification

Recommended literature:

A. von Engel: *Ionized Gases* (Clarendon Press, 1965)

Y. P. Raizer: *Gas Discharge Physics* (Springer, 1991)

M. A. Liebermann & A. J. Lichtenberg: *Principles of Plasma Discharges and Materials Processing* (Wiley, 1994)

3.2.11 Optical Measurement Techniques (*Aladár Czitrovszky*)

- Application of lasers in high-resolution measurements: interferometry; flatness and surface inspection; displacement and acceleration measurement; vibration analysis; laser Doppler velocimetry; correlation measurements
- Use of light scattering in optical metrology: nephelometry, turbidimetry; particle counting (measurement of aerosols and hydrosols); surface inspection; anemometry; LDA and PDA systems
- Quantum-optical measurement techniques and applications: generation of light with various photon statistics; coincidence and correlation; characterization of photodetectors; quantum-limited detector systems; absolute quantum-efficiency measurement by one- and two-detector methods; measurement of nonlinear parameters in optical crystals
- Application of optical methods in environmental protection: optical and meteorological parameters of the atmosphere; effects of air pollution on the optical parameters of the atmosphere; laser methods for measuring atmospheric pollution

Recommended literature:

A. Mercer: *Optical Metrology for Fluids, Combustion and Solids* (Springer, 2003)

H. E. Albrecht: *Laser Doppler and Phase Doppler Measurement Techniques* (Springer, 2001)

A. Hariharan: *Optical Interferometry* (Elsevier, 2003)

3.2.12 Machine-Level Programming of Microcontrollers (*Gábor Almási*)

- Architectural characteristics of microcontrollers: von Neumann vs. Harvard architecture
- Communication peripherals of microcontrollers
- Interface between the analog and digital worlds: analog peripheral components
- Programming for CISC and RISC instruction sets
- Structure of instruction sets I (assignment, addressing modes, data transfer)
- Structure of instruction sets II (logical and arithmetic operations)
- Structure of instruction sets III (control transfer, conditional instructions, interrupt handling)
- Options for interrupt control
- Special Function Registers (SFRs)
- Development of event-driven programs
- Semiconductor-based storage in microcontrollers (ROM, EPROM, EEPROM, Flash memory)
- Memory expansion options
- Programming microcontrollers using high-level languages

- TASKING 8051 — presentation of a complete development system
- IAR — design and implementation of finite-state machines

Recommended literature: (*not specified in the source*)

3.2.13 Laser Physics (*Péter Jani*)

- Atomic dipole transitions, Rabi frequency
- Semiclassical radiation theory, Maxwell–Bloch equations
- Laser pumping, population inversion, gain
- Linear and nonlinear pulse propagation
- Laser mirrors and laser oscillation: dynamics, oscillation threshold
- Wave optics: Gaussian beam, beam perturbations, diffraction
- Paraxial resonator theory; stable and unstable resonators
- Laser dynamics
- Q-switching, mode locking
- Quantum theory of laser operation

Recommended literature:

A. E. Siegman: *Lasers* (University Science Books, 1986)

P. W. Milonni & J. H. Eberly: *Lasers* (John Wiley, 1988)

3.2.14 Laser-Induced Plasma Emission Spectroscopy (*Béla Németh*)

- Fundamentals of atomic and molecular spectroscopy
- Basics of materials structure
- General questions of microanalysis
- Qualitative and quantitative analysis by LIBS technique
- Studies of metal alloys; industrial (metallurgical) applications
- Geological and geophysical applications
- Environmental applications
- Forensic applications
- Applications to metals, semiconductors, and surface analysis
- Medical applications (cardiology, urology, nephrology)

Recommended literature:

J. Nölte: *ICP Emission Spectrometry: A Practical Guide* (Wiley-VCH, 2003)

3.2.15 Materials Characterization Methods (*Péter Jani*)

- Microscopy: light microscopy, electron microscopy, scanning-probe microscopies
- Diffraction methods: XRD, X-ray photoelectron diffraction
- Electron and X-ray emission spectroscopies: XPS, UPS, Auger, X-ray fluorescence
- Vibrational spectroscopies: FTIR, Raman
- Nuclear magnetic resonance
- Ion-scattering methods: RBS
- Mass and optical spectroscopic methods

Recommended literature:

D. Brune et al.: *Surface Characterization: A User's Handbook* (John Wiley, 1996)

C. R. Brundle: *Encyclopedia of Materials Characterisation* (Manning Publishing Co., 1992)

3.2.16 Applications of Lasers in Biology and Medicine (*Béla Németh*)

- Refraction, reflection, scattering, absorption in biological tissue; penetration and damage: biological and physical mechanisms
- Photon transport theory
- Measurement of optical properties of tissues
- Mechanisms of laser–tissue interaction: photochemical (photodynamic therapy, biostimulation), photothermal (laser-induced thermal therapy), photoablation, plasma-induced tissue ablation, shock-wave generation, cavitation
- Medical applications of lasers: surgery, dentistry, dermatology, plastic surgery, tissue soldering, internal medicine
- Lasers in genetic engineering
- Production of biocompatible materials
- Diagnostic methods: tomographic imaging, two-photon microscopy

Recommended literature:

M. H. Niemz: *Laser–Tissue Interactions: Fundamentals and Applications* (Springer-Verlag, 2003)

C. Fotakis, T. G. Papazoglou & C. Kalpouzos: *Optics and Lasers in Biomedicine and Culture* (Springer-Verlag, 2000)

3.2.17 Thin Films and Their Applications (Zsuzsanna Márton)

- Basics of vacuum physics, gas kinetics and flows, Knudsen equation, mean free path, transport properties
- Vacuum technology: pressure measurement, vacuum pumps, vacuum systems
- Physics and chemistry of evaporation
- Discharges, plasmas, ion–surface interaction; plasma and ion-beam methods for thin-film preparation
- Chemical vapor deposition
- Substrate surfaces and nucleation: thermodynamic and kinetic aspects; experimental experience
- Epitaxy: high- and low-temperature epitaxy; semiconductor devices; controlled layer growth
- Structure and analysis of thin films

Recommended literature:

M. Ohring: *The Materials Science of Thin Films* (Academic Press, 2002)

A. Roth: *Vacuum Technology* (North-Holland, 1989)

Donald L. Smith: *Thin Film Deposition: Principles and Practice* (McGraw-Hill, 1995)

J. A. Mahan: *Physical Vapor Deposition of Thin Films* (Wiley-Interscience, 2000)

3.2.18 Applications of Lasers in Materials Science (Zsuzsanna Márton)

- Principles of laser operation; laser types and their application areas
- Physical processing with lasers; focusability of lasers; absorption properties of gases, metals, semiconductors, insulators; laser excitation mechanisms
- Laser heating, temperature distribution, surface melting
- Reaction kinetics, transport processes, nucleation mechanisms
- Evaporation; plasma generation; cutting, drilling, welding, engraving
- Ablation: mechanisms; nanosecond and femtosecond ablation
- Etching of metals and semiconductors in dry and wet environments
- Chemical vapor deposition; thin films; microstructures
- Laser direct writing; liquid-phase deposition; pulsed laser deposition
- Laser surface modification: hardening, recrystallization, cleaning (semiconductors, paintings), doping, alloying, oxidation, nitridation
- Analysis of laser-induced processes: optical, mass, and X-ray spectroscopic methods; time-resolved tracking of the plasma plume and shock waves

Recommended literature:

D. Bäuerle: *Laser Processing and Chemistry* (Springer-Verlag, 2000)

M. Ohring: *The Materials Science of Thin Films* (Academic Press, 2002)

D. L. Smith: *Thin Film Deposition: Principles and Practice* (McGraw-Hill, 1995)

3.2.19 Electron Microscopy (Béla Pécz)

- Fundamentals of electron microscopy
- Electron microscopy in materials science
- Electron-beam sources; theory of image formation; aberrations of electromagnetic lenses; limits of resolution
- Conventional electron microscopy: various crystal structures; dislocations and other defects; grain boundaries
- Lattice-resolution electron microscopy
- Electron diffraction
- Preparation of electron-transparent samples

Recommended literature:

L. Reimer: *Transmission Electron Microscopy* (Springer-Verlag, 1989)

P. E. J. Flewitt & R. K. Wild: *Physical Methods for Materials Characterisation* (Institute of Physics, 2003)

D. B. Williams & C. B. Carter: *Transmission Electron Microscopy: A Textbook for Materials Science* (Plenum Press, 1996)

G. Radnóczy: *Fundamentals of Transmission Electron Microscopy and Electron Diffraction* (University Textbook, University of Debrecen, 1994)

3.2.20 Laser Spectroscopy (Imre Sánta)

- Conventional absorption spectroscopy with lasers
- Atomic and molecular beams
- Spectroscopy at high pressure and low temperature
- Laser-excited fluorescence spectroscopy
- Optoacoustic and optogalvanic spectroscopy
- LIDAR; isotope separation
- Saturation of absorption (“hole burning,” Lamb dip)
- Nonlinear Raman interactions and coherent Raman scattering (CARS)
- Optical nutation, free induction decay (FID), and photon echo
- Transient absorption
- Time-resolved CARS; phase relaxation
- Transient optical Kerr effect

Recommended literature:

B. E. A. Saleh & M. C. Teich: *Fundamentals of Photonics* (Wiley-Interscience, 1991)

3.2.21 Optoelectronics (Ervin Hartmann)

- Basic concepts of light transmission: interference, reflection, absorption
- Control of light propagation: Kerr, Pockels, and Faraday effects
- Acousto-optics
- Integrated optics: waveguides, couplers; coupling methods
- Light sources: properties of LEDs and semiconductor lasers
- Photodetectors and their characteristics: spectral sensitivity, linearity, noise, response time, quantum efficiency
- Fiber optics: single- and multimode fibers, propagating modes, pulse dispersion

- Types of optical fibers and bundles; splicing; characteristics and their measurement
- Structure of optical communication systems
- PCM technique; impedance matching
- Transmission characteristics in telecommunications: allowable attenuation, noise, dispersion

Recommended literature:

B. E. A. Saleh & M. C. Teich: *Fundamentals of Photonics* (Wiley-Interscience, 1991)

A. Yariv: *Quantum Electronics* (John Wiley, New York, 1988)

R. G. Hunsperger: *Integrated Optics: Theory and Technology* (Springer-Verlag, 1995)

K. Okamoto: *Fundamentals of Optical Waveguides* (Academic Press, 1995)

3.2.22 Optomechanics and Optoelectronics (Imre Sánta)

- Optical mounts, rails, tables, and constructions: carriers, magnetic bases, rod systems
- Mirror mounts and adjusters (gimbal, three-point, flexure-plate), rotators
- Linear stages (prismatic, ball-screw, roller, flexure); load capacity
- Motorized drives (lead screw, hysteresis, DC, AC servo, stepper, microstepping; controllers)
- Piezo actuators (linear, inchworm)
- Encoders and scales; position control (PID)
- Position control with microcontroller or PC; distributed intelligence
- Light sources: incandescent, fluorescent, LEDs, semiconductor lasers
- Photodetectors and their characteristics: spectral sensitivity, linearity, noise, quantum efficiency
- Signal processing and selective amplification (boxcar, lock-in, photon counting, TCSPC)
- Basic concepts of light transmission: reflection, absorption, scattering, interference
- Control of light propagation: Kerr, Pockels, Faraday effects; acousto-optics
- Integrated optics: waveguides, couplers, coupling methods
- Fiber optics: single- and multimode fibers and bundles; propagating modes; pulse dispersion; measurement of characteristics
- Structure of optical communication systems; transmission parameters (attenuation, noise, dispersion); PCM technique; impedance matching

Recommended literature:

B. E. A. Saleh & M. C. Teich: *Fundamentals of Photonics* (Wiley-Interscience, 1991)

Imre Sánta: *Optoelectronics*, TÁMOP-4.1.2.A/1-11/1 MSc, SZTE, Szeged, 2014.

A. Yariv: *Quantum Electronics* (John Wiley, New York, 1988)

R. G. Hunsperger: *Integrated Optics: Theory and Technology* (Springer-Verlag, 1995)

K. Okamoto: *Fundamentals of Optical Waveguides* (Academic Press, 1995)

3.2.23 Femtosecond and Nonlinear Optics (György Tóth)

- Overview of the subject; description of ultrashort pulses
- Propagation of ultrashort pulses in dispersive media; propagation of Gaussian pulses
- Dispersion properties of optical elements (dielectrics, gases, optical fibers; interferometric structures: Fabry–Pérot, Gires–Tournois interferometer; chirped mirrors)
- Dispersion properties of optical elements (slit, prism, grating, pulse compressors, lenses); light propagation in anisotropic media
- Angular dispersion and its effects: pulse-front tilt, spatial chirp
- Nonlinear wave equation; sum- and difference-frequency generation
- Second-harmonic generation; phase matching; quasi-phase matching
- Parametric amplification; optical parametric amplifier and oscillator
- Nonlinear refractive index: self-phase modulation, self-focusing; measurement of nonlinear index by the Z-scan method
- Measurement of ultrashort pulses: autocorrelation, FROG, GRENOUILLE, SPIDER

- Modeling of nonlinear optical processes

Recommended literature:

J.-C. Diels & W. Rudolph: *Ultrashort Laser Pulse Phenomena* (Academic Press, 2006)
 R. W. Boyd: *Nonlinear Optics* (Academic Press, 2003)
 B. E. A. Saleh & M. C. Teich: *Fundamentals of Photonics* (Wiley, 1991)
 R. D. Guenther: *Modern Optics* (Wiley, 1990)
 R. Trebino: *Frequency-Resolved Optical Gating: The Measurement of Ultrashort Laser Pulses*

3.2.24 Technology of Semiconductor Devices (Miklós Serényi)

- Production of single-crystal ingots and wafers; quality parameters
- Epitaxial processes: VPE, LPE, MBE, MOCVD
- Heterojunctions
- Diffusion
- Ion implantation
- Dielectric layers: thermal oxide; CVD processes
- Lithographic processes; etching and metallization techniques
- Contacts: formation of ohmic and Schottky junctions
- Dicing, assembly, packaging, qualification
- Elements of integrated circuits I: MOS
- Elements of integrated circuits II: bipolar
- Design methods; ASIC
- Fabrication and assembly of high-frequency and quantum devices
- Production and assembly of LEDs and lasers
- Considerations in the fabrication of photodetectors and solar cells
- Sensors and microengineering

Recommended literature:

Imre Mojzes (ed.): *Microelectronics and Electronic Technology* (Műszaki Könyvkiadó, Budapest, 1995)

3.2.25 Photonic Crystals (György Kádár)

- Fundamental concepts: wave interference, diffraction
- Electromagnetic waves in periodic structures; electrons in crystals; analogy between Maxwell's and Schrödinger's equations
- Experiments and results in metamaterials
- Structures with periodicity on the scale of the wavelength: photonic crystals
- Finite-difference time-domain (FDTD) method for solving Maxwell's equations
- Modeling one- and two-dimensional photonic crystals using FDTD
- Comparison of model calculations with experimental data
- Defect structures in regular periodicity and their modeling
- Fabrication of regular and defect photonic crystals
- Experimental and practical application areas of photonic crystals
- Topical literature at the time of the lectures
- Summary

Recommended literature:

K. Sakoda: *Optical Properties of Photonic Crystals* (Springer, 2001)
 D. M. Sullivan: *Electromagnetic Simulations Using the FDTD Method* (IEEE Press, 2000)
 S. G. Johnson & J. D. Joannopoulos: *Photonic Crystals: The Road from Theory to Practice* (Kluwer, 2002)

3.2.26 Magnetic Materials Science (György Kádár)

- Review of fundamental concepts: $\mathbf{B}$, $\mathbf{H}$, $\mathbf{M}$, χ , μ ; measurement methods
- Dipole fields; diamagnetism and paramagnetism; Bohr–van Leeuwen theorem
- Atomic magnetic interactions: quantum-mechanical exchange contribution of the Coulomb field
- Atomic-scale magnetic structures: ferro-, ferri-, and antiferromagnetism; spin glasses; amorphous magnets
- Theory of magnetic neutron scattering
- Determination of magnetic structures by neutron diffraction
- Other experimental methods for studying microscopic magnetism
- Macroscopic properties of ferro- and ferrimagnetic materials; magnetic hysteresis
- Magnetic domains and domain walls; Landau–Lifshitz–Gilbert equation; micromagnetic calculations
- Stoner–Wohlfarth model in single-domain grains; nanomagnetism
- Magnetic memories: core, drum, tape, disk, bubble
- Magnetic thin films and multilayers; magnetoresistance changes; GMR
- Soft and hard magnetic materials; other applications

Recommended literature:

Károly Simonyi: *Electromagnetism* (Akadémiai Kiadó, Budapest, 1973)

C. Kittel: *Introduction to Solid State Physics* (Műszaki Könyvkiadó, Budapest, 1981, Hungarian ed.)

J. M. Schultz: *Diffraction Methods in Materials Science* (Műszaki Könyvkiadó, Budapest, 1987, Hungarian ed.)

D. Jiles: *Introduction to Magnetism and Magnetic Materials* (CRC Press, 1991)

A. Aharoni: *Introduction to the Theory of Ferromagnetism* (Clarendon Press, 2000)

3.3 Physics of Many-Particle Systems Program

3.3.1 Physics of Many-Particle Systems (Tamás Gál)

3.3.2 Mathematical Methods in the Description of Many-Particle Systems (Tamás Gál)

3.3.3 Tensors and Differential Forms (Alice Fialowski)

- Tensor algebra; Grassmann algebra
- Generalizations of the inverse mapping
- Manifolds; parametrization
- Volume of a parametrized manifold
- Integration of scalar functions defined on manifolds
- Vector fields on manifolds; operations with vector fields
- Integration on manifolds

Recommended literature:

Munkres: *Analysis on Manifolds*

Spivak: *Calculus on Manifolds*

Guillemin: *MIT Lecture Notes*, 2008

3.3.4 Sobolev Spaces and Partial Differential Equations (Vilmos Komornik)

- Hilbert spaces; orthogonal projection; Riesz–Fréchet theorem; spectral theorem for completely continuous symmetric operators
- Sobolev spaces; Gauss–Ostrogradsky and Green formulas; trace theorems; elliptic boundary-value problems: Dirichlet and Neumann problems for the Laplace operator
- Spectral theorem for the Laplace operator
- Solution of the heat equation and more general parabolic evolution equations by the Fourier method: irreversibility, infinite propagation speed, and the maximum principle
- Solution of the wave equation and more general hyperbolic evolution equations by the Fourier method: reversibility, energy conservation, finite propagation speed

Recommended literature:

H. Brezis: *Functional Analysis, Sobolev Spaces and Partial Differential Equations*, Springer, 2011

V. Komornik: *Lectures on Functional Analysis and the Lebesgue Integral*, Springer, 2017

Ádám Besenyei, Vilmos Komornik, László Simon: *Parciális differenciálegyenletek* (Partial Differential Equations), ELTE, TypoTeX, 2013

3.4 Scientist–Teacher Training Program

3.4.1 Teaching Physics I (Classical Physics) (László Pálfalvi)

- Aims and means of teaching physics
- Institutional frameworks for teaching physics
- The National Core Curriculum (NAT)
- Models and abstraction in teaching classical physics
- Teaching the main chapters of classical physics (mechanics, thermodynamics, electromagnetism, optics)
- Discussion of sections that are difficult to teach (e.g. Second Law of Thermodynamics, entropy, electromagnetic induction, wave motion)
- Demonstrations and student experiments in physics teaching
- The role of computers in measurement, simulation, and knowledge acquisition

Recommended literature:

András Juhász, Péter Tasnádi, Péter Jenei, Judit Illy, Csilla Wiener, István Főzy: *A fizika tanítása a középiskolában I. (mechanika I., hőtan)*, ELTE Doctoral School of Physics notes

András Juhász, Péter Tasnádi, Csilla Wiener, Éva Gócz: *A fizika tanítása a középiskolában II. (mechanika II., elektromágnesség)*, ELTE Doctoral School of Physics notes

3.4.2 Teaching Physics II (Modern Physics) (László Pálfalvi)

- Teaching the main chapters of modern physics (elements of statistical physics, nuclear physics, shell model, quantum mechanics, solid-state physics and materials science, astronomy and astrophysics)
- Discussion of sections that are difficult to teach (e.g. statistical entropy, hydrogen atom, molecules, spin)
- Models and abstraction in teaching modern physics
- Measurement methods
- Pioneers and prominent figures of modern physics; Hungarian contributions
- The role of modern physics in shaping our worldview
- The role of computers in measurement, simulation, and knowledge acquisition

Recommended literature:

András Juhász, Péter Tasnádi, Csilla Wiener, Éva Gócz: *A fizika tanítása a középiskolában III. (modern fizika)*, ELTE Doctoral School of Physics notes

3.4.3 The System of Concepts and Laws in Physics (László Pálfalvi)

- From everyday notions to physical concepts and definitions
- Development of physical concepts with schooling
- Axioms, axiom systems, postulates, laws, theorems
- Principles in physics
- Inductive and deductive approaches

Recommended literature:

András Juhász, Péter Tasnádi, Péter Jenei, Judit Illy, Csilla Wiener, István Főzy: *A fizika tanítása a középiskolában I. (mechanika I., hőtan)*, ELTE notes

András Juhász, Péter Tasnádi, Csilla Wiener, Éva Gócz: *A fizika tanítása a középiskolában II. (mechanika II., elektromágnesség)*, ELTE notes

András Juhász, Péter Tasnádi, Csilla Wiener, Éva Gócz: *A fizika tanítása a középiskolában III. (modern fizika)*, ELTE notes

3.4.4 Selected Chapters from Classical Physics (László Pálfalvi)

- On planetary motion
- The adiabatic double pendulum
- Mechanics of variable-mass systems
- Adiabatic and polytropic processes
- Theoretical background to Eötvös's famous experiments
- Reciprocity relations in classical physics
- Hidden momentum

Recommended literature:

P. Horváthy: "On Planetary Motion in Connection with an Old Competition Problem," *Fizikai Szemle* 2003/11

P. Horváthy: "Planetary Motion and Geometry I," *Fizikai Szemle* 2005/2

P. Horváthy: "Planetary Motion and Geometry II," *Fizikai Szemle* 2005/8

L. Pálfalvi: "The 2004 Eötvös Competition Problem: The Kepler Problem in a Magnetic Field," *Fizikai Szemle* 2005/2

L. Pálfalvi: "Mars Close to Earth Again," *Fizikai Szemle* 2005/9

J. Cserti, Gy. Dávid: "Formulas for the Eötvös Balance," *Fizikai Szemle* 2019/7–8

I. Groma: "The Eötvös Balance," *Fizikai Szemle* 2019/12

L. Pálfalvi – V. Kovács: "On the Applicability of the Law $pV^\kappa = \text{const}$ in Light of a Competition Problem," *Fizikai Szemle* 2021/11

A. Siposs: "On Polytropic Processes of Gases," *Fizikai Szemle* 2022/1–2

L. Pálfalvi – V. Kovács: "Green's Reciprocity Theorem I," *Fizikai Szemle* 2021/7–8

L. Pálfalvi – V. Kovács: "Green's Reciprocity Theorem II," *Fizikai Szemle* 2021/9

P. Gnädig: "Can Something Have Momentum If It Is Not Moving?" *Fizikai Szemle* 2022/1–2

3.4.5 Selected Chapters from Modern Physics (Tamás Gál)

- Supersymmetries
- String theory
- Superfluidity
- Quantum (fractional) Hall effect
- High-temperature superconductivity

Recommended literature:

John Dirk Walecka: *Introduction to Modern Physics: Theoretical Foundations*, World Scientific, 2008

3.4.6 Methodology of Problem Solving (László Pálfalvi)

- Methods for solving simple problems
- Intermediate-level problems (school-leaving/competition problems solvable with modest mathematical tools)
- Problems requiring trigonometric identities
- Problems requiring complex numbers
- Problems requiring limits, differential and integral calculus; extremum problems
- Problems solvable by partitioning into finite elements and summation
- Problems based on differential equations
- Problems based on physical/mathematical analogies
- Problems based on symmetry considerations
- Synthesizing theoretical physics knowledge in problems

Recommended literature:

Problems and solutions from *Középiskolai Matematikai Lapok*

László Holics: *A fizika OKTV feladatai és megoldásai 1961–2003*, Typotex
László Holics: *A fizika OKTV feladatai és megoldásai 2004–2016*, Typotex

3.4.7 The Synthesis of Physics (Tamás Gál)

- Axiomatic structure of physics
- Empirical approach to physics
- Principles of physics (principle of least action, Fermat's principle, principle of least constraint, principle of virtual work, energy-minimum principle); implications for public education
- Inertial and accelerating frames (fictitious forces, inertial forces); Galilean and Einsteinian relativity
- Causality
- Conservation laws and symmetries
- Meeting points of physics disciplines (mechanics–thermodynamics; electromagnetism–wave theory–optics; wave optics–geometrical optics)

Recommended literature:

R. Feynman: *Mai Fizika* series (Hungarian edition of lecture materials)
ELTE Doctoral School of Physics notes I–III listed above

3.4.8 The Relationship between Physics and the Natural Sciences (László Pálfalvi)

- Physics in chemistry
- Physics in biology and physiology
- Physics in geography
- Physics and astronomy
- Physics and the engineering sciences

Recommended literature:

ELTE Doctoral School of Physics notes I–III listed above
P. W. Atkins: *Physical Chemistry* I–III, 6th ed., Budapest: Nemzeti Tankönyvkiadó, 2002 (Hungarian edition)

3.4.9 Physical Applications and Research (László Pálfalvi)

- Astronomy and cosmology
- Global issues, energy, economy
- Medical and industrial applications; physics and astronomy
- Environment and health
- Physics and physiology; physics in sports
- Current major directions in physical research
- Outlook on new results in physics

Recommended literature:

Ádám Kiss, Péter Tasnádi: *Környezetfizika*, Typotex Electronic Publishing, 2012
(http://etananyag.ttk.elte.hu/FiLeS/downloads/EJ-Kiss-Tasnadi_Kornyezetfizika.pdf)
György Vajda: *Energia és társadalom*, in the series *Magyarország az ezredfordulón*, MTA Társadalomtudományi Központ, 2009, ISBN 9789635085705

3.4.10 E-Learning in Physics Education (Ágnes Várnai)

- Theories of learning (cognitive load theory; multimedia learning; displacement theory; problem solving)

- Concrete forms of application (simulations; instructional videos; modeling systems; video-analysis software)

Recommended literature:

Tamara Phillips Fudge – Susan Shepherd Ferebee (2021): *Curriculum Development and Online Instruction for the 21st Century*, Information Science Reference, Hershey (PA)

Linda Daniela (2020): *Pedagogies of Digital Learning in Higher Education*, Routledge, London

3.4.11 Electronics in Demonstration and Measurement Experiments (János Szász)

- Designing demonstration measurements
- Use of electronic measuring instruments in demonstrations
- Power supplies and auxiliary circuits
- Measurement control in demonstration experiments
- Electronic data acquisition
- Data processing and presentation of results
- Possibilities for interactivity in demonstration experiments

Recommended literature:

Sándor Kemény, András Deák, Kinga Lakné Komka, Péter Kunovszki: *Kísérletek tervezése és értékelése*, Typotex, 2016

Miklós Lambert: *Szenzorok – elmélet és gyakorlat*, IM Kiadó és Mérnöki Iroda Kft., 2009