Physics MSc 2026

FINAL EXAM TOPICS

1. Approximation methods in quantum mechanics. Time-independent degenerate and nondegenerate perturbation theory. Time-dependent perturbation theory.

2. Description of mixed states in quantum mechanics. The density operator and its properties. The time evolution operator.

3. Relativistic quantum mechanics. Klein-Gordon equation. The Dirac equation. Conservation of angular momentum; the spin. Negative energy solutions, antiparticles. Solution for particle in rest. Parity, invariance under space inversion.

4. Particles and their interactions. The nuclear force. Classification of hadrons. Strong interaction, quarks, gluons. Beta decay. Neutrinos. Leptons. Essential conservation laws, symmetries. Violation of space inversion symmetry. Weak interaction and its mediating bosons.

5. Quantum statistics. Symmetry requirements for systems of identical particles, fermions and bosons. Description of many-particle states by occupation numbers of one-particle states. The grand canonical ensemble. Derivation of average occupation number for ideal Fermi gas and ideal Bose gas based on grand canonical ensemble.

6. The black-body radiation. Photon properties: energy, momentum, polarization. Density of photon states in wave-vector space. Mean number of photons in thermal equilibrium with walls of enclosure of given volume and photon frequency in given infinitesimal interval, spectral distribution of black-body radiation (Planck's formula). Power emitted by black body.

7. **Lattice structure**. Bravais-lattice, basis. Coordination number. Most frequent lattice types. Primitive cell. Wigner–Seitz-cell. Reciprocal-lattice. The first Brillouin-zone.

8. **Lattice vibrations**. The adiabatic (Born-Oppenheimer) approximation. Harmonic approximation. Dispersion relation of the lattice vibrations. Acoustic and optical vibrations.

9. Statistical hypothesis testing and parameter estimations. The general method and steps of hypothesis testing. T-tests, Chi-square test for the variance, F-test for comparing two variances. Properties of parameter estimations. The method of maximum likelyhood estimation.

Computational physicist topics

1. Information theory 1.: Noiseless channels, data compression (Shannon-entropy and its main properties. Asymptotic equipartition. Entropy rate of stochastic processes. Expected code length, Huffman-coding, and its optimality.)

2. Information theory 2.: Channel capacity (The Kullback-Leibler distance and the properties of the mutual information. Description of noisy channels, channel capacity, and its meaning. Error-correcting codes.)

3. Operating systems II/1: Storage devices, file handling in operating systems. Types of file systems, their functions, and their implementation. Organization of storage media: RAID systems, network storage.

4. Operating systems II/2: Special operating systems (Specific issues of embedded, real time, multimedia systems (i.e. timing in real-time systems), and specific solutions.)

5. Signal processing 1.: Basic principles of analog signal processing. Linear systems, Fourier-transformation, spectrum, convolution theorem, sampling theorem, Laplace transformation, and its usage in analysis and design of systems.

6. Signal processing 2.: Digital sampling. Important properties and some simple types of DA and AD converters. Z-transforms and digital filters. The usage of the most essential LabVIEW DAQmx vi-s (presentation of an example vi.)

7. Application of microcontrollers 1.: Microcontrollers' architectural classification (CISC, RISC, Neumann, Harvard), the structure of event-based programs, typical peripheries (watchdog, timer, UART, EEPROM, ADC)

8. Application of microcontrollers 2.: The typical instructions of assembly codes (arithmetic, logical, data movement, control transfer, special), addressing modes (immediate, register, direct, indirect…), the role of segments in programming x86 type systems, methods of passing parameters to subroutines.

9. Computer networks: The layers of network software, presentation of the protocols of the application layer (http, ftp, smtp, pop3, imap, dns), the service models and protocols of the transport layer (TCP, UDP), trusted and not trusted services in the transport layer

10. Object-oriented programming 1.: Classes, general description of objects: definition of class and object. Encapsulation. Access control (public, protected, private). Data members, properties, methods. Static members and their applications. Initialization and removal of object instances. Abstract classes and methods.

11. Object-oriented programming 2.: Code reuse on OOP basis: Embedding types in other types. Inheritance. Definition and usage of interfaces. Protected members. Base class expansion, function modification. Initialization of the derived class using the constructor of the base class. Polymorphism, its importance, virtual functions (virtual, new, override).

Applied Physicist topics

1. Gaussian beams and laser resonator modes. Matrices in geometrical and physical optics.

2. Absorption and emission of light. Absorption and emission cross sections. Amplification coefficient. Saturation. Homogeneous and inhomogeneous broadening of spectral lines.

3. Properties and applications of main laser types.

4. Generation and measurement methods of short and ultrashort laser pulses.

5. Propagation of light in waveguides. Description with geometrical and wave optics. Optical fibers. Fiber lasers.

6. Physical properties of magnetic materials.

7. Nanostructures and their observation.

8. Physical properties of nanostructures.

9. Methods of materials characterization

10. Definition of spectrum. Main features of spectroscopic devices. Presentation of a few devices that apply different principles for measuring the spectrum.