Physicist-Engineer BSc
Nanotechnology and Quantum Applications Specialization
Final exam topics

The examinee receives one topic from the CORE SUBJECTS (1–10) and one topic from the SPECIALIZATION SUBJECTS (11–20). In the latter, *Quantum Physics* is mandatory for everyone (11–15); however, the examinee decides in advance whether to choose the remaining topics on *Nano and Quantum Phenomena in Solids* (N16–N20) or *Optics* (O16–O20). The examiners may ask short questions from other topics as well.

A: CORE SUBJECTS

Modern Physics

1 The experimental basis of quantum physics.

2 Structure of the atom, de Broglie waves.

3 Wave functions, Schrödinger equation.

4 Particle in a box, quantum tunneling.

5 Atomic physics: hydrogen atom, quantum numbers, Zeeman effect, total angular momentum.

Solid State Physics

6 **Phonons in solids**: heat capacity of solids, Bose–Einstein statistics, phonon dispersion relations, chain models, density of states, Debye model.

7 **Electrons in metals**: From Drude theory to free electron model, Fermi–Dirac statistics, electron dispersion relation, density of states.

8 **Structure of crystalline solids**: lattice, reciprocal lattice, Brillouin zone, symmetries, scattering experiments (Bragg's law, structure & form factor).

9 **Electronic bands in solids**: nearly free electron model, Bloch's theorem, electronic bands of a chain, metals and insulators.

10 **Electrons in solids II**: tight-binding approximation, effective mass, metals and insulators.

B: SPECIALIZATION SUBJECTS

Quantum Physics

11 Linear algebra and quantum postulates.

12 Two-levels systems, Rabi oscillations.

13 Quantum harmonic oscillator.

14 Quantum entanglement, quantum advantage.

15 Quantum applications: lasers, NV centers.

Nano and Quantum Phenomena in Solids (either these or the O16–O20 topics are chosen)

N16 Semiconductor physics and devices.

N17 Basic nano phenomena: quantum dots and quantum wires.

N18 Non-equilibrium distribution function and the Boltzmann equation; calculation of the conductance.

N19 Magnetism: atomic magnetic moment, Hund's rule, exchange energy, mean-field theory, magnetic ordering.

N20 Superconductivity: macroscopic wave function and Meissner effect; some quantum devices: Josephson junction, SQUID and transmon.

Optics (either these or the N16–N20 topics are chosen)

O16 Light models, Fermat's principle, Huygens' principle and Huygens–Fresnel principle. Electromagnetic wave equation in dielectrics and absorbing materials, complex refractive index, properties of monochromatic plane waves in homogeneous, isotropic media.

O17 Properties of polarized light, representation by Jones vectors. Description of polarization-sensitive elements by Jones matrices. Optical phenomena at boundary surfaces: refraction, reflection, phase matching, Brewster's effect, total internal reflection.

O18 Validity criteria and characteristics of the geometrical optics approximation. Meaning of the eikonal and the eikonal equation. Interpretation of wavefronts, light rays and beams. Paraxial approximation, ABCD formalism, principal planes, effective focal length.

O19 Two-beam interference, basic interferometers. Multiple-beam interference, operation of diffraction gratings. Scalar diffraction, Fresnel–Kirchhoff diffraction integral, Fresnel and Fraunhofer approximations. Diffraction at rectangular and circular apertures.

O20 Statistical optics, temporal and spatial coherence, quasi-monochromatic light. Description in frequency domain: normalized coherence function and its connection with power spectral density. Time-domain investigation with the autocorrelation function.