Ministry of Science and Higher Education of the Russian Federation
Federal State Autonomous Educational Institution of Higher Education
"Peter the Great St. Petersburg Polytechnic University"

Institute of Electronics and Telecommunications

APPROVED
Director of IEaT
______________A.S. Korotkov
"____" October 2024

PROGRAM

entrance test for applicants to the master's degree program in the direction of training / educational program: 16.04.01 Applied Physics / 16.04.01_17 «Nanotechnology and Nanobioengineering» (international educational program Nanotechnology and Nanobioengineering)

Saint Petersburg

2024

ANNOTATION

The program contains a list of topics (questions) on the disciplines of the professional curriculum for bachelor's training plan in the major 16.03.01 **Applied Physics**, included in the test assignments of entrance exams for the master's degree.

Entrance test is evaluated on a 100-point scale. The minimum number required for passing the interdisciplinary examination is 50 points (50%).

Entrance tests for English-language educational programs are conducted in English.

Authors:

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The program was reviewed and recommended for publication by the educational and methodological council of the **Institute of Electronic and Telecommunication** (Protocol No. 2 dated “22” October 2024).

1. DISCIPLINES INCLUDED IN THE PROGRAM OF INTERDISCIPLINARY EXAM

1.1. General Physics

1.2. Solid State and Semiconductor Physics

1.3. Physical Foundations of Medical and Biological Research

2. CONTENT OF EDUCATIONAL DISCIPLINES

2.1. General Physics

1. Physical Foundations of Mechanics.

Velocity and acceleration of a material point. Newton's second law. Newton's third law. Gravitational force, gravity force, elastic force and friction force. Mechanical work and power. Kinetic and potential energy. Law of energy conservation. Law of momentum conservation. Rotational motion. Law of angular momentum conservation. Two-body problem. Motion in the central field.

2. Molecular Physics and Thermodynamics.

Thermodynamic system and thermodynamic parameters. Absolute temperature and entropy. The first law of thermodynamics. The law of increasing entropy. The basic equation of molecular kinetic theory. Internal energy of an ideal gas. Theorem on uniform distribution of energy over degrees of freedom. Maxwell, Boltzmann and Maxwell-Boltzmann distributions. Heat capacity of solids. Equation of state of an ideal gas. Real gases. Van der Waals equation. Phase transformations. Transport phenomena. Einstein's relation. Diffusion in solids.

3. Electricity and Magnetism.

Law of charge conservation and continuity equation. Electric field of a system of charges. Dipole moment of a system of charges. Relationship between the intensity and potential of an electrostatic field. Conductors in an electric field. Polarization of dielectrics. Polarizability and permittivity. Boundary conditions for E and D vectors. Electric capacity of conductors and capacitors. Electric field energy. Piezo- and ferroelectrics. Stationary electric current. Ohm's and Joule-Lenz's laws. Constant magnetic field. Biot–Savart–Laplace law. Vector potential of magnetic field. Magnetic field of a system of currents. Ampere force and Lorentz force. Magnetic moment of a system of moving charges. Boundary conditions for B and H vectors. Electromagnetic induction. Faraday's law. Self-induction and mutual induction. Magnetic susceptibility and magnetic permeability. Diamagnetism. Paramagnetism. Ferromagnetism. Magnetic field energy. Maxwell's equations. Electromagnetic wave.

4. Oscillations and Waves.

Harmonic oscillations. Damped oscillations. Forced oscillations. Resonance.

Addition of oscillations. Elastic waves. Phase and group velocity. Poynting vector. Dispersion. Classical dispersion theory. Scattering of light. Laws of radiation of an absolutely black body. Spontaneous and stimulated emission. Lasers. Nonlinear optical phenomena.

5. Optics.

Relationship between wave and geometric optics. Interference of light waves. Coated optics. Diffraction of light. Diffraction grating. Polarization of light. Malus' law. Linear and circular polarization. Polarization in reflection and refraction of light. Brewster's law. Fresnel formulas. Double refraction. Quarter and half wave plate. Nicol prism. Kirchhoff's law. Planck's formula. Quanta of light.

6. Quantum and Nuclear Physics.

Wave properties of microparticles. Heisenberg uncertainty relation. Schrodinger equation. Principle of superposition of states. Energy quantization using a rectangular one-dimensional well as an example. Average value of the measured physical quantity. Hydrogen-like atom in a stationary state. Spin. The principle of indistinguishability of identical particles. Fermions and bosons. The Pauli exclusion principle. Periodic table of elements. Nuclear forces. Nuclear binding energy. General concepts of nuclear and thermonuclear reactions.

Literature to prepare for exam:

1. D.V. Sivukhin. General Physics Course. In 5 volumes. – M.: Fizmatlit, 2012.
2. A.A. Matyshev. Atomic Physics. – M: Yurait, 2016.
3. G.S. Landsberg. Optics. – M.: FIZMATLIT, 2003.

2.2. Solid State and Semiconductor Physics

1. Band Theory of Solids.

Energy spectrum, allowed and forbidden bands. Dielectrics, metals, semiconductors and semimetals from the point of view of their energy structure. Dispersion law, effective mass of electrons and density of states near the minimum energy and far from it.

2. Statistics of Electrons and Holes in Semiconductors.

Intrinsic and impurity semiconductors. Shallow hydrogen-like impurity centers. Donor and acceptor impurities. Distribution functions of electrons and holes in semiconductors and their features. Cases of strong and weak degeneracy. Concentration of electrons and holes in a semiconductor. Effective density of states of the valence band and conduction band.

3. Electron Transport Phenomena.

Phenomenological approach to the description of kinetic phenomena. Coefficients of specific resistance, isothermal diffusion, Peltier, Seebeck and thermal conductivity. Free electron time. Boltzmann kinetic equation and its solution in the relaxation time approximation. Basic mechanisms of charge carrier scattering. Specific electrical conductivity and mobility, their temperature and concentration dependence. Peltier, Seebeck and electron thermal conductivity effects. Galvano- and thermomagnetic phenomena.

4. Optical Properties of Semiconductors.

Direct and indirect interband optical transitions. Excitons in semiconductors. Exciton absorption of light in direct and indirect transitions to bound and unbound states of an exciton. Absorption of radiation by neutral shallow hydrogen-like donors (acceptors). Absorption of light by free electrons, classical and quantum theory. Absorption of light by lattice vibrations. Long-wave IR dispersion. Lydden-Sachs-Teller relation. Reflection and absorption of light in the residual ray band. Fundamental absorption edge in a strong electric field. Theory of the Franz-Keldysh effect for an ideal edge. Influence of the exciton effect on electroabsorption. Electron energy spectrum and density of states in a uniform quantizing magnetic field. Optical transitions between Landau subbands. Cyclotron resonance. Interband optical transitions in a magnetic field: quantum theory for simple parabolic bands. Effect of heavy doping on light absorption near the fundamental band edge. Burstein-Moss effect. Electron energy spectrum, density of states and interband light absorption in heavily doped semiconductors.

5. Magnetoplasma Phenomena.

Phenomenological theory of light propagation in a crystal placed in a magnetic field. Wave equation and Fresnel equation. Normal waves in the Faraday configuration and in the Voigt configuration. Faraday effect on free electrons. Magnetoplasma reflection in the Faraday and Voigt configurations.

6. Fundamentals of the Theory of Semiconductor Devices.

Calculation of potential in p-n homo- and heterojunctions. Energy diagram of metal-semiconductor contact. Schottky layer, diffusion potential. Dielectric relaxation time, screening radius. Quasineutrality and Dember emf. Bipolar diffusion and drift. Built-in field of an inhomogeneous semiconductor. Electron thermalization, Fermi quasi-levels. Diffusion bias length, carrier injection and extraction. Einstein relation, current density equation. Statistical estimate of current. Continuity equation for electrons and holes. Bias current, quasi-stationary current. Current-voltage characteristic of an ideal diode on a p-n junction. Fermi quasi-levels in a thin junction. Thin junction at a high injection level. Breakdown of the junction. Capacitance and transient characteristic of the p-n junction. Above-barrier emission current and barrier capacitance of an ideal heterojunction. Distribution of charge carriers and currents in a bipolar transistor. Transistor parameters at low frequency. Connection diagrams and maximum gain. Transistor operating modes. Thyristor. Electron energy spectra on the surface. Surface potential and charge. Conductivity of the near-surface layer. Field effect. Capacitance-voltage characteristic of a metal-insulator-semiconductor (MIS) structure. Charge-coupled devices (CCD). Family of MIS transistor characteristics. Tunnel diode. Long diode. Double-base diode. Avalanche diode. Varicap. Basic equation of a photodiode. Photodiode inertia. Photocell. Light-emitting diode. Semiconductor laser injection diode.

Literature to prepare for exam:

1. Yu Peter, Cardona Manuel. Fundamentals of Semiconductor Physics. – Moscow: FIZMATLIT, 2002. 560 p.
2. K. Seeger. Physics of Semiconductors. – M.: Mir, 1977. 615 p.
3. S. Zi. Physics of semiconductor devices. – M.: Mir, 1984, book 1 - 456 p., book 2 - 456 p.

2.3. Physical Foundations of Medical and Biological Research

Physics and technology of ultra-high frequencies (UHF) in biomedical research. UHF hyperthermia. Infrared multiphoton dissociation of biomolecules. Infrared spectroscopy of biomolecules. Biophysical and medical-biological foundations of thermodiagnostics. Thermal imaging. Interaction of visible light with biomolecules. Physicochemical foundations of photobiological processes. X-ray radiation, methods of production and characteristics. Linear and cyclic particle accelerators. Isotopes and their abundance. Particle and radiation detectors. Ultraviolet radiation, sources and characteristics. Fundamentals of mass spectrometry.

Literature to prepare for exam:

1. Tsybin O.Yu. Vacuum mass spectrometers. Tutorial. Tutorial in the electronic library of St. Petersburg State Polytechnical University. 2020. – 66 p. – DOI: 10.18720/SPBPU/2/s20-60.
2. Russell K. Hobbie, Bradley J. Roth. Intermediate Physics for Medicine and Biology. Fourth Edition. Springer, 2015.

3. EXAMPLE OF TEST TASKS

Peter the Great St. Petersburg Polytechnic University

Institute of Electronics and Telecommunications

APPROWED

Head of the educational program

_______________ /M.Ya. Vinnichenko/

«____» _____ ________ 20___ г.

Examples of test assignments (20 questions, 3 points each)

1. Newton's third law is valid in reference frames:

moving with acceleration

rotating

moving in a straight line and uniformly

there is no correct answer

2. The occurrence of polarization of a dielectric under the influence of mechanical stress is called

ferroelectricity

piezoelectricity

paramagnetism

ferromagnetism

3. The photoelectric effect in p-n junctions is…

the emission of light when a forward voltage is applied to the junction

the formation of nonequilibrium electron-hole pairs when irradiated with light and the occurrence of photoEMF

the occurrence of photoconductivity in adjacent regions when irradiated with light

the occurrence of induced emission in the junction when irradiated with light

4. The wave function of a particle allows us to find:

trajectory of motion

momentum of a particle at different points in space

probability of detecting a particle at different points in space

energy of a particle at different points in space

5. What property of silicon makes it the main material for electronics and microelectronics

band gap width

presence of a continuous and strong oxide film

carrier mobility values

there is no correct answer

Examples of open question (2 questions of 20 points)

1. The law of conservation of charge and the continuity equation. The relationship between tension and potential. Electric field of a system of charges.
2. Burstein-Moss effect in semiconductors

4. CRITERIA FOR ASSESSING THE ENTRANCE EXAMINATION

The entrance examination consists of test tasks reflecting questions on the main sections listed in paragraph 1.
The test tasks are to be completed without the use of auxiliary study materials.

Types of test tasks.
Test tasks can be of the following main types based on the method of response:

- Closed test questions, in which the applicant must choose one or more correct answers from the provided options;
- Open test questions, in which there are no provided correct answers, and the applicant must give the detailed answer independently.

The test questions are divided into two blocks:
Block 1: closed test tasks – 20;
Block 2: open test tasks – 2.
The total score is 100.

Assessment Criteria.
For each correctly solved closed test task, up to 3 points are awarded.
For each correctly solved open task, up to 20 points are awarded.

The response to the open question may include handwritten and explanatory materials. All materials must be combined into a single file before uploading. Illegible, incomplete, unreadable, or damaged files will not be considered by the examination committee.

One of the open questions may require writing a motivational letter. It should be prepared in advance. The motivational letter must include the following information: why you want to study in this master's program; a brief description of the relevance of your thesis that was completed as part of your previous education, and the results obtained; an assessment of how your skills match the requirements of the educational program; information about your professional achievements and links to your publications.