**Entrance exam program in training of**
**highly qualified personnel**
**(Ph.D. programme)**
**1.3. "PHYSICAL SCIENCES"**

Program of the entrance examination for postgraduate study in the direction of training of higher qualification 1.3. Physical sciences; by scientific specialty 1.3.21. Medical physics contains sections:

**MECHANICS.** Basic laws of mechanics. Space and time in physics. Kinematics of a material point. Linear and angular velocities and accelerations. Dynamics of a material point. Newton's laws. Equations of motion. Dynamics of the system of material points. Conservation laws in mechanics. Movement in a centrally symmetric field. The law of universal gravitation. Kepler's laws. Lagrange function and Lagrange equations of a system of material points. Integrals of motion. Dynamics of an absolutely rigid body. The inertia tensor. Euler's equations. Motion relative to non-inertial reference frames. Equations of motion. Inertia forces. Hamilton's variational principle. Conservation laws and symmetry properties of space and time. Oscillations of systems with one and many degrees of freedom. Free and forced fluctuations. Damped oscillations. Attenuation indicator. Canonical Hamilton equations. Poisson brackets. Hamilton-Jacobi equations. Mechanics of liquids and gases. The flow of an ideal liquid. The Bernoulli equation. Laminar and turbulent flows. Reynolds number. The flow of a viscous liquid. The Navier-Stokes equation. The Poisel formula. Waves in a continuous medium. The wave equation. Acoustic waves. Ultrasound. The Doppler effect.

**Recommended literature:**

1. Course of general physics. In 3 volumes. Volume 1. Mechanics. Molecular physics: textbook for universities / I.V. Savelyev. - 18th ed., erased. — St. Petersburg: Lan, 2022. — 436 p.
2. Landau L.D., Lifshits E.M. Theoretical physics: textbook for universities in 10 volumes. Vol. 1. Mechanics. - 5th ed., stereot. — M.: Fizmatlit, 2004. - 224 p.

**MOLECULAR PHYSICS.** Thermodynamic and statistical approach to the description of molecular phenomena. Temperature. Boltzmann constant. The first beginning of thermodynamics. Internal energy, heat and work. Cyclic processes. Carnot cycle and its efficiency. The second beginning of thermodynamics. Entropy of a thermodynamic system. Thermodynamic probability and entropy. Thermodynamic potentials. General conditions of phase equilibrium. Interaction of molecules. Ideal gas. Basic gas laws. Distribution of gas molecules by velocities. An ideal gas in an external potential field. Boltzmann distribution. Real gases. The Van der Waals equation. The canonical Gibbs distribution. The statistical sum and the free energy of the system. Bose-Einstein statistics and Fermi-Dirac statistics. Equilibrium radiation. The spectral density of radiation. Planck's formula. The heat capacity of solids. Debye and Einstein models. Theory of fluctuation. Density fluctuation. Brownian motion. Einstein's formulas for momentum dispersion and displacement of a Brownian particle. Liquids. Surface phenomena. Pressure under the curved surface. Wettability and capillary phenomena, adhesion and adsorption. Solid bodies. Crystals. Symmetry of crystals. Defects in crystals. Phase transitions of the first and second kind. Conditions of equilibrium and stability of phases. Transfer phenomena. Diffusion, Fick's law; internal friction, Newton-Stokes law; thermal conductivity, Fourier law. The kinetic Boltzmann equation. The concept of the H-

theorem. Plasma state of matter. The kinetic equation of Vlasov. The concept of a self-consistent field.

**Recommended literature:**

1. Course of general physics. In 3 volumes. Volume 1. Mechanics. Molecular physics: textbook for universities / I.V. Savelyev. - 18th ed., erased. — St. Petersburg: Lan, 2022. - 436 p.
2. Molecular physics. Thermodynamics. Condensed states / S.A. Piralishvili, E.V. Shalagina, N.A. Kalyaeva, E.A. Popkova. — St. Petersburg: Lan, 2022. — 200 p.

**ELECTRODYNAMICS AND OPTICS.** Electrostatic fields. Coulomb's law. The Gauss theorem. Potential and its decomposition into multipoles. Magnetostatic fields. The Bio-Savard-Laplace law. The theorem on the circulation of the magnetic field intensity vector. Maxwell's equations in a vacuum. Scalar and vector potentials. Emission of electromagnetic waves in the electric dipole approximation. Radiation friction. Maxwell's equations in the medium. Material equations and boundary conditions. Spatial and temporal dispersion of dielectric permittivity. The physical meaning of its real and imaginary parts. Conductors, superconductors, dielectrics and magnets, their physical properties. The Lorentz transformation. Laws of transformation of charge and current densities, fields and potentials in Lorentz transformations. Transformation of the frequency and wave vector of an electromagnetic wave in Lorentz transformations. The Doppler effect. Fundamentals of the electromagnetic theory of light. Energy and momentum of light waves. Lebedev's experiments on measuring light pressure. Interference of light. Temporal and spatial coherence. Interferometers. Dielectric mirrors and interference filters. Diffraction of light. The Fresnel and Fraunhofer approximations. Spectral devices. The role of diffraction in the formation of optical images. Dispersion and absorption of light. Phase and group speeds of light. Reflection and refraction of light. Molecular light scattering. Rayleigh's formula. Spectral composition of scattered light. Scattering in turbid media. Radiation of an ensemble of statistically independent oscillators. The natural width of the spectral line. Shock (collision) and Doppler broadening of lines. Quasi-stationary approximation in macroscopic electrodynamics and the limits of its applicability. Skin effect. Quantum theory of radiation. Laws of thermal radiation of condensed media, Planck's formula. Radiation of light by atoms and molecules. Two-level system. Spontaneous and forced transitions. Light amplification, lasers.

**Recommended literature:**

1. General physics course. In 3 volumes. Volume 2. Electricity and Magnetism. The waves. Optics / I.V. Saveliev. — 17th ed., erased. — St. Petersburg: Lan, 2023. — 500 p.
2. Aplesnin S.S. Fundamentals of electrodynamics. Theory, tasks and tests / S.S. Aplesnin, L.I. Chernyshova. — St. Petersburg: Lan, 2022. — 576 p.

**ATOMIC PHYSICS AND QUANTUM THEORY.** Experimental facts underlying quantum theory. Atomic radiation spectra. A hydrogen atom. Bohr's postulates. Experiments on diffraction of electrons and atoms. Wave and corpuscular properties of matter. The de Broglie hypothesis. The basic postulates of quantum mechanics. Coordinate and momentum operators. Hamiltonian. Pure

and mixed states of a quantum mechanical system. The wave function and its properties. Probability density and density matrix. The uncertainty principle. Description of the evolution of quantum mechanical systems. The Heisenberg and Schrodinger equations. Stationary states. Linear quantum harmonic oscillator. Energies and wave functions of stationary states. Passage of particles through a potential barrier. Tunnel effect. Movement in the central field. The hydrogen atom: wave functions and energy levels. Orbital mechanical and magnetic moments. Addition of moments. Spectra of alkali metal atoms. Stationary perturbation theory in the absence and in the presence of degeneracy. Zeeman and Paschen-Bak effects. The Stark effect. The Dirac equation. Quasi-relativistic approximation. Spin-orbit interaction. The fine structure of the spectrum of the hydrogen atom. Systems of identical particles. Symmetric and antisymmetric wave functions. Bosons and fermions. The Pauli principle. A multi-electron atom. Approximation of a self-consistent field. The electronic configuration of the atom. Term. The thin structure of the term. Approximation of LS and JJ connections. Hund rules. The periodic system of elements. Periods and groups. Transitional elements. Nonstationary perturbation theory. The probability of transition in a quantum system. Electromagnetic transitions in atoms and molecules. Selection rules. Theory of elastic scattering. The Born approximation. Partial decomposition of the scattering amplitude. Fundamentals of molecular physics. Adiabatic approximation. Terms of a diatomic molecule. Types of chemical bonds. Spectra of diatomic molecules. Motion of particles in a periodic field, band structure of energy spectra.

**Recommended literature:**

1. General physics course. In 3 volumes. Volume 3. Quantum Optics. Atomic physics. Solid state physics. Physics of the atomic nucleus and elementary particles / I. V. Saveliev. — 14th ed., ster. — St. Petersburg: Lan, 2023. — 320 p.
2. Bedanokov R.A. Quantum physics and elements of quantum mechanics / R.A. Bedanokov. — 3rd ed., ster. — St. Petersburg: Lan, 2023. — 116 p.

**PHYSICS OF THE ATOMIC NUCLEUS AND PARTICLES.** Main characteristics of atomic nuclei. Protons and neutrons. The mass and binding energy of the nucleus. Quantum characteristics of nuclear states. The spin of the core. Radioactivity. The law of radioactive decay, α - decay, β - decay and ¡-radiation of nuclei. The Mossbauer effect. Fission and synthesis of nuclei. Chain reaction, fission and thermonuclear reaction. Nuclear energy. Reactors. Models of atomic nuclei. Fermi gas model, shell model, liquid drop model and generalized core model. Mechanisms of nuclear reactions. Cross sections of reactions. Channels of reactions. Nuclear forces and their properties. Particles and interactions. Interaction as an exchange of quanta of the calibration field (calibration bosons). The fundamental particles are leptons and quarks. Antiparticles. Electromagnetic interaction. Strong interaction. The quark structure of hadrons. The color charge of quarks. Gluons. Weak interaction and the processes caused by it. Weak decays of quarks and leptons. Neutrinos and antineutrinos. The interaction of neutrinos with matter. Symmetries and conservation laws. Combining interactions. Nucleosynthesis in the universe. Nuclear reactions in stars. Interaction of particles and radiation with matter. Principles and methods of acceleration of charged particles. Methods of particle detection.

**Recommended literature:**

1. General physics course. In 3 volumes. Volume 3. Quantum Optics. Atomic physics. Solid state physics. Physics of the atomic nucleus and elementary particles / I. V. Saveliev. — 14th ed., ster. — St. Petersburg: Lan, 2023. — 320 p.
2. Atomic and nuclear physics: studies. manual / A.N. Kislov. — Yekaterinburg: Ural Publishing House. un-ta, 2017.— 271 p.

**MEDICAL PHYSICS.** Membrane potential. Electrogenic pumps. Action potential. Mathematical description of the kinetics of ion currents, selectivity of ion channels. Propagation of the action potential along the nerve fiber. External electric fields of tissues and organs. The potential of the electric field of the current unipole. The potential of the electric field created by the final current dipole. Dipole equivalent electric generator of the heart. Einthoven's theory of leads, the genesis of electrocardiograms. Electroencephalography. Electrical properties of body tissues. Electrical conductivity of body tissues for direct current. Ohm's law for electrolytes, ion mobility. The nature of the capacitive properties of body tissues. Tissue impedance, equivalent circuits. Assessment of viability and pathological changes of tissues and organs based on the frequency dependence of the impedance and the angle of phase shift between current and voltage. Dielectric permittivity of biological tissues. Dispersion of electrical properties of body tissues. The effect of non-ionizing and radiation (electric, magnetic and electromagnetic fields) on biological objects and systems, tissues of a living organism. Types of interactions in biological molecules. Conformational energy and spatial organization of biopolymers. Levels of structural organization of biopolymers. Interaction of macromolecules with solvent. The state of water and hydrophobic interactions in biostructures. Features of the spatial organization of proteins. Mechanisms of enzymatic catalysis. Features of spatial organization and physico-chemical properties of DNA and chromatin. The mechanism of DNA polymerization reaction and its catalysis. Replication and repair. Transcription. The mechanism of protein synthesis. Energy conversion in a living cell. The membrane as a universal component of biological systems. Selective permeability of biomembranes. Liquid mosaic model. Passive and active transport of substances through the membrane structures of the cell. Physical research methods and technologies in biology and medicine. Optical spectroscopy. Absorption spectroscopy in the ultraviolet and visible regions. Absorption spectra of proteins. Absorption spectra of nucleic acids. Fluorescence spectroscopy. Resonant energy transfer (FRET). Circular dichroism. Small-angle scattering of X-rays and neutrons. X-ray diffraction analysis and crystallography of biomolecules. Basic principles of NMR spectroscopy. Application of NMR spectroscopy in structural and dynamic studies of biomolecules. High-resolution NMR, pulsed NMR methods, molecular dynamics methods. Electron microscopy, cryo-electron microscopy and tomography. Laser spectroscopy, studies of electron-rotational spectra, photochemical research methods. Application of EPR spectroscopy in the study of biological objects. EPR spectroscopy in the study of biological membranes. Methods of studying conformational mobility: isotope exchange, luminescent methods, gamma-resonance spectroscopy. Mass spectrometry. Methods of ionization of biological macromolecules. Laser desorption-ionization from the matrix (MALDI). Ultrasound. The use of ultrasound in biomedicine. Positron emission tomography.

**Recommended literature:**

1. Naumyuk E. P. Fundamentals of medical physics with elements of biophysics: tutorial / E. P. Naumyuk, A. V. Kopytsky, V. M. Zavadskaya; compilers in. - Grodno: State Medical University, 2021. - 408 p.

2. Remizov A.N. Medical and biological physics: textbook / A.N. Remizov - M.: GEOTAR-Media, 2016. - 656 p.
3. Kostylev V.A. Medical physics: teaching aid / V.A. Kostylev, B.Y. Narkevich-Moscow: Medicina, 2008. - 464 p.