Federal State Autonomous Educational Institution of Higher Education "Moscow Institute of Physics and Technology (National Research University)"

APPROVED
Vice Rector for Academic Affairs

A.A. Voronov

Work program of the course (training module)

course:	General Physics: Quantum Physics/Общая физика: квантовая физика
major:	Biotechnology
specialization:	Biomedical Engineering/Биомедицинская инженерия
	Phystech School of Biological and Medical Physics
	Chair of General Physics
term:	3
qualification:	Bachelor

Semester, form of interim assessment: 6 (spring) - Exam

Academic hours: 60 AH in total, including:
- lectures: 30 AH.
- seminars: 30 AH.
- laboratory practical: 0 AH.

Independent work: 45 AH.

Exam preparation: 30 AH.

In total: 135 AH, credits in total: 3

Number of course papers, tasks: 2

Authors of the program:

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The program was discussed at the Chair of General Physics 04.06.2020

Annotation

Mastering by students of basic knowledge in the field of quantum physics for further study of the relevant sections of theoretical physics, as well as in-depth study of the fundamental foundations of modern physics.

1. Study objective

Purpose of the course

Development of students ' basic knowledge in the field of quantum physics for further study of the relevant sections of theoretical physics, as well as in-depth study of the fundamental foundations of modern physics.

Tasks of the course

- Formation of students ' basic knowledge and concepts in the field of quantum mechanics and physics;
- formation of skills and abilities to apply the studied theoretical laws and mathematical tools for solving problems of quantum physics;
- formation of physical culture: the ability to distinguish the essential physical phenomena and to disregard the irrelevant; ability to conduct evaluations of physical quantities; ability to build a simple theoretical model is described serving the physical processes.

2. List of the planned results of the course (training module), correlated with the planned results of the mastering the educational program

Mastering the discipline is aimed at the formation of the following competencies:

Code and the name of the competence	Competency indicators
UC-1 Search and identify, critically assess, and synthesize information, apply a systematic approach to problem-solving	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
Gen.Pro.C-3 Write scientific and/or technical (technological, innovative) reports (publications, projects)	Gen.Pro.C-3.1 Adopt the general criteria for submission of manuscripts, scientific and technical documentation, using relevant software applications
	Gen.Pro.C-3.2 Employ practical methodologies for preparing scientific and technical reports (projects)
	Gen.Pro.C-3.3 Visually and graphically present scientific (scientific and technical, innovative technological) outcomes in the form of reports, scientific publications
Gen.Pro.C-4 Collect and process scientific and technical and/or technological data for fundamental and applied problem-solving	Gen.Pro.C-4.1 Apply scientific research and intellectual analysis methods for professional problem-solving
	Gen.Pro.C-4.2 Search for primary sources of scientific and technical and/or technological information in professional settings
	Gen.Pro.C-4.4 Use computer and network skills to obtain, store, and process scientific (technical, technological) information
Pro.C-1 Plan and conduct scientific experiments (in a selected subject area) and/or theoretical (analytical and simulation) research	Pro.C-1.1 Understand the fundamental concepts, laws, and theories of modern physics and biology

3. List of the planned results of the course (training module)

As a result of studying the course the student should:

know:

- Fundamental laws and concepts of quantum mechanics, as well as the limits of their applicability;
- basic ideas and concepts: wave-particle dualism, de Broglie waves, Heisenberg uncertainty principle, wave function, probabilistic interpretation of the wave function;
- fundamental quantum experiments: photoelectric effect, Compton effect, di is the fraction of x-ray radiation and electrons reflected from the crystal chandelier-ray structures, electron interference (including single-particle), linyca-tide spectra of emission and absorption of atoms, the tunneling radiation of absolutely black body;
- characteristic time and spatial scales on which quantum phenomena are manifested;
- Bohr postulates for the hydrogen atom and the quasi-classical Bohr-Sommerfeld approximation;
- the schrödinger wave equation for the evolution of the wave function over time, as well as for the determination of stationary energy levels of the quantum system;
- laws of quantization of frequently occurring types of motion: one-dimensional harmonic oscillator, quantum rotator, electron in a hydrogen atom;
- features of interaction of quantum particles with potential wells and barriers. Tunneling;
- gyromagnetic ratio and the coupling between the mechanical and the magnetic moment mi;
- what is the orbital and spin moments, the connection of thin splitting in the spec-Trach radiation of atoms with the spin-orbital interaction;
- what is hyperfine splitting and spin of an atomic nucleus;
- communication statistics of fermions with Pauli exclusion rule and the exchange interaction. Hund rule of filling of atomic shells;
- basic laws of the Zeeman effect. Complex and simple Zeem-on effects. Magnetic resonance phenomena. (EPR and NMR);
- what is the droplet and shell model of the atomic nucleus. Have an understanding of the strong interaction. Know the characteristic size of atomic nuclei and the magnitude of the binding energies of nucle;
- what is the quark composition of a proton and neutron;
- what is radioactive decay. Alpha, beta and gamma decay. Have an idea of the biological danger of radioactive decay;
- what is the weak interaction, the features of beta decay, the life time Neutro-on, the concept of an antineutrino;
- the main provisions of the theory of neutron scattering by heavy nuclei (resonance and nonresonance interaction, the concept of a composite nucleus);
- basic provisions of quantum optics: photons, forced and spontaneous emission, physics of lasers, Planck's formula for radiation of an absolutely black body.

be able to:

- Apply the studied laws of quantum physics to solve specific problems;
- apply the Bohr-Sommerfeld approximation to solve problems on the motion of a particle (electron) in a given static potential;
- apply the schrödinger equation to determine the energy levels of the STA-tional States, as well as to determine the transmission and reflection coefficients of potential barriers and potential wells;
- calculate the value of the spin-orbital splitting of the energy levels of an atom in the framework of the LS-coupling model
- calculate the value of the splitting of spectral lines in the Zeeman effect taking into account the selection rules
- determine the binding energy of the atomic nucleus within the droplet and shell of the nucleus.
- calculate the probability of neutron scattering by atomic nuclei
- apply the laws of blackbody radiation in thermal radiation problems
- analyze physical problems, highlighting the essential and non-essential aspects of the phenomenon, and on the basis of the analysis to build a simplified theoretical model of physical phenomena;
- apply various mathematical tools for solving problems based on the formulated physical laws, and carry out the necessary analytical and numerical calculations;

master:

- The main methods of solving problems of quantum physics;
- basic mathematical tools characteristic of quantum physics problems.

4. Content of the course (training module), structured by topics (sections), indicating the number of allocated academic hours and types of training sessions

4.1. The sections of the course (training module) and the complexity of the types of training sessions

№	Topic (section) of the course	Types of training sessions, including independent work			
		Lectures	Seminars	Laboratory practical	Independent work
1	Ultraviolet catastrophe. Planck's hypothesis. Black body radiation laws.	2	2		3
2	Corpuscular properties of electromagnetic waves.	2	2		3
3	Wave properties of particles. The ratio of uncertainties.	2	2		3
4	Formalism of quantum mechanics.	2	2		3
5	Potential barriers. Potential holes. Oscillator.	2	2		3
6	Movement in the central field. Vibrational and rotational spectra of molecules.	2	2		3
7	Hydrogen-like atoms. Magnetic moment. Spin. Fine and hyperfine structure of the hydrogen atom.	2	2		3
8	Identity of particles. Exchange interaction. Complex atoms.	2	2		3
9	Spin-orbital interaction. Atom in a magnetic field. Zeeman effect. Radiation, selection rules.	2	2		3
10	EPR and NMR. Spontaneous and stimulated emission. Lasers.	2	2		3
11	Nuclear models.	2	2		3
12	Test.	2	2		3
13	Radioactivity. Alpha, beta, gamma decays.	2	2		3
14	Nuclear reactions. Cross-section estimation.	2	2		3
15	Fundamental interactions and particles. Elementary particles.	2	2		3
AH in total		30	30		45
Exam preparation		30 AH.			
Total complexity		135 AH., credits in total 3			

4.2. Content of the course (training module), structured by topics (sections)

Semester: 6 (Spring)

1. Ultraviolet catastrophe. Planck's hypothesis. Black body radiation laws.

The main unsolved problems of classical physics at the turn of the XIX-XX centuries. Counting the number of field states in a given volume; phase volume per one quantum state, density of states. Rayleigh-Jeans formula and ultraviolet catastrophe, Wien's formula. Planck's hypothesis, Planck's distribution. Wien's displacement law. Equilibrium radiation as an ideal gas of photons. Absolutely black body. Kirchhoff, Lambert and Stefan-Boltzmann laws.

2. Corpuscular properties of electromagnetic waves.

Main experimental results on the external photoelectric effect. Einstein's hypothesis regarding light quanta (photons). Einstein's equation and explanation of the photoelectric effect. Photon momentum. Compton's experiment on scattering of X-rays by light nuclei, the formula for changing the wavelength of quanta when scattered by free electrons, Compton wavelength.

3. Wave properties of particles. The ratio of uncertainties.

De Broglie's hypothesis about the wave properties of material particles - wave-particle dualism. De Broglie wavelength of a nonrelativistic particle. Experiments of Davisson-Jermer and Thomson on electron diffraction. The criterion for the quantumness of the system. Uncertainty relations (coordinate-momentum; energy-time). Virtual particles. Interaction radius for the exchange of virtual particles (fundamental bosons). Wave function of a free particle (de Broglie wave). Born's probabilistic interpretation of the wave function. The concept of hidden parameters (Einstein's hypothesis) and Bell's inequalities.

4. Formalism of quantum mechanics.

The concept of operators of physical quantities. Operators of coordinate, momentum, potential and kinetic energy of the system, Hamiltonian. Eigenfunctions and eigenvalues. Schrödinger equation. Properties of the wave function of stationary problems: continuity, finiteness, uniqueness, continuity of the derivative. Superposition principle of quantum states. Formula for the average value of a physical quantity in a given state. Probability conservation law, probability flux density vector. Process of quantum measurement of a physical quantity is an ability to obtain only its eigenvalues in the process of ideal measurement. Reduction of the wave function during the measurement. The need for a series of identical measurements. The criterion for the possibility of simultaneous measurement of several physical quantities.

5. Potential barriers. Potential holes. Oscillator.

Scattering of particles at a potential step of finite height, passage of a particle over wells and barriers of finite width, Ramsauer effect. Passage of a particle through a rectangular potential barrier of finite width (tunnel effect), derivation of a formula for the transparency of a barrier of arbitrary shape in the semiclassical approximation. An infinitely deep potential pit. Bound states of a particle in a one-dimensional symmetric potential well of finite depth. Energy levels of a one-dimensional harmonic oscillator (no derivation).

6. Movement in the central field. Vibrational and rotational spectra of molecules.

The angular momentum operator. Quantization of the eigenvalues of the projection of the angular momentum onto the selected axis and the square of the angular momentum. Motion in a central field, centrifugal energy, radial quantum number, degeneracy multiplicity. s-states in a three-dimensional spherically symmetric well of finite depth, the condition for the existence of a bound state. Adiabatic approximation in molecular theory. Rotational and vibrational spectra, energy scales of the corresponding excitations.

7. Hydrogen-like atoms. Magnetic moment. Spin. Fine and hyperfine structure of the hydrogen atom.

Thomson and Rutherford's models of the atom. Regularities of optical spectra of atoms. Motion in the Coulomb field. Bohr's phenomenological theory. Spectrum of hydrogen atom and hydrogen-like atoms, principal quantum number, degeneracy multiplicity, isotopic shift. Mesoatoms. Wave function of the ground state of the hydrogen atom. The qualitative nature of the behavior of the radial and angular parts of the wave functions of excited states. Magnetic orbital moment of electrons, gyromagnetic ratio, Bohr magneton. Stern-Gerlach experiment, Uhlenbeck and Goudsmit hypothesis on the electron spin, spin g-factor. Einstein-de Haas experiment. Vector model of addition of spin and orbital moments of an electron, operator of total angular momentum, Lande g-factor.

8. Identity of particles. Exchange interaction. Complex atoms.

Particle identity, wave function symmetry with respect to particle rearrangement, bosons and fermions, Pauli's principle. Exchange interaction. Self-consistent field in complex atoms, electronic configuration of an atom. Madelung-Klechkovsky rule. Periodic table. Atomic terms, a method for finding terms for a given electronic configuration, spectroscopic recording of the state of an atom. Hund rules. Characteristic X-ray radiation (Moseley's law).

9. Spin-orbital interaction. Atom in a magnetic field. Zeeman effect. Radiation, selection rules.

Spin-orbital interaction. Bond types: Russell-Saunders (LS) and j-j. Fine structure of the term for the case of LS-connection. The Zeeman effect for cases of weak and strong magnetic fields by the example of 3P – 3S transitions. Superfine interaction. The concept of the spin (helicity) of a photon, its connection with polarization. Classification of photons by total angular momentum and parity (E- and M-photons). Intensity of electric dipole radiation, the ratio of the radiation intensities of photons of various types and multipoles. Natural level width.

10. EPR and NMR. Spontaneous and stimulated emission. Lasers.

Nuclear and electronic magnetic resonance (quantum mechanical interpretation). Strict and lax selection rules for absorption and emission of photons by atoms (for example, the Zeeman effect and NMR). Two-level quantum system in the field of equilibrium radiation, the principle of detailed equilibrium, spontaneous and induced transitions, Einstein's relations. Transmission of radiation through a medium, amplification condition (inverse population of levels). The principle of operation of the laser and its structure.

11. Nuclear models.

Experiments of Rutherford and Geiger on the scattering of α-particles in gases. The discovery of the neutron by Chadwick. Experimental dependence of the specific binding energy of a nucleus on the mass number A. Properties of nuclear forces: radius of action, depth of potential, saturation of nuclear forces, spin dependence. Nuclear forces as a manifestation of strong interaction. Yukawa's model. Model of a liquid charged drop. Weizsacker's formula for the binding energy of a nucleus. Shell model and magic numbers in the oscillatory potential. Single-particle and collective excited states of the nucleus.

12. Test.

Test.

13. Radioactivity. Alpha, beta, gamma decays.

Radioactivity. The law of radioactive decay, decay constant, half-life, average lifetime, secular equation. Alpha decay, Geiger – Nettol law and its derivation (Gamow's formula). Beta decay, energy spectrum of beta decay, neutrino hypothesis and its experimental detection, internal conversion of electrons, K-capture. Gamma radiation, isomerism of nuclei. Spontaneous fission of nuclei, the mechanism of formation of a fission barrier - the dependence of the Coulomb and surface energies on deformation, the fission parameter, the energy released during fission of nuclei, the limit of stability of nuclei with respect to fission.

14. Nuclear reactions. Cross-section estimation.

Nuclear reactions: exothermic and endothermic reactions, reaction threshold, reaction cross section (total and partial cross sections), reaction channels, channel widths. Bohr's compound nucleus model: classical geometric cross section, corrections for the wave character of particle motion, Bethe's law on the example of particle penetration into a rectangular well. Resonant reactions, Breit – Wigner formula. Fission of nuclei under the action of neutrons, prompt and delayed neutrons, chain fission reaction. The role of delayed neutrons in the operation of a nuclear reactor. Thermal reactor diagram.

15. Fundamental interactions and particles. Elementary particles.

Methods for registration of elementary particles. Discovery of W and Z bosons, t quark and Higgs boson. Standard model. Conservation laws and internal quantum numbers. The quark structure of hadrons - mesons and baryons. Resonances. Hadronic jets. Elements of quantum chromodynamics: asymptotic freedom, hypothesis of confinement of quarks and gluons, quark potential. Estimation of hadronic cross sections at high energies. Parity nonconservation with weak interaction, Wu's experiment. The problem of solar neutrinos, neutrino oscillations

5. Description of the material and technical facilities that are necessary for the implementation of the educational process of the course (training module)

Facilities and Resources:
- A lecture audience equipped with a multimedia projector and a screen.
- Equipment for lecture demonstrations.
- Classrooms equipped with a board.
- Libraries of educational and technical literature, including electronic libraries, necessary for individual work of students.

6. List of the main and additional literature, that is necessary for the course (training module) mastering

Main literature

1. Physics: A General Course v. 1: Mechanics, Molecular Physics (by I.V. Savelyev), Central Books Ltd (1981), Mir Publishers (1989)
2. General Physics: Mechanics and Molecular Physics (by L. Landau, A. Akhiezer, E. Lifshitz), Pergamon Press (1967)
3. Problems in General Physics (by I.E. Irodov), Mir Publishers (Revised edition 1988)

Additional literature

1. Fundamental Laws of Mechanics (by I.E. Irodov), Mir Publishers (Moscow), CBS Publishers & Distributors (India), 6th edition (2016)
2. Berkeley Physics Course: Vol. 1 - Mechanics (by C. Kittel, W.D. Knight, and M.A. Ruderman), McGraw-Hill, New York, second edition (1973)
3. The Feynman Lectures on Physics, The Definitive Edition Volume 1: (2nd Edition) by Richard P. Feynman and Robert B. Leighton, Addison Wesley; 2nd edition (2005)

7. List of web resources that are necessary for the course (training module) mastering

1. http://mipt.ru/education/chair/physics/S_IV/Metod_4/— методический раздел сайта кафедры Общей физики
2. http://lib.mipt.ru/catalogue/1412/?t=750 – электронная библиотека МФТИ, раздел «Общая физика»

8. List of information technologies used for implementation of the educational process, including a list of software and information reference systems (if necessary)

The List of Informational Resources:
1. Methodical section of the Department of General Physics website: http://mipt.ru/education/chair/physics/S_I/method/.
2. MIPT electronic library, the General Physics section: http://lib.mipt.ru/catalogue/1412/?t=750.
Lecture halls are equipped with multimedia and presentation facilities.

The recommended literature is available in electronic form (see paragraphs [1, 2] of the list of Internet resources necessary for mastering the discipline modules) so that the students may read textbooks using their tablets.

9. Guidelines for students to master the course

Guidelines for Students on Mastering the Discipline:

A student studying the general physics course must learn the general physics laws and concepts, and how to apply them in practice.

Successful mastering of the course requires intensive individual work of each student. The course program informs of the minimum time required for the student to work on the course topics. The individual work includes:

- reading and making summary of recommended literature,
- studying educational materials (lecture notes, educational and scientific literature), preparing answers to questions intended for self-study;
- solving the problems offered to students in lectures and seminars,
- passing assignments and preparing for seminars, tests, and exams.

Guidance and control of individual work is offered to students in the form of individual consultations.

The ability to solve problems is an indicator of the student's mastery of physics. To develop such ability, a student needs to solve as many problems as possible. When solving a problem, a student must be able to explain each action on the basis of the studied theoretical topics and carry out all the necessary calculations to bring the solution to a final answer. A problem is considered solved if it contains substantiated actions including references to the applicable physical laws and correct calculations, as well as the correct numerical answer (if the problem contains numerical data).

When preparing for a seminar, students must learn the basic concepts and laws to which the seminar will be devoted, and solve the problems envisaged for preparation to the seminar topic.

Physics makes use of many concepts and methods of calculus. If a student encounters a mathematical concept that has not yet been studied in the framework of mathematical courses then he/she must learn the relevant section of math individually. The necessary minimum of mathematical information is presented both at lectures and in the recommended literature.

The mid-semester control of knowledge is conducted in the form of a written test, in which the student is offered to solve five problems on the studied topics. The written test is given in the format similar to a written exam. In order to test the student's level of knowledge and understanding of the material, the teacher may ask the student, during the presentation of the assignment, additional theoretical questions on the syllabus or give additional problems to solve. Each student is required to complete, in a special notebook, the homework assignments and submit them for inspection.

At the written exam, the student is asked to solve five problems. The subjects of the problems are fully consistent with the physics course syllabus. However, all the problems in the written exam are completely non-typical. At the exam, students are allowed to use a sheet of paper with formulas written on it in advance. Such form of exam eliminates mindless memorization of formulas and is aimed at checking the depth of understanding of the material and the ability to apply physical laws in an unusual situation.

Students are recommended to study individually various topics related to general physics, possibly beyond the scope of the program, thus expanding their physical horizon. At the exam, the student is offered to present any theoretical or experimental topic prepared in advance and related to the course of physics. This can be either an in-depth presentation of one of the syllabus topics or a topic not covered in the syllabus, which can, however, be considered as part of the physics course studied, thus demonstrating the ability to understand various issues and problems of physics based on the use of general physical laws.

SUPPLEMENT

Assessment funds for course (training module)

major:	Biotechnology
specialization:	Biomedical Engineering/Биомедицинская инженерия
	Phystech School of Biological and Medical Physics
	Chair of General Physics
term:	3
qualification:	Bachelor

Semester, form of interim assessment: 6 (spring) - Exam

Authors:

P.V. Popov, candidate of physics and mathematical sciences
A.V. Ilin, candidate of physics and mathematical sciences, associate professor

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
UC-1 Search and identify, critically assess, and synthesize information, apply a systematic approach to problem-solving	UC-1.1 Analyze problems, highlight the stages of their solution, plan the actions required to solve them
	UC-1.2 Find, critically assess, and select information required for the task in hand
	UC-1.3 Consider various options for solving a problem, assess the advantages and disadvantages of each option
	UC-1.4 Make competent judgments and estimates supported by logic and reasoning
	UC-1.5 Identify and evaluate practical consequences of possible solutions to a problem
Gen.Pro.C-3 Write scientific and/or technical (technological, innovative) reports (publications, projects)	Gen.Pro.C-3.1 Adopt the general criteria for submission of manuscripts, scientific and technical documentation, using relevant software applications
	Gen.Pro.C-3.2 Employ practical methodologies for preparing scientific and technical reports (projects)
	Gen.Pro.C-3.3 Visually and graphically present scientific (scientific and technical, innovative technological) outcomes in the form of reports, scientific publications
Gen.Pro.C-4 Collect and process scientific and technical and/or technological data for fundamental and applied problem-solving	Gen.Pro.C-4.1 Apply scientific research and intellectual analysis methods for professional problem-solving
	Gen.Pro.C-4.2 Search for primary sources of scientific and technical and/or technological information in professional settings
	Gen.Pro.C-4.4 Use computer and network skills to obtain, store, and process scientific (technical, technological) information
Pro.C-1 Plan and conduct scientific experiments (in a selected subject area) and/or theoretical (analytical and simulation) research	Pro.C-1.1 Understand the fundamental concepts, laws, and theories of modern physics and biology

2. Competency assessment indicators

As a result of studying the course the student should:

know:

- Fundamental laws and concepts of quantum mechanics, as well as the limits of their applicability;
- basic ideas and concepts: wave-particle dualism, de Broglie waves, Heisenberg uncertainty principle, wave function, probabilistic interpretation of the wave function;
- fundamental quantum experiments: photoelectric effect, Compton effect, di is the fraction of x-ray radiation and electrons reflected from the crystal chandelier-ray structures, electron interference (including single-particle), linyca-tide spectra of emission and absorption of atoms, the tunneling radiation of absolutely black body;
- characteristic time and spatial scales on which quantum phenomena are manifested;
- Bohr postulates for the hydrogen atom and the quasi-classical Bohr-Sommerfeld approximation;
- the schrödinger wave equation for the evolution of the wave function over time, as well as for the determination of stationary energy levels of the quantum system;
- laws of quantization of frequently occurring types of motion: one-dimensional harmonic oscillator, quantum rotator, electron in a hydrogen atom;
- features of interaction of quantum particles with potential wells and barriers. Tunneling;
- gyromagnetic ratio and the coupling between the mechanical and the magnetic moment mi;
- what is the orbital and spin moments, the connection of thin splitting in the spec-Trach radiation of atoms with the spin-orbital interaction;
- what is hyperfine splitting and spin of an atomic nucleus;
- communication statistics of fermions with Pauli exclusion rule and the exchange interaction. Hund rule of filling of atomic shells;
- basic laws of the Zeeman effect. Complex and simple Zeem-on effects. Magnetic resonance phenomena. (EPR and NMR);
- what is the droplet and shell model of the atomic nucleus. Have an understanding of the strong interaction. Know the characteristic size of atomic nuclei and the magnitude of the binding energies of nucle;
- what is the quark composition of a proton and neutron;
- what is radioactive decay. Alpha, beta and gamma decay. Have an idea of the biological danger of radioactive decay;
- what is the weak interaction, the features of beta decay, the life time Neutro-on, the concept of an antineutrino;
- the main provisions of the theory of neutron scattering by heavy nuclei (resonance and nonresonance interaction, the concept of a composite nucleus);
- basic provisions of quantum optics: photons, forced and spontaneous emission, physics of lasers, Planck's formula for radiation of an absolutely black body.

be able to:

- Apply the studied laws of quantum physics to solve specific problems;
- apply the Bohr-Sommerfeld approximation to solve problems on the motion of a particle (electron) in a given static potential;
- apply the schrödinger equation to determine the energy levels of the STA-tional States, as well as to determine the transmission and reflection coefficients of potential barriers and potential wells;
- calculate the value of the spin-orbital splitting of the energy levels of an atom in the framework of the LS-coupling model
- calculate the value of the splitting of spectral lines in the Zeeman effect taking into account the selection rules
- determine the binding energy of the atomic nucleus within the droplet and shell of the nucleus.
- calculate the probability of neutron scattering by atomic nuclei
- apply the laws of blackbody radiation in thermal radiation problems
- analyze physical problems, highlighting the essential and non-essential aspects of the phenomenon, and on the basis of the analysis to build a simplified theoretical model of physical phenomena;
- apply various mathematical tools for solving problems based on the formulated physical laws, and carry out the necessary analytical and numerical calculations;

master:

- The main methods of solving problems of quantum physics;
- basic mathematical tools characteristic of quantum physics problems.

3. List of typical control tasks used to evaluate knowledge and skills

1. The quantum nature of light. External photoelectric effect. Einstein's equation.
2. Wave nature of particles. Compton effect.
3. Spontaneous and stimulated emission. Inverse population of levels. The principle of laser oper-ation.

4. Radiation of an absolutely black body. Planck's formula, Wien's and Stefan-Boltzmann's laws.
5. Corpuscular-wave dualism. De Broglie waves. Experiments of Davisson-Jermer and Thomson on electron diffraction.
6. Wave function. Coordinate and momentum operators. Average values of physical quantities.
7. Uncertainty relation for position and momentum.
8. Bohr's postulates. Energy spectrum of hydrogen-like atoms.
9. Characteristic radiation, Moseley's law.
10. Stationary and non-stationary Schrödinger equation. Evolution of the wave function.
11. Quantum Harmonic Oscillator.
12. Quantum rotator.
13. Molecular spectra: vibrational and rotational levels.
14. Experiments by Stern and Gerlach. Spin of an electron. Orbital and spin magnetic moments of an electron.
15. Identity of particles. Symmetry of the wave function with respect to the permutation of par-ticles. Bosons and fermions. Pauli's principle.

4. Evaluation criteria

- Determine the de Broglie wavelength of an electron with a kinetic energy of 10 eV.
- Formulate Einstein's law for the photoelectric effect.
- Give a definition of the Compton wavelength of an electron.
- Determine the energy spectrum of the hydrogen atom in the framework of the Bohr model.
- Calculate the distance between the zero and first rotational levels of the ground state of the ni-trogen molecule. The distance between the nuclei is 0.3 nm.
- Write down the spectrum of a quantum harmonic oscillator consisting of a particle of mass m and a "spring" of elasticity k.
- Determine the magnetic moment of an electron in the 2p state in a hydrogen atom.
- Obtain the value of the splitting energy for the 1s states of the hydrogen atom in a magnetic field B = 1T.
- Formulate the Pauli exclusion principle.
- Formulate Hund rules for filling atomic shells.
- Formulate the rules for selecting radiative transitions between atomic levels.
- Composition of the atomic nucleus. Explain the reason for the stability of the nucleus.
- Within the framework of the droplet model of the nucleus, determine the type of decay of the 27Mg nucleus (the mass number A does not change).
- Within the framework of the shell model of the nucleus, explain the special stability of nuclei with "magic" mass numbers: 4, 16, 40.
- Determine the size of the nucleus of the lead atom.
- Explain the reason for the continuity of the energy spectrum of electrons appearing during beta decay.
- A neutron with energy of 100 keV is elastically scattered by the nucleus. What is the minimum possible value of the impact parameter b is realized in such process?
- The neutral pion decayed into two gamma quanta with energies of 3.1 GeV and 2.0 GeV. Find the angle between gamma quanta.
- At what temperature is the equilibrium radiation pressure equal to 1 atm?
- Estimate the effective temperature of continuous radiation of a helium-neon laser with a power of 1 mW and a spectral line width of 104 Hz.

Ticket 1
1. Determine the energy spectrum of the hydrogen atom in the framework of the Bohr model.
2. Calculate the distance between the zero and first rotational levels of the ground state of the ni-trogen molecule. The distance between the nuclei is 0.3 nm.

To be admitted to the test, the student must solve all the problems from the assignments. On the test, the teacher appreciates the solutions to problems from homework, for which he can ask the student to comment on the solution to any problem from the assignment. The student's answer to the theoretical question is assessed as a whole, and the grade is given according to the criteria below and the notes on the written part of the exam above:

The mark "excellent (10)" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and beyond, as well as the ability to confidently apply them in practice when solving complex non-standard problems.

The mark "excellent (9)" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems.

The mark "excellent (8)" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems, but who made some inaccuracies in the answer.

The mark "good (7)" is given to a student if he has demonstrated solid knowledge and confident understanding of the curriculum material and the ability to freely apply physical laws in practice in solving typical problems.

The mark "good (6)" is given to a student if he has demonstrated solid knowledge of the curriculum material and the ability to apply physical laws in practice when solving typical problems.

The mark "good (5)" is given to a student if he has demonstrated solid knowledge and understanding of the curriculum material and the ability to apply physical laws in practice when solving typical problems, but made a number of gross inaccuracies in answering.

The mark "satisfactory (4)" is given to a student who has shown the fragmented nature of knowledge, who made inaccuracies in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The mark "satisfactory (3)" is given to a student who has shown a highly fragmented nature of knowledge, who made gross errors in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The grade "unsatisfactory (2)" or "unsatisfactory (1)" is given to a student who does not know a significant part of the main content of the program, systematically makes gross errors in the formulation of basic physical laws, or is unable to correctly apply physical laws even for solving simple problems.

5. Methodological materials defining the procedures for the assessment of knowledge, skills, abilities and/or experience

The test takes place in the form of a conversation between a teacher and a student on the topics of selected tasks theoretical questions.

The student is given from 30 to 45 minutes to prepare for an answer on a theoretical question.

In the process of answering a theoretical question or explaining the solution of problems from the assignment, the teacher can ask clarifying questions. After the answer, the teacher has the right to ask the student any additional questions about the course program.

3. A list of typical test items used to assess knowledge, skills, and abilities

Intermediate certification in the discipline "General Physics: Quantum Physics" is carried out in the form of a differential test. The test includes a check of the student's homework and theoretical knowledge. A list of theoretical questions is given below:

1. The quantum nature of light. External photoelectric effect. Einstein's equation.
2. Wave nature of particles. Compton effect.
3. Spontaneous and stimulated emission. Inverse population of levels. The principle of laser operation.
4. Radiation of an absolutely black body. Planck's formula, Wien's and Stefan-Boltzmann's laws.
5. Corpuscular-wave dualism. De Broglie waves. Experiments of Davisson-Jermer and Thomson on electron diffraction.
6. Wave function. Coordinate and momentum operators. Average values of physical quantities.
7. Uncertainty relation for position and momentum.
8. Bohr's postulates. Energy spectrum of hydrogen-like atoms.
9. Characteristic radiation, Moseley's law.
10. Stationary and non-stationary Schrödinger equation. Evolution of the wave function.
11. Quantum Harmonic Oscillator.
12. Quantum rotator.
13. Molecular spectra: vibrational and rotational levels.
14. Experiments by Stern and Gerlach. Spin of an electron. Orbital and spin magnetic moments of an electron.
15. Identity of particles. Symmetry of the wave function with respect to the permutation of particles. Bosons and fermions. Pauli's principle.
16. Exchange interaction. Hund's rule for filling electron orbitals. Electronic structure of atoms. Periodic table.
17. Fine and hyperfine structure of optical spectra. Spin-orbital interaction.
18. Selection rules for absorption and emission of photons by atoms. Multiplicity of photons.
19. Zeeman effect in weak magnetic fields.
20. Zeeman effect in strong magnetic fields.
21. Nuclear and electronic magnetic resonances.
22. Drip model of the nucleus and the Weizsacker formula
23. Shell model of the nucleus and magic numbers.
24. The law of radioactive decay. Half-life and lifetime.
25. Tunneling of particles through a potential barrier. Alpha decay. Geiger-Nattall's law and its explanation.
26. Types of beta decays. Explanation of the continuity of the energy spectrum of electrons. Neutrino.
27. Gamma radiation, isomerism of nuclei. Interaction of gamma radiation with matter.
28. Methods for registration of high-energy particles. Scintillation detectors, Geiger counters. Gamma spectrometers.
29. Nuclear reactions. Composite nucleus. Cross section for nonresonant reactions. Bethe's law.
30. Resonant nuclear reactions, Breit-Wigner formula.
31. Fission of nuclei under the action of neutrons. The principle of operation of a nuclear reactor using thermal neutrons.
32. The ratio of uncertainties for energy and time. Estimation of the lifetime of virtual particles, radii of strong and weak interactions.
34. Fundamental interactions and fundamental particles (leptons, quarks and carriers of interactions). Quark structure of hadrons.

Examples of simple questions and tasks to obtain a satisfactory grade:
• Determine the de Broglie wavelength of an electron with a kinetic energy of 10 eV.
• Formulate Einstein's law for the photoelectric effect.
• Give a definition of the Compton wavelength of an electron.
• Determine the energy spectrum of the hydrogen atom in the framework of the Bohr model.
• Calculate the distance between the zero and first rotational levels of the ground state of the nitrogen molecule. The distance between the nuclei is 0.3 nm.
• Write down the spectrum of a quantum harmonic oscillator consisting of a particle of mass m and a "spring" of elasticity k.
• Determine the magnetic moment of an electron in the $2p$ state in a hydrogen atom.
• Obtain the value of the splitting energy for the $1s$ states of the hydrogen atom in a magnetic field B = 1T.
• Formulate the Pauli exclusion principle.
• Formulate Hund rules for filling atomic shells.
• Formulate the rules for selecting radiative transitions between atomic levels.
• Composition of the atomic nucleus. Explain the reason for the stability of the nucleus.
• Within the framework of the droplet model of the nucleus, determine the type of decay of the ^{27}Mg nucleus (the mass number A does not change).
• Within the framework of the shell model of the nucleus, explain the special stability of nuclei with "magic" mass numbers: 4, 16, 40.
• Determine the size of the nucleus of the lead atom.
• Explain the reason for the continuity of the energy spectrum of electrons appearing during beta decay.
• A neutron with energy of 100 keV is elastically scattered by the nucleus. What is the minimum possible value of the impact parameter b is realized in such process?
• The neutral pion decayed into two gamma quanta with energies of 3.1 GeV and 2.0 GeV. Find the angle between gamma quanta.
• At what temperature is the equilibrium radiation pressure equal to 1 atm?
• Estimate the effective temperature of continuous radiation of a helium-neon laser with a power of 1 mW and a spectral line width of 10^4 Hz.

4. Assessment criteria

To be admitted to the test, the student must solve all the problems from the assignments. On the test, the teacher appreciates the solutions to problems from homework, for which he can ask the student to comment on the solution to any problem from the assignment. The student's answer to the theoretical question is assessed as a whole, and the grade is given according to the criteria below and the notes on the written part of the exam above:

The mark "**excellent (10)**" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and beyond, as well as the ability to confidently apply them in practice when solving complex non-standard problems.

The mark "**excellent (9)**" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems.

The mark "**excellent (8)**" is given to a student who has shown comprehensive systematized deep knowledge of the curriculum and the ability to confidently apply them in practice when solving non-standard problems, but who made some inaccuracies in the answer.

The mark "**good (7)**" is given to a student if he has demonstrated solid knowledge and confident understanding of the curriculum material and the ability to freely apply physical laws in practice in solving typical problems.

The mark "**good (6)**" is given to a student if he has demonstrated solid knowledge of the curriculum material and the ability to apply physical laws in practice when solving typical problems.

The mark "**good (5)**" is given to a student if he has demonstrated solid knowledge and understanding of the curriculum material and the ability to apply physical laws in practice when solving typical problems, but made a number of gross inaccuracies in answering.

The mark "**satisfactory (4)**" is given to a student who has shown the fragmented nature of knowledge, who made inaccuracies in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The mark "**satisfactory (3)**" is given to a student who has shown a highly fragmented nature of knowledge, who made gross errors in the formulation of basic laws and basic concepts, but at the same time demonstrated the ability to solve simple problems and master the main sections of the curriculum necessary for further education.

The grade "**unsatisfactory (2)**" or "**unsatisfactory (1)**" is given to a student who does not know a significant part of the main content of the program, systematically makes gross errors in the formulation of basic physical laws, or is unable to correctly apply physical laws even for solving simple problems.

5. Methodological materials defining procedures for assessing knowledge, skills, abilities and (or) experience

Differential test procedure.

The test takes place in the form of a conversation between a teacher and a student on the topics of selected tasks theoretical questions.

The student is given from 30 to 45 minutes to prepare for an answer on a theoretical question. In the process of answering a theoretical question or explaining the solution of problems from the assignment, the teacher can ask clarifying questions. After the answer, the teacher has the right to ask the student any additional questions about the course program.

0-1-1. Due to the increase in temperature, the position of the maximum of the spectral radiant luminosity of an absolutely black body has shifted from 2 μm to 1 μm. How many times has its integral energy luminosity changed?

0-1-2. Estimate the pressure of thermal radiation in the inner region of the Sun, where the temperature is $1{,}3\cdot10^7$ K.

0-2-1. In the experiments of P.N. Lebedev, who proved the existence of light pressure, the incident luminous flux was 6 W/cm^2. Calculate the pressure experienced by the blackened and mirrored petals of his measuring device.

0-3-1. Determine the kinetic energy of an electron at which its de Broglie and Compton wavelengths are equal to each other.