Exam questions for applicants to the PhD program 8D05301 – Physics

Level 1

1. The principle of relativity. The Galilean and Lorentz transformations. Equations of physics in covariant form.
2. The principle of symmetry, superposition, uncertainty principle. The correspondence principle as a reference point in the construction of new physical theories.
3. The law of conservation of energy and the uniformity of time.
4. The laws of conservation of momentum and angular momentum as a consequence of translational invariance and isotropy of space.
5. Quantum numbers and the energy of the hydrogen atom. Quantum superposition. Classical superposition.
6. The uncertainty relation for energy-time. Uncertainty ratio, the uncertainty principle.
7. Magnetic field and its characteristics.
8. Classification of materials, data on their shape, methods for studying thermal, electrical, magnetic and optical properties.
9. Amorphous materials and their characteristics.
10. The structure of materials. Concept: component, phase, composition. Micro- and macro-analysis. The concept of physical methods of materials research.
11. Types of defects, their classification, influence on properties.
12. Metals. Features of the atomic crystal structure of metals. Isotropy, anisotropy, allotropy. Construction of real metals. Mechanisms of metal crystallization.
13. Ferrous metals. Cast iron: properties and use of cast iron, classification of cast iron. Steel: classification of steel, quality and structure. Two-phase diagrams. Structural steel. Heat-resistant steels. Structures of the pearlitic, martensitic and martensitic-ferritic classes.
14. Melts of metals. Tool steels and alloys. Non-ferrous metals and alloys: aluminum and its alloys; copper and its melts. Application of metals.
15. Ceramics: areas of production and use of ceramic materials, their advantages and disadvantages. Methods of fighting fever. Areas of operation of ceramic materials.
16. Glass: inorganic glass, its types and heat treatment, areas of use. Organic glasses, their advantages and disadvantages. Application areas.
17. Polymers. Classification of polymer materials. General characteristics, types and properties, areas of use.
18. Semiconductors. Basic information about semiconductors. Semiconductor structures.
19. Electronic excitations in alkali-halide crystals.
20. Impurity defects in alkali-halide crystals.
21. Dislocations in alkali-halide crystals.
22. Mechanical compression of the crystal lattice in alkali-halide crystals.

23. Hydrostatic compression of alkali-halide crystals.
24. Uniaxial compression of alkali-halide crystals.
25. Basic information about uniaxial deformation of alkali-halide crystals.
26. Halogen radiation defects in alkali-halide crystals.
27. Plastic and elastic deformation of alkali-halide crystals.
28. Main characteristics of composite materials and methods of production.
29. Mechanical properties. Stress and strain. Elastic deformation. Plastic deformation.
30. Electrical properties: theory of conductivity; conductors, insulators, superconductors.
31. Optical properties: transparent and opaque materials. Colour. Luminescence. Optical fibers and modern optical devices. Lasers.
32. Magnetic properties: magnetic materials. General information about ferromagnets. Magnetic materials and their requirements. Diamagnets.
33. Open systems that exchange matter, energy, and information with the environment. Examples of open systems from living and inanimate nature.
34. Information and entropy. Information and open systems. Conditions for generating information. Entropy as the average value of information.
35. Fractals and dynamic chaos. Fractal objects in nature. Fractal dimension. Multifractals. Examples of multifractals. Interaction of fractals.
36. Crystallography and crystal structure. Classification of crystals by symmetry type. Bravais lattices. Interatomic interactions and binding energy in crystals.
37. Heat capacity of crystals (Einstein and Debye models). Anharmonicity and thermal expansion of solids.
38. The law of conservation of charge. Lorentz force.
39. Maxwell's equations in integral and differential form, their physical meaning.
40. The Fourier method. Green's theorems.
41. Motion of charged particles in the electromagnetic field.
42. Plane monochromatic waves. Scale of electromagnetic waves.
43. The Lorentz condition.
44. Electric dipole field.
45. The principle of relativity of Galileo. The Galilean transformations.
46. The relativistic law of addition of velocities.
47. Electrostatics. Electrostatics of conductors.
48. Electrostatics of dielectrics.
49. Forces acting on conductors and dielectrics.
50. Superconductors and their characteristics.
51. Errors of optical systems and methods for their elimination. Optical instruments.
52. Internal energy and enthalpy as a function of state.

53. Coriolis theorem on the addition of point accelerations. Vector expression, physical meaning, modulus and direction of Coriolis acceleration.
54. Decay of excitons into primary radiation defects in alkali halide crystals.
55. Tunneling recharge of radiation defects in alkali halide crystals.
56. Obtaining ultrapure alkali halide crystals.
57. Methods for growing alkali halide crystals.
58. Low-temperature uniaxial deformation of alkali halide crystals.
59. Electronic excitations in the field of vacancy defects in alkali halide crystals.
60. Lagrange equations of the second kind. The methodology for compiling these equations for a mechanical system.
61. Entropy. The physical meaning of entropy. Gui–Stodola equation.
62. The principle of possible displacements. Application of this principle in theoretical mechanics.
63. Differential equations of motion of a material point in Cartesian coordinates. Natural equations of motion of a point (equations in projections on the axis of a natural trihedron).
64. Lagrange equations in the case of potential forces.
65. Variation of movements. Function variation. Differential variational principles.
66. Quantization of the magnetic flux. The Josephson effect. The Meissner–Oxenfeld effect.
67. Discovery of superconductivity. Superconducting elements and compounds.
68. Normal skin effect. Surface impedance.
69. Ferrous metals. Cast iron: properties and use of cast iron, classification of cast iron. Steel: classification of steel, quality and structure.
70. Multifractals. Examples of multifractals. Interaction of fractals.
71. Magnetic properties of superconductors of the first kind. Intermediate state. Magnetic properties of superconductors of the second kind.
72. The equations of the Ginzburg–Landau theory. The density of free energy. Gradient invariance of the Ginzburg–Landau theory.
73. Critical thermodynamic magnetic field. Entropy of a superconductor. Heat capacity. Free energy.
74. Fractals and dynamic chaos. Fractal objects in nature. Fractal dimension.
75. Crystallography and crystal structure. Classification of crystals by type of symmetry.
76. Kinetic inductance. Complex conductivity of a superconductor.
77. London's first equation. London's second equation. The depth of penetration of the magnetic flux.

78. Plastics, their structure, properties. Filler in plastics, inhibitors. Their influence on plastic properties. Methods of obtaining polymer materials.
79. Two-phase diagrams. Structural steel. Heat-resistant steels. Structures of the pearlitic, martensitic, and martensitic-ferritic classes.
80. Dielectric materials. The main types of dielectrics. Electrical conductivity of dielectrics.
81. Quantum generalization of the London equation. Quantization of the magnetic flux.
82. Field and current distribution in the simplest configurations of superconductors. The plate is in a parallel field. A plate with a current. A plate with a current in a uniform transverse magnetic field. The film is above the screen. The principle of closure.

Level 2

1. Using the uncertainty relation for the coordinate and momentum to estimate the zero-point energy of a harmonic oscillator.
2. Spherical potential well, the energy of zero oscillations of the harmonic oscillator.
3. Explanation of the stability of the atom and the impossibility of finding an electron inside the nucleus based on the uncertainty ratio. Tunnel effect and over-barrier scattering.
4. Introduction using the uncertainty relation for energy and time, the concept of virtual particles in the microcosm. Estimation of the mass of quanta. The concept of virtual particles in the microcosm.
5. Particle beam accelerators — synchrotrons and synchrophasotrons. Accelerators on opposite beams. Particle beam accelerators — synchrotrons and colliders. Large Hadron Collider.
6. Multiplet. Zeeman splitting of atomic levels in a magnetic field. Splitting of atomic levels in an electric field. The Stark effect.
7. The relation of the spectral function to entropy. The evolution of entropy. Prigogine's theorem, minimum entropy production. Nonequilibrium and stationary states.
8. Decay of electronic excitations in alkali-halide crystals. Radiative annihilation of electronic excitations in alkali-halide crystals.
9. Decay of autolocalized excitons into anionic Frenkel defects.
10. Decay of autolocalized excitons into cationic Frenkel defects.
11. Association of halogen radiation defects in alkali-halide crystals.
12. Local disturbances of the crystal lattice in alkali-halide crystals.
13. Physico-chemical properties of alkali-halide crystals doped with homologous cations.
14. General regularities of luminescence and radiation defect formation during the decay of autolocalized excitons in alkali-halide crystals under low-temperature deformation.

15. Methods for evaluating mechanical strength. Methods for determining hardness. Properties that can be detected during dynamic tests. The effect of residues on metals and melts. Methods for determining the strength of materials.
16. Modern methods of materials research. Optical microscopy. Scanning electron microscopy. Scanned probe microscopy.
17. Nonlinearity and stochastization of dynamical systems. Nonlinear pendulum, phase portrait. An attractor and a strange attractor. Dynamic and statistical patterns in nature.
18. Self-organization in living and inanimate nature. Klimontovich's theorem. Renormalization of temperature. Decrease in entropy during self-organization.
19. The zone theory of solids. Classification of solids by the energy spectrum of electrons. Free Fermi electron gas.
20. Bloch's theorem. Brillouin zones. Analysis of dispersion laws, allowed and forbidden energy states. Effective mass of the electron.
21. Energy zones and the Fermi surface. Thermal conductivity and electrical conductivity of crystals.
22. Defects in crystals. Classification of defects, types of crystal lattice defects. The effect of defects on the physical properties of crystals.
23. Objects and methods of research in corpuscular optics.
24. Mathematical apparatus of electrodynamics. The nabla operator. The Ostrogradsky–Gauss and Stokes theorems.
25. Wave equations. Electromagnetic waves in a vacuum. The speed of light. Combining electricity, magnetism and optics.
26. Analytical functions of a complex variable.
27. Cauchy–Riemann conditions.
28. The Biot–Savart–Laplace law and its application for calculating fields.
29. Equations for a constant magnetic field in a vacuum in integral and differential form.
30. The circulation theorem and its application for calculating the magnetic field.
31. Faraday's law of electromagnetic induction in integral and differential forms.
32. The complete system of Maxwell's equations for vacuum, displacement current.
33. Multipole decomposition of the potential.
34. Experimental foundations of special relativity. The Michelson–Morley experiment.
35. Lorentz transformations. Lorentz contraction.
36. Einstein's postulates. A thought experiment with a light clock.
37. Derivation of Lorentz transformations.
38. Consequences of the Lorentz transformations and their experimental confirmation.
39. The law of conservation of energy for the particle + field system. Energy density and energy flux density of the electromagnetic field.
40. Integrated capacity.

41. Conformal transformations.
42. Poisson formula for the upper half-plane.
43. Solving mixed boundary value problems.
44. The Keldysh–Sedov method.
45. The Euler method.
46. The Adams method.
47. The Runge–Kutta method.
48. Image method for plane and sphere.
49. Invariants of the electromagnetic field.
50. Covariant expression for the Lorentz force.
51. The classical theory of electrical conductivity in a magnetic field. Hall effect. Energy levels and density of states in a magnetic field.
52. Electronic heat capacity and electronic conductivity
53. Impurity and vacancy defects. Dislocation.
54. Crystal structure of semiconductors. Energy zones of electrons
55. Optical conductivity of alkali metals. Optical absorption in semiconductors.
56. X-ray wave diffraction. Diffraction of electrons. Atomic and geometric structural factors. Bloch waves in crystals.
57. Lattice heat capacity. Theoretical sketches of Einstein and Debye temperatures.
58. Wave mechanics of phonons. Creation and annihilation operators.
59. Elastic waves and lattice vibrations in one-dimensional crystals. Lattice vibrations in the case of a diatomic linear chain.
60. Energy levels and density of states in a magnetic field. Breakdown phenomena in strong electric and magnetic fields.
61. Landau's theory of Fermi liquid. Secondary quantization and the method of equations of motion.
62. Derivation of the Lagrange equations. Lagrange equations with indefinite factors for systems with additional holonomic constraints.
63. Hamilton's equations.
64. Poisson's theorem and its application in the integration of equations of dynamics in Hamilton's variables. Poisson brackets and their basic properties.
65. Jacobi method of integration of dynamic Hamilton equations. Hamilton–Jacobi theorem.
66. Two characteristic length scales in superconductors. Coherence length and penetration depth. The proximity effect.
67. The energy of the interface between the normal and superconducting phases. The critical field of a thin film. The critical current of the thin film.
68. Phase coherence and types of weak bonds. Stationary Josephson effect.
69. The nonstationary Josephson effect. Resistive characteristics of Josephson junctions. Josephson generation.
70. Fluctuations of the critical current. Thermal fluctuations of the critical current in the Josephson junction. Macroscopic quantum tunneling and coherence.
71. Superconducting quantum interferometers. Two-contact SQUID. Single SQUID.

72. The Ferrell–Prange equation. Penetration of the magnetic field into the junction. Josephson vortices.
73. The field of a single vortex. The first critical field. Interaction of vortices. The second critical field. Reversible magnetic moment of a superconductor of the second kind.
74. Surface superconductivity. The third critical field. Surface barrier. Overheating of the Meissner state.
75. Interaction of vortices with a flat surface of a superconductor. Interaction of a vortex with a cavity in a superconductor.
76. The structure of the substance. Ionic, covalent, metallic and molecular bonds in materials.
77. The Biot–Savart–Laplace law and its application for calculating fields. Cauchy–Riemann conditions.
78. Bravais lattices. Interatomic interactions and binding energy in crystals.
79. Solving mixed boundary value problems. The Keldysh–Sedov method.
80. Composite materials with metal and polymer matrices. Their advantages and disadvantages. Methods for obtaining the main types of composite materials: glass granules, carbon blocks, etc.
81. The Euler method. The Runge–Kutta method.

Level 3

1. Phase equilibrium diagrams. Thermodynamic conditions of equilibrium of a two-component melt.
2. Formation of the structure of materials during crystallization. Thermodynamic bases, mechanisms of metal crystallization, and kinetics. Methods of research of amorphous materials.
3. Thresholds of nuclear reactions, production of antiprotons. Short-lived resonant particles. The lifetime of fast-moving elementary particles.
4. Exciton mechanism of formation of radiation defects in alkali-halide crystals.
5. Violation of the lattice of alkali-halide crystals by point defects and mechanical compression.
6. Creation of electronic excitations in the field of vacancy defects of alkali-halide crystals.
7. Equipment for measuring the absorption characteristics of alkali-halide crystals.
8. Experimental setup for measuring the luminescent characteristics of alkali-halide crystals.
9. Technology of low-temperature deformation of alkali-halide crystals.
10. Method of measuring the ionic conductivity of alkali-halide crystals.
11. Methods of growing alkali-halide crystals.
12. Continuum theory of exciton autolocalization in ionic crystals.
13. Continuum theory of exciton hole component autolocalization in undeformed alkali-halide crystals.
14. Quantitative calculation of the barrier height for exciton autolocalization in alkali-halide crystals.

15. Continuum theory of exciton autolocalization in comprehensively compressed alkali-halide crystals.
16. Continuum theory of exciton autolocalization in alkali-halide crystals under uniaxial compression.
17. Mechanisms of exciton decay into primary radiation defects in alkali-halide crystals.
18. Tunnel recharge of radiation defects in alkali-halide crystals.
19. Specific features of radiative and nonradiative relaxation of excitons in the continuum model of their autolocalization in alkali-halide crystals.
20. Stabilization of halogen radiation defects in KBr crystals under low-temperature uniaxial deformation.
21. Radiation defect formation in alkali-halide crystals under low-temperature uniaxial deformation.
22. Geometric criteria for the formation of H-centers in alkali-halide crystals under low-temperature uniaxial deformation.
23. Temperature dependence of the luminescence of autolocalized excitons in alkali-halide crystals under low-temperature uniaxial deformation.
24. Dynamics of the crystal lattice. Vibrations of atoms in one-dimensional and three-dimensional lattices. Acoustic and optical phonons.
25. Synergetics, its role in the knowledge of nature and society. Application of the theoretical provisions of synergetics to condensed matter physics, turbulence, biological and social systems.
26. Solving two-dimensional problems in corpuscular optics.
27. Calculations of electrostatic potentials reduced to two-dimensional ones.
28. Circulation of the electrostatic field strength. The potential of the point charge field. The superposition principle for the potential.
29. The differential form of the equations of electrostatics and their solution for a given charge distribution.
30. The Poisson equation and its solution for a given charge distribution. The Laplace equation.
31. Radiation of electromagnetic waves. Electric dipole radiation. Near and wave zones.
32. Harmonic dipole emitter. The intensity of the radiation.
33. Calculation of the field of dipole systems.
34. Calculation of the field of quadrupole systems.
35. Vector potential of a current loop.
36. Physically infinitesimal volume. Averaging of microscopic fields.
37. The problem of averaging the charge density and current density. The polarization vector and the magnetization vector.
38. Maxwell's equations for averaged fields in matter.
39. Material equations. Boundary conditions.
40. Some methods for solving electrostatic problems.
41. Magnetostatics. The field of stationary currents in bulk and linear conductors.
42. Coefficients of induction and mutual induction.

43. Equations for a constant magnetic field in a vacuum in integral and differential forms. Vector potential. The Poisson equation for the vector potential.
44. Calculation of the field of a conducting ball in a homogeneous electric field.
45. Analysis of the band structure by the density of states.
46. Solid-phase synthesis of phosphors and determination of structural features by X-ray diffractometry.
47. Determination of solute concentration by absorption spectra.
48. Molecular absorption spectroscopy.
49. Atomic emission spectroscopy.
50. Atomic absorption spectroscopy.
51. Radiation defects in alkali halide crystals
52. Basic information on uniaxial deformation of alkali halide crystals
53. Influence of X-ray radiation on ionic conductivity of alkali halide crystals
54. General regularities of nonradiative decay of self-trapped excitons near vacancy defects in alkali halide crystals
55. Luminescence of self-trapped excitons in alkali halide crystals under low-temperature uniaxial deformation
56. Influence of low-temperature uniaxial deformation on the configuration of self-trapped excitons in alkali halide crystals
57. Wave packet. Group velocity, Rayleigh's formula
58. Displacement currents. Maxwell's second equation
59. Various formulations of the main postulate expressing the second law of thermodynamics
60. Ferromagnetism. Elementary carriers of ferromagnetism are electron spins. Domain theory of ferromagnetism. Ferromagnet magnetization. Curie point
61. Experimental evidence of wave and corpuscular properties of light. Young's experiments. Compton effect
62. The work function of an electron from a metal. Thermionic emission. Boguslavsky–Langmuir law. Richardson's formula
63. The principle of superposition of temperatures. Temperature waves
64. The electrical capacity of conductors. Electric capacity of a flat capacitor and a solitary sphere. Capacitors. Units of electrical capacity
65. Classical theory of heat capacity of solids (crystals)
66. Electron–phonon interaction. The distribution of electrons in the ground state. The energy of the ground state
67. Energy gap. The density of states of elementary excitations of a superconductor and the coherence length. Dependence of the magnitude of the energy gap
68. Tunneling effects in superconductors. Tunnel characteristics. The binding energy of the SIS junction and the temperature dependence of the critical current
69. The main types of crystal lattice. Methods of structure research
70. Undamped current and the Meissner–Oxenfeld effect. The connection of microtheory with the Ginzburg–Landau theory

71. Andreev reflection. Andreev levels in the SNS transition. The population imbalance of the branches of the spectrum of elementary excitations and the electric field in a superconductor
72. Quasiparticles: electrons and holes. The charge of a quasiparticle in a superconductor. Relaxation time
73. Experimental study of the nonequilibrium state of a superconductor near the NS boundary. The experiments of Yu and Mercereau. Excess resistance of the NS boundary
74. Nonequilibrium amplification of superconductivity. Longitudinal thermoelectric effect (Seebeck effect) in superconductors
75. Elements of semiconductors and semiconductor chemical compounds. Germanium and silicon, their properties and their application. Semiconductor structures
76. Thermosetting polymers, their description
77. The Josephson SNS transition in heat flow. The influence of the magnetic field on thermoelectric phenomena in Josephson SNS junctions