Faculty Engineering and technological
Department Technical physics and heat power engineering

The program of the entrance exams to PhD-doctoral studies in the group of educational program DO90 Physics

Semey – 2024

1 DEVELOPED

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2 DISCUSSED

At the meeting of the department « Technical Physics and Heat Power Engineering»
Protocol № 9 «25» april 2024

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1. Introduction

The program of the entrance exam for the special discipline of PhD-doctoral studies is formed in the scope of the programs of the previous stages of higher education (bachelor's degree) and postgraduate education (master's degree).

2. The name of the discipline and its main sections

2.1 General physics. Mechanics

Topic 1. Kinematics

Mechanical movement. Vectors. Speed. Acceleration. Translational motion of a solid body.

Topic 2. Dynamics of the material point

Inertial reference systems. The law of inertia. Force and mass. Newton's second law. Newton's Third law. Forces. Gravity and weight. Elastic forces. Friction forces.

Topic 3. Conservation laws

Conserved values. The law of conservation of momentum. Energy and work. The scalar product of the vectors Kinetic energy and work. Work. Conservative forces. The potential energy of a material point in an external force field. The potential energy of the interaction. The law of conservation of energy. Collision of bodies. The moment of power. The law of conservation of angular momentum.

Topic 4. Solid state mechanics

Kinematics of rotational motion. Flat motion of a rigid body. Motion of the center of mass of a solid. Rotation of a solid body around a fixed axis. Moment of inertia. Kinetic energy of a rotating body. The kinetic energy of a body in flat motion. Gyroscopes.

Topic 5. Non-inertial reference frames

Forces of inertia. The centrifugal force of inertia. The power of Coriolis. Fluid mechanics. Description of the movement of liquids. The Bernoulli equation. The flow of liquid from the hole. Viscosity. The flow of liquid in the pipes. The motion of bodies in liquids and gases.

Topic 7. Elements of the special theory of relativity

Galileo's principle of relativity. Postulates of the special theory of relativity. Lorentz transformations. Corollaries from the Lorentz transformations. Interval. Conversion and addition of velocities. Relativistic momentum. A relativistic expression for energy. The relationship between mass and energy. Rest. Zero-mass particles. Limits of applicability of Newtonian mechanics.

Topic 8. Gravity

The law of universal gravitation. The gravitational field. Cosmic speeds. The theory of relativity.

2.2. Thermodynamics and molecular physics

Topic 1. Temperature

Temperature and thermodynamic equilibrium. Thermoscope and temperature points. Empirical temperature scales. Ideal-gas temperature scale. Types of thermometers. International practical Temperature scale. Laws of ideal gases. The equation of state and its consequences for infinitesimal processes. Macroscopic parameters.

Topic 2. The first beginning of thermodynamics

Quasi-static processes. Macroscopic work. The first beginning of thermodynamics for a system in an adiabatic shell. Internal energy. The amount of heat. Mathematical formulation of the first principle of thermodynamics. Hess ' law. Heat capacity. The internal energy of an ideal gas. Joule's law. The Robert Mayer equation. Adiabatic process. The Poisson equation. Determination of Cp/Cv by the Clement and Desormat method. The speed of sound in gases. The Bernoulli equation. The rate of gas outflow from the hole.

Topic 3. The second beginning of thermodynamics

Various formulations of the main postulate expressing the second principle of thermodynamics. Reversible and irreversible processes. The Carnot cycle and Carnot's theorem. Thermodynamic temperature scale. The identity of the thermodynamic temperature scale with the scale of the ideal gas thermometer. Bringing the gas thermometer scale to the thermodynamic scale. The Clausius inequality (for the special case). The Clausius inequality in general. The principle of dynamic heating. The Clausius equality. Entropy. The law of increasing entropy. Generalization of the concept of entropy to nonequilibrium states. The increase in entropy during the diffusion of gases. The Gibbs paradox. Thermodynamic functions. Thermodynamic theory of the Joule-Thomson effect. Maximum work and free energy. Electromotive force of the galvanic cell. General criteria for thermodynamic stability. The Le Chatelier-Brown principle and the stability of thermodynamic equilibrium.

Topic 4. Thermal conductivity

The equation of thermal conductivity. Stationary problems of thermal conductivity. Non-stationary problems. The uniqueness theorem. The principle of superposition of temperatures. Temperature waves. The problem of cooling the half-space. External heat transfer.

Topic 5. Molecular-kinetic theory of matter

Gas pressure from the point of view of molecular-kinetic theory. The velocity of the thermal motion of gas molecules. The pressure of the photonic gas. Molecular-kinetic meaning of temperature. Uniform distribution of the kinetic energy of thermal motion over translational degrees of freedom. Uniform distribution of kinetic energy over degrees of freedom. Brownian motion. Rotational Brownian motion The classical theory of the heat capacity of ideal gases of the molecular-kinetic theory of matter. Adiabatic heating and cooling of a gas from the point of view of molecular kinetic theory. Classical theory of the heat capacity of solids (crystals). The insufficiency of the classical theory of heat capacities. The concept of quantum theory (qualitative consideration).

Topic 6. Statistical

distributions The velocity distribution of a gas molecule. Maxwell's law of velocity distribution. Distribution of molecules by absolute values of velocities. Average molecular

velocities. The principle of detailed equilibrium. Boltzmann distribution law. Entropy and probability. Fluctuations. The most probable distribution method in Boltzmann statistics. Fermi-Dirac and Bose-Einstein statistics. Nernst's theorem. Einstein's quantum theory of heat capacities.

Topic 7. Transport phenomena in gases

Average free run length. Effective cross-section. Attenuation of the beam of molecules in the gas. Viscosity and thermal conductivity of gases. Self-diffusion in gases. The relation of diffusion to the mobility of a particle. Concentration diffusion in gases. Brownian motion as a diffusion process. Thermal diffusion in gases. Phenomena in rarefied gases. Molecular flow of ultra-rarefied gas through a straight pipe.

Topic 8. Real gases

Molecular forces and deviations from the laws of ideal gases. The Van der Waals equation.The Diterici equation. Van der Waals gas isotherms. Isotherms of real gas. Maxwell's rule. Continuity of the gaseous and liquid states of matter. Properties of a substance in a critical state. Determination of critical parameters. The internal energy of the Van der Waals gas. The Joule-Thomson effect for Van der Waals gas. Methods for obtaining low temperatures and liquefying gases.

Topic 9. Surface tension

Thermodynamics of surface tension. The pressure difference on different sides of the curved surface of the liquid. The Laplace formula. Capillary-gravitational waves of small amplitude.

Topic 10. Phase equilibria and phase transformations

Phases and phase transformations. The condition of the equilibrium of the phases of a chemically homogeneous substance. The Clapeyron-Clausius equation. Evaporation and condensation. Melting and crystallization. The dependence of the saturated steam pressure on the temperature. The heat capacity of saturated steam. Triple points. Status diagrams. Boiling and overheating of the liquid. The dependence of the saturated vapor pressure on the curvature of the liquid surface. Metastable states. Phase transformations of the second kind. Convective stability of liquids and gases.

Topic 11. Solutions

Solubility of bodies. Osmosis and osmotic pressure. Raoul's law. Raising the boiling point and lowering the freezing point of the solution. The phase rule. Diagrams of the state of binary mixtures.

Topic 12. Symmetry and structure of crystals

The symmetry of bodies. Crystal lattices. Crystal systems. Spatial groups and crystal classes of crystals. Miller indices and direction indices. Lattices of chemical elements and compounds. Defects in crystals.

2.3. General physics course. Electricity

Topic 1. Electric field in a vacuum

Electric charge. Coulomb's law. Electric field. Field strength. Potential. The interaction energy of the charge system. The relationship between the electric field strength and the potential. Dipole. . The field of the charge system at large distances.

Description of the properties of vector fields. Circulation and rotor of the electrostatic field. Gauss ' theorem.

Topic 2. Electric field in dielectrics

Polar and nonpolar molecules. Polarization of dielectrics. The field inside the dielectric. Volume and surface bound charges. The electric displacement vector. Conditions at the boundary of two dielectrics. The forces acting on the charge in the dielectric. Ferroelectrics.

Topic 3. Conductors in the electric field

The balance of charges on the conductor. A conductor in an external electric field. Electrical capacity. Capacitors.

Topic 4. Electric field energy

The energy of a charged conductor. The energy of a charged capacitor. The energy of the electric field.

Topic 5. Direct electric current

Electric current. The continuity equation. Electromotive force. Ohm's law. Resistance of the conductors. Ohm's law for an inhomogeneous section of a chain. Branched chains. The Kirchhoff rules. Current power. The Joule —Lenz law.

Topic 6. Magnetic field in a vacuum

Interaction of currents. Magnetic field. The field of a moving charge. The Bio-Savard law. The Lorentz force. Ampere's law. Magnetic interaction as a relativistic effect. A circuit with a current in a magnetic field. The magnetic field of the circuit with current. The work performed when moving a current in a magnetic field. Divergence and magnetic field rotor. The field of the solenoid and toroid.

Topic 7. Magnetic field in matter

Magnetization of a magnet. The strength of the magnetic field. Calculation of the field in magnets. Conditions at the boundary of two magnets. Types of magnets. Magnetomechanical phenomena. Diamagnetism. Paramagnetism. Ferromagnetism.

Topic 8. Electromagnetic induction

The phenomenon of electromagnetic induction. Electromotive force of induction. Methods for measuring magnetic induction. The Foucault currents. The phenomenon of self-induction. Current when the circuit is closed and opened. Mutual induction. The energy of the magnetic field. Operation of the ferromagnet remagnetization.

Topic 9. Maxwell's equations

Vortex electric field. Offset current. Maxwell's equations.

Topic 10. Motion of charged particles in electric and magnetic fields

The motion of a charged particle in a uniform magnetic field. Deflection of moving charged particles by electric and magnetic fields. Determination of the charge and mass of the electron. Determination of the specific charge of ions. Mass spectrographs. Charged particle accelerators.

Topic 11. Classical theory of electrical conductivity of metals

The nature of current carriers in metals. Elementary classical theory of metals. The Hall effect.

Topic 12. Electric current in gases

Independent and independent conductivity. Non-independent gas discharge. Ionization chambers and meters. Processes that lead to the appearance of current carriers during independent discharge. Gas-discharge plasma. Smoldering discharge. Arc discharge. Spark and corona discharges.

Topic 13. Electrical oscillations

Quasi-stationary currents. Free oscillations in the circuit without active resistance. Free damped oscillations. Forced electrical oscillations. Alternating current.

2.4. Solid state physics

Topic 1. Crystal structure and methods of its determination

Point symmetry of crystals. The spatial lattice of the crystal. Translational symmetry of crystals. Crystallographic coordinate systems of Bravais translational lattices. Crystallographic symbols of nodal planes and straight lines. Translational elements of symmetry. The inverse lattice. Basic concepts of crystal chemistry. Methods for determining the atomic structure of solids. Symmetry and physical properties of crystals.

Topic 2. Interatomic interaction. The main types of bonds in solids

Classification of solids. Types of communication. The binding energy. Molecular crystals. Ionic crystals. Covalent crystals. Metals.

Topic 3. Defects in solids

Classification of defects. Thermal point defects. Equilibrium concentration of point defects. Thermal defects in binary crystals. Radiation defects. Dislocations. Contour and Burgers vector. The stresses required for the formation of a dislocation in a perfect crystal. Movement of dislocations. Stresses associated with dislocations. Dislocation energy. Interaction of dislocations with point defects. Sources of dislocations. Packaging defects and partial dislocations. Grain boundaries.

Topic 4. Mechanical properties of solids

Stress and strain states of solids. Elasticity. Hooke's law for isotropic solids. Hooke's law for anisotropic solids. Plastic properties of crystalline solids. Brittle destruction.

Topic 5. Vibrations of the atoms of the crystal lattice

One-dimensional vibrations of a homogeneous string. Elastic waves in single crystals. Oscillations of a monatomic linear chain. Oscillations of a one-dimensional lattice with a basis. Vibrations of atoms in a three-dimensional lattice.

Topic 6. Thermal properties of solids

The heat capacity of solids. The law of Dulong-Petit. Einstein's theory of heat capacity. Debye's theory of heat capacity. Derivation of the formula for the heat capacity, based on the concept of phonons. The heat capacity of metals. Thermal expansion of solids. Thermal conductivity of solids. Thermal conductivity due to atomic vibrations. Thermal conductivity of metals. Diffusion in solids.

Topic 7. Fundamentals of the band theory of solids

Classification of solids by electrical conductivity. The Schrodinger equation for a solid. One-electron approximation of the Bloch Function. Properties of the electron wave vector in a crystal. Brillouin zones. The Fermi surface. The energy spectrum of electrons in a crystal. The Kronig-Penny model. Filling the zones with electrons. Metals, dielectrics,

and semiconductors. The effective mass of the electron. Energy levels of impurity atoms in a crystal. Localized states associated with the surface.

Topic 8. Electrical properties of solids

Basic properties of metals. Electrical conductivity of metals. The intrinsic conductivity of semiconductors. The conductivity of impurity semiconductors. Electrical conductivity of dielectrics. Properties of solids in strong electric fields. The Hall effect. Influence of surface levels on the electrical properties of solids.

Topic 9. Properties of dielectrics

Polarization of dielectrics. Electronic elastic polarization. Ionic elastic polarization. Dipole elastic polarization. Features of thermal polarization. Ionic thermal polarization. Electronic thermal polarization. Dipole thermal polarization. The relationship between permittivity and polarizability. Frequency dependence of the permittivity. Some features of the polarization of non-centrosymmetric dielectrics. Ferroelectrics. Dielectric losses.

Topic 10. Magnetic properties of solids

Classification of magnets. The nature of diamagnetism. The nature of paramagnetism. Diamagnetism and paramagnetism of solids. Ferromagnetism. The Weiss molecular field. The Dorfman experience. Exchange interaction and its role in the occurrence of ferromagnetism. Spin waves. Antiferromagnetism and ferrimagnetism. Ferromagnetic domains. Magnetic resonance.

Topic 11. Superconductivity

Zero resistance. The temperature of the superconducting transition. Perfect diamagnetism. Critical magnetic field. Crystal structure and isotopic effect. Electronic contribution to the heat capacity. Absorption of electromagnetic radiation. Quantization of the magnetic flux. Josephson effects. High-temperature superconductivity. The theory of superconductivity by F. and G. Londonov. The Ginzburg-Landau theory. The attraction between the electrons. Cooper pairs. The Bardeen—Cooper—Schrieffer theory.

Topic 12. Optical properties of solids

Types of interaction of light with a solid. Optical constants. Light absorption by crystals. Recombination radiation in semiconductors. Spontaneous and induced radiation. Solid-state lasers.

Topic 13. Physical properties of amorphous solids

Structure of amorphous solids. Energy spectrum of non-crystalline solids. Amorphous semiconductors. Application of amorphous semiconductors. Amorphous dielectrics. Amorphous metals.

3. List of recommended literature

3.1 Кириченко Н.А., Крымский К.М. Общая физика. Механика: учебное пособие. – М.: МФТИ, 2013. – 290 с.

3.2 Савельев, И.В. Курс общей физики. В 3 т. Т. 1. Механика. Молекулярная физика / И.В. Савельев. – СПб.: Лань, 2016. – 432 с.

3.3 Кириченко II. А. Термодинамика, статистическая н молекулярная физика/ Учебное пособие. 3-е изд. – М.: Физматкнига, 2005. – 176 с.

3.4 Сивухин Д.В. Общий курс физика. Т. II. Термодинамика и молекулярная физика. – М.: ФИЗМАТЛИТ, 2005. – 352 с.

3.5 Савельев, И.В. Курс общей физики. В 3 т. Т. 1. Механика. Молекулярная физика / И.В. Савельев. – СПб.: Лань, 2016. – 432 с.

3.6 Савельев И.В. Курс общей физики, том II. Электричество и магнетизм, – СПб.: Лань, 2011. – С.352.

3.7 Павлов П.В., Хохлов А.Ф. Физика твердого тела. – М.: Высшая школа. – 3-е изд. – М., 2000. – 494 с.