ENTRANCE EXAMINATION PROGRAM

FOR LANDAU PHYSTECH SCHOOL OF PHYSICS AND RESEARCH
PHYSICAL SCIENCES
COMPETITIVE GROUP

FOR APPLICANTS ENTERING PHD PROGRAMS

At the entrance examination applicants will be asked questions on their final qualifying work and questions from the section corresponding to specialty of their future research activity.

Questions on the final qualifying work (master or specialist's degree):

1. Main provisions.
2. Novelty.
3. Relevance.

PLANETARY RESEARCH SECTION

1.Elements of the physics of planetary atmospheres

- 1.1.Vertical structure of planetary atmospheres. Troposphere, stratosphere, mesosphere, thermosphere. Homosphere and heterosphere. Exosphere. Comparative analysis of the structure of the atmospheres of Venus, Earth, Mars and Jupiter.
- 1.2.General circulation of planetary atmospheres. Equations of hydrodynamics on a rotating sphere. Two modes of general circulation. Hadley cells and jet streams. Thermal wind. planetary boundary layer. The concept of hydrodynamic models of planetary atmospheres.
- 1.3.Waves in the atmosphere of the planet. Barotropic and baroclinic modes. Internal gravitational waves. Gravitational and thermal tides. Rossby waves.
- 1.4.Turbulent motion in atmospheres. Kolmogorov's spectrum. Convective and shear instability. Richardson number. Turbulent boundary layer. Turbulent exchange coefficients.
- 1.5.Spectroscopy of atmospheric gases. Basic laws of rotational, vibrational-rotational and electronic spectra of molecules. Spectroscopic databases. Emission and absorption processes, line broadening mechanisms in planetary atmospheres. Local thermodynamic equilibrium.
- 1.6.Aeronomy. Chemical processes in planetary atmospheres. Dissociation. Ionization. The structure of the upper atmospheres of the planets. Ionosphere.
- 1.7.Aerosols in planetary atmospheres. Clouds, aerosol haze, their types, formation processes. Microphysical processes.

2.Spectroradiometer methods for studying planets

2.1. Line radiative transfer. Growth curves. True absorption and scattering at different levels of the atmosphere. Formation of the spectrum of the outgoing thermal radiation of the planet.
2.2. Optical properties of clouds and aerosols. Mie theory.
2.3. Devices for remote sensing of planets in the optical range of the spectrum. UV, visible and IR radiation receivers. Diffraction spectrometers. Fourier spectrometers. Acousto-optic filtering of

radiation. Mapping spectrometers. High-resolution spectroscopy for planetary studies: Echelle spectrometers, Fabry-Pérot interferometers, heterodyne spectrometers.

3. Objects of the Solar System
3.1. Mercury. Orbital characteristics. The concept of planetary radar, its role in the study of Mercury. The surface of Mercury, the main features of its structure. Space expeditions Mariner-10, Messenger.
3.2. Venus. Surface. Composition and vertical structure of the atmosphere. The main characteristics of the cloud layer. Thermal regime of the lower atmosphere. Dynamics
atmosphere. Radio emission. Upper atmosphere. The problem of climate evolution. Space expeditions to Venus from Venera 4 to Venera Express.
3.3. Earth as a planet. The concept of tectonics. Atmospheric and oceanic circulation. Hydrosphere and biosphere. Their influence on the characteristics of the atmosphere and climate. Greenhouse effect. The problem of climate stability.
3.4. Moon. Structure and evolution of the surface. Hypotheses of the origin of the moon. Volatile elements problem. Discovery of water ice on the Moon. Apollo Moon exploration program
modern spacecraft research (LRO, Chandrayaan, Luna-Resource).
3.5. Mars. Relief, surface, models of the internal structure. Composition of the atmosphere, its vertical structure and dynamics. Atmospheric aerosol, clouds, dust storms. The problem of paleoclimate. Exploration of Mars with the help of spacecraft.
3.6. Jupiter. Composition and structure of the atmosphere. The nature of the cloud layer. The phase state of the subsoil. Atmospheric dynamics, belts and zones. Comet Shoemaker-Levy colliding with Jupiter. Magnetosphere. Voyager and Galileo missions.
3.7. Jupiter's Galilean moons: Io, Europa, Ganymede and Callisto. Their orbits, surface, atmospheres, models of internal structure. Exospheres of the Galilean moons of Jupiter.
3.8. Saturn. Models of the internal structure. Features of the dynamics of the atmosphere. The system of rings and moons of Saturn. Voyager and Cassini missions.
3.9. Moons of Saturn. Titanium: composition, vertical structure and dynamics of the atmosphere. Aerosol component of Titan's atmosphere. The concept of the hydrocarbon cycle. Huygens mission. Enceladus: orbit, surface, internal structure, cryovolcanism.
3.10. Uranus and Neptune. Features of heat balance, atmospheric dynamics, internal structure. magnetic fields. Systems of rings and moons. Voyager mission.
3.11. Minor planets. Main belt. Motion, Lagrange points, resonances.
3.12. Comets, their classification. Modern concepts of comet nuclei. Oort cloud. Kuiper belt. Pluto-Charon system. Space exploration of comets. Vega, Giotto and Rosetta missions.

4. Extrasolar planetary systems
4.1. Modern ideas about the formation and early evolution of the solar system. Characteristics of stars with planetary systems.
4.2. Extrasolar planetary systems. Detection methods and typical characteristics of extrasolar planets. Models of exoplanet atmospheres.
4.3. The concept of the habitable zone. Search for extrasolar terrestrial planets.

Reference

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3. Витязев А.В., Печерников Г.В., Сафронов В.С., Планеты земной группы, М., Наука, 1990.
4. Герцберг Г. Спектры и строение двухатомных молекул, М., ИЛ, 1949 (гл. 1 - 4).
5. Голицын Г.С. Введение в динамику планетных атмосфер. Л., Гидрометеоиздат, 1973.
6. Горькавый Н.Н., Фридман А.М. Физика планетных колец. М., Наука,1994
7. Гуди Р. Атмосферная радиация. М., Мир, 1966.
8. Гуди Р., Дж Уокер. Атмосферы. М., Мир, 1975.

9. Жарков В.Н. внутреннее строение Земли и планет. М., Мир, 1978.
10. Жарков В.Н. и Мороз В.И. Почему Марс? Природа, № 6, 58-67, 2000
11. Ипатов С.И. Миграция небесных тел в Солнечной системе. М., «Эдиториал УРСС», 2000(гл. 1).
12. Космонавтика, Энциклопедия. Под ред. В.П. Глушко. М., Наука, 1978, «Советская энциклопедия», 1985
13. Краснопольский В.А. Фотохимия атмосфер Марса и Венеры. М., Наука, 1982.
14. Мороз В.И. Физика планет. М., Наука, 1967 (гл. 1 и раздел 4.3).
15. Мюррей К., Дермотт С. Динамика Солнечной системы, Москва, Физматлит, 2009.
16. Соболев В.В. Перенос излучения в атмосферах звезд и планет. М., ГТТИ, 1956.
17. Соболев В.В. Рассеяние света в атмосферах планет. М., Наука, 1972.
18. Соболев В.В. Курс теоретической астрофизики. М., Наука, 1975.
19. Тверской П.Н. Курс метеорологии (физика атмосферы), Л., Гидрометеоиздат, 1962.
20. Чемберлен Дж. Теория планетных атмосфер. М., Мир, 1981.
21. Физика космоса. Маленькая энциклопедия. Под ред. Р.А. Сюняева, М., «Советскаяэнциклопедия», 1986.
22. Левантовский В.К. Механика космического полета. М., Мир, 1975.
23. Encyclopedia of the Solar system (second edition), edited by McFadden L.-A., Weissman P.R.,Johnson T.V., Elsevier, 966, 2007.
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26. Sanchez-Lavega A., An Introduction to Planetary Atmospheres, CRC press: Taylor & Francis,629 с., 2010.
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Additional literature

1. Александров Ю.В. Введение в физику планет. Киев, Вища школа, 1982.
2. Барсуков В.JI. (ред) Планета Венера. М., Наука, 1989.
3. Боярчук А.А. (ред) Угроза с неба: рок или случайность? М., Космоинформ, 1999.
4. Гуди Р. Атмосферная радиация. М., Мир, 1966.
5. Дейменджан Д. Рассеяние электромагнитного излучения сферическимиполидисперсными частицами. М., Мир, 1971.
6. Ельяшевич М.А. Атомная и молекулярная спектроскопия. М., Наука,1962; М., ЭдиториалУРСС, 2001 (2-е изд.).
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21. Сурков Ю.А. Космические исследования планет и спутников. М., Наука, 1985.
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23. Шульман Л.М. Ядра комет. М., Наука, 1978.
24. Юпитер. Сб. под ред. Т. Герелса. М., Мир, 1978.
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31. Jupiter. The planet, satellites and magnetosphere, Edited by F. Bagenal, T.Dowling,W.McKinnon, CAMBRIDGE UNIVERSITY PRESS, 719 c, 2006.
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35. Rodgers C.D. Inverse methods for atmospheric sounding. Theory and practice. World scientific,240 c., 2000.

THEORETICAL PHYSICS SECTION

1. Mechanics

1.1. Equations of motion. Generalized coordinates, stationary-action principle, Lagrange function. Symmetries. Noether's theorem. Laws of conservation of energy, momentum, angular momentum.

1.2. Integration of the equations of motion. One-dimensional motion, reduced mass, motion in a central field.

1.3. Particle decay, elastic collisions. Particle scattering cross section, Rutherford scattering.

1.4. Small oscillations. Free and forced one-dimensional vibrations, parametric resonance. Oscillations of systems with many degrees of freedom, polar coordinates. Oscillations in the presence of friction.

1.5. Motion of rigid bodies. Angular velocity, moment of inertia and angular momentum of rigid bodies. Euler angles and the Euler equation.

1.6. Canonical equations, Hamilton equation, Poisson brackets, action as a function of coordinates, Liouville's theorem. Hamilton-Jacobi equation, separation of variables.

1.7. The principle of relativity. The rate of propagation of interactions. Interval. Proper time. Lorentz transformation. Speed conversion. 4D vectors. 4D speed.

1.8. Relativistic mechanics. Stationary-action principle. Energy and momentum. Disintegration of particles. Elastic collisions of particles.

1.9. Equations of motion. Generalized coordinates, stationary-action principle, Lagrange function. Conservation laws, energy, momentum, angular momentum. Integration of the equations of motion. One-dimensional motion, reduced mass, motion in a central field. Particle decay, elastic collisions, particle scattering cross sections, Rutherford formula. Small fluctuations. Free and forced one-dimensional oscillations, oscillations of systems with many degrees of freedom, normal coordinates. Motion of rigid bodies. Angular velocity, moment of inertia, angular momentum of rigid bodies. Euler angles and the Euler equation. Canonical variables, Hamilton-Jacobi equation, separation of variables. Action-angle variables. adiabatic invariant.

2. Field theory.

2.1. Charge in an electromagnetic field. Four-dimensional field potential. Equations of motion of a charge in a field, gauge (gradient) invariance. Electromagnetic field tensor. Lorentz transformation for the field. Field invariants.

2.2. Action for an electromagnetic field. Electromagnetic field equations. 4D current vector. Continuity equation. Density and energy flow. The energy-momentum tensor. The energy-momentum tensor of the electromagnetic field.
2.3. Constant electromagnetic field. Coulomb's law. Electrostatic energy of charges. Dipole moment. Multipole moments. System of charges in an external field. Permanent magnetic field. magnetic moment. Larmor theorem.
2.4. Electromagnetic waves. wave equation. Flat waves. Monochromatic plane wave. Spectral decomposition. Polarization characteristics of radiation. Decomposition of the electrostatic field.
2.5. The field of moving charges. Retarded potentials. Liénard-Wiechert potentials. Radiation of electromagnetic waves. The field of a system of charges at long distances. Multipole radiation. Radiation from a fast-moving charge. Scattering by free charges.
2.6. Motion of a particle in a gravitational field. Metrics. Covariant differentiation. Christoffel symbols. Action for a particle in a gravitational field.
2.7. Einstein field equations. Riemann curvature tensor. Action for the gravitational field. The energy-momentum tensor. Einstein's equations.
2.8. Non-relativistic limit of Einstein's equations. Newton's law. Centrally symmetric gravitational field. Schwarzschild metric. Gravitational collapse.
2.9. Observable effects of general relativity in the Newtonian and post-Newtonian approximations (gravitational redshift, light beam deflection, signal delay, gyroscope precession, planetary orbit precession). Gravity lenses.
2.10. Relativistic cosmology. Open, closed and flat models. Hubble’s law. Expansion of the universe at radiation-dominated, dust-like and vacuum-dominated stages.
2.11. Physical processes in the early universe. Neutrino quenching. Primary nucleosynthesis. Recombination, relic photons.
2.12. The principle of relativity. The rate of propagation of interactions. Interval. Proper time. Lorentz transformation. Speed conversion. 4D vectors. 4D speed. The principle of least action. Energy and momentum. Disintegration of particles. Elastic collisions of particles. Charge in an electromagnetic field. Four-dimensional field potential. Equations of motion of a charge in a field, gradient invariance. Electromagnetic field tensor. Lorentz transformation for the field. Field invariants. Electromagnetic field equation. The first pair of Maxwell's equations. Action for an electromagnetic field. 4D current vector. Continuity equation. The second pair of Maxwell's equations. Density and energy flow. The energy-momentum tensor of the electromagnetic field. Constant electromagnetic field. Coulomb's law. Electrostatic energy of charges. Dipole moment. Multipole moments. System of charges in an external field. Permanent magnetic field. magnetic moment. Larmor theorem. Electromagnetic waves. wave equation. Flat waves. Monochromatic plane wave. Spectral decomposition. Decomposition of the electrostatic field. The field of moving charges. Retarded potentials. Liénard-Wiechert potentials. Spectral decomposition of retarded potentials. Radiation of electromagnetic waves. The field of a system of charges at long distances. Dipole radiation. Radiation from a fast-moving charge. Synchrotron radiation.

3. Electrodynamics of continuous media
3.1. Electrostatics of dielectrics and conductors. Dielectric permittivity and conductivity. Thermodynamics of dielectrics. Magnetic properties. Permanent magnetic field. Magnetic field of direct currents. Thermodynamic relations. Dia-, para-, ferro- and antiferromagnets.
3.2. Superconductors. Magnetic properties. Superconducting current. Critical field.
3.3. Equations of electromagnetic waves. Field equations in the absence of dispersion. Dispersion of the permittivity. Kramers-Kronig relations. Plane monochromatic wave. Propagation of electromagnetic waves. Reflection and refraction. The principle of reciprocity.

3.4. Electromagnetic waves in anisotropic media. Kerr and Faraday effects. Spatial dispersion. Natural optical activity.
3.5. Magnetic hydrodynamics. MHD waves. Dynamo problem.

3.6. Nonlinear optics. Nonlinear permeability. Self-focusing. Second-harmonic generation.
3.7. Ionization losses of fast particles. Cherenkov radiation. Scattering of electromagnetic waves in media. Rayleigh scattering.
3.8. Electrostatics of conductors. Electrostatic field of conductors. Energy of the electrostatic field of conductors. Electrostatics of dielectrics. Electrostatic field in dielectrics. The dielectric constant. Thermodynamics of dielectrics and ferroelectrics. Direct current. Current density and conductivity. Permanent magnetic field. Magnetic field of direct currents. Thermodynamic relations in a magnetic field. Ferromagnetism. Ferromagnets and ferroelectrics near the Curie point. Superconductivity. Magnetic properties of superconductors. superconducting current. critical field. Quasi-stationary electromagnetic field. Eddy currents: skin effect. Complex resistance. The equation of electromagnetic waves. Field equations in the absence of dispersion. Dispersion of the permittivity. Dielectric permittivity at high frequencies. Relationship between real and imaginary parts of permeability. Plane monochromatic wave. Propagation of electromagnetic waves. Reflection and refraction of waves. The principle of interconnection. Passage of fast particles through matter. ionization losses. Vavilov-Cherenkov radiation and transition radiation. Magnetic hydrodynamics. Freezing-in. MHD waves.

4. Continuum mechanics and physical kinetics
4.1. Ideal liquid. Continuity equation. Euler equation. Energy flow. Stream of impulse. Preservation of circulation speed. Potential flow around bodies: added mass, drag force, Magnus effect.
4.2. Viscous liquid: equations of motion of a viscous liquid. Energy dissipation in an incompressible fluid.
4.3. Transition to turbulence. Instabilities of laminar flows. Landau-Hopf theory. Types of attractors. Strange attractor. Transition to turbulence by doubling periods. developed turbulence. Turbulence spectrum in the viscous interval. Kolmogorov spectra.
4.4. Sound. Sound waves. Geometrical acoustics.
4.5. One-dimensional motion of a compressible gas. Characteristics. Riemann invariants. Simple Riemann wave. The formation of shock waves. shock adiabat. Weak discontinuities. The strong explosion theory.
4.6. Shock waves of low intensity. Burgers' equation.
4.7. Sound waves with weak dispersion. KdV equation. Solitons and their interaction. Collisionless shock waves.
4.8. Hydrodynamics of a superfluid liquid. Two-fluid description.
4.9. Kinetic theory of gases. Boltzmann equation. H-theorem. Thermal conductivity and viscosity of gases. Symmetries of kinetic coefficients. diffusion approximation. Fokker-Planck equation.
4.10. Collisionless plasma. Vlasov equations. Dielectric permittivity of a collisionless plasma. Landau damping. Langmuir and ion-sound waves. Beam instability: hydrodynamic and kinetic stages. Quasilinear theory.
4.11. Collisions in plasma. Landau collision integral. The path length of particles in plasma.
4.12. Ideal liquid. Euler equation. Continuity equation. Hydrostatics. The condition for the absence of convection. Bernoulli equation. Energy flow. Stream of impulse.

5. Quantum mechanics
5.1. Fundamentals of quantum mechanics. The principle of uncertainty. The principle of superposition. Operators. Discrete and continuous spectra. Hamiltonian. Stationary states. Heisenberg picture. Uncertainty relations.

5.2. Schrödinger equation. Basic properties of the Schrödinger equation. One-dimensional movement. One-dimensional oscillator. Flux density. Semiclassical wave function. Passing through the barrier.
5.3. Moment of momentum. Eigenfunctions and eigenvalues of the angular momentum. Parity. Addition of moments. Clebsch-Gordan decomposition.
5.4. Movement in the central field. Spherical waves. Decomposition of a plane wave. Radial Schrödinger equation. Hydrogen atom.
5.5. Perturbation theory. Perturbations that do not depend on time. Periodic perturbations. Semiclassical perturbation theory.
5.6. Spin. Spin operator. Fine structure of atomic levels.
5.7. Identity of particles. Permutation symmetry of particles. Second quantization for bosons and fermions. Exchange interaction.
5.8. Atom. The state of the electrons of an atom. Energy levels. Self-consistent field. Thomas-Fermi equation. Fine structure of volume levels. Periodic system of Mendeleev.
5.9. Movement in a magnetic field. Schrödinger equation for motion in a magnetic field. Flux density in a magnetic field.
5.10. Collisions of particles. General theory. Bohr formula. Resonant scattering. Collision of identical particles. Elastic scattering in the presence of inelastic processes. Scattering matrix. Breit-Wigner formula.
5.11. Basic concepts of quantum mechanics. Measurement process and complementarity principle. Uncertainty principle. The principle of superposition. Operators, their addition and multiplication. Discrete and continuous spectrum. Operators of energy and momentum. Hamiltonian and differentiation of operators with respect to time. Stationary states. Representation of operators in the form of matrices. Heisenberg representation. Momentum operator. Uncertainty relation. Schrödinger equation. Basic properties of the Schrödinger equation. One-dimensional movement. One-dimensional oscillator. Flux density. Semiclassical wave function. Passing through the barrier. Moment of momentum. Eigenfunctions and eigenvalues of the angular momentum. Parity. Addition of moments. Movement in the central field. Spherical waves. Decomposition of a plane wave. Radial Schrödinger equation. Perturbation theory. Perturbations that do not depend on time. secular equation. Perturbations depending on time. Periodic perturbations. Spin. Spin operator. Identity of particles. The principle of indistinguishability. Symmetry in the permutation of particles. exchange interaction. Second quantization for bosons and fermions. Atom. The state of electrons in an atom. Energy levels. Self-consistent field. Thomas-Fermi equation. Fine structure of atomic levels. Periodic system of Mendeleev. Movement in a magnetic field. Schrödinger equation for motion in a magnetic field. Flux density in a magnetic field.

6. Statistical physics
6.1. Basic principles of statistics. Distribution function and density matrix. statistical independence. Liouville's theorem. The role of energy. Entropy increase law. Microcanonical distribution. Gibbs distribution. Gibbs distribution with a variable number of particles.
6.2. Thermodynamic quantities. Temperature. work and heat. Thermodynamic potentials. Thermodynamic inequalities. Le Chatelier's principle. Nernst's theorem. Systems with a variable number of particles. Free energy in the Gibbs distribution. Derivation of thermodynamic relations.
6.3. Thermodynamics of ideal gases. Boltzmann distribution. Collision of molecules. Non-equilibrium ideal gas. The law of equipartition.
6.4. Fermi and Bose distribution. Degenerate ideal Fermi gas. Properties of matter at high densities. Degenerate Bose gas. Bose-Einstein condensation. Equilibrium thermal radiation. Planck’s law. Blackbody radiation.

6.5. Non-ideal gases and condensed media. Phonon spectra and thermodynamic properties of gas. Thermodynamic properties of an ideal classical gas.
6.6. Phase balancing. Clausis Clapeyron equation. Critical point.
6.7. Systems with different particles. Phase rule. Weak solutions. Mixture of ideal gases. mixture of isotopes. Chemical reactions. The condition of chemical equilibrium. The law of active masses. Heat of reaction. Ionization equilibrium.
6.8. Weakly imperfect Bose gas. Bogolyubov model. Excitation spectrum. Superfluidity. Quantum vortex.
6.9. Solids. Crystal structures. Fermi surface. Zone structure. Quasiparticles.
6.10. Lattice vibrations. Theory of elasticity. Sound in solids. Processes of decay and fusion of phonons. Scattering of phonons on impurities. Kinetic equation for phonons. Thermal conductivity.
6.11. Superconductivity. Cooper pair. BCS theory. London Theory. Ginzburg-Landau theory. Current, gauge invariance, flux quantization. Superconductors of the first and second kind. Josephson effect.
6.12. Fluctuations. Gibbs distribution. Fluctuations of basic thermodynamic quantities. Poisson formula. Temporary fluctuations. Symmetries of kinetic coefficients. Fluctuation-dissipation theorem.
6.13. Phase transitions of the second kind. Landau's theory. Critical indices. Scale invariance. Fluctuations in the vicinity of the critical point.
6.14. Basic principles of statistics. Statistical distribution. Statistical independence. Liouville's theorem. The role of energy. Entropy. The law of entropy increase. Thermodynamic quantities. Temperature. adiabatic process. Pressure. Work and heat. Thermodynamic potentials. Maximum work. Thermodynamic inequalities. Le Chatelier's principle. Nernst's theorem. System with a variable number of particles. Equilibrium of a body in an external field. Gibbs distribution. Free energy and the Gibbs distribution. Derivation of thermodynamic relations. Thermodynamics of ideal gases. Boltzmann distribution. Collision of molecules. Non-equilibrium ideal gas. Free energy and the equation of state. The law of equipartition. Monatomic ideal gas. Fermi and Bose distribution. Non-equilibrium Fermi and Bose gases. Fermi and Bose gases of elementary particles. Degenerate electron gas. Degenerate Bose gas. Condensed bodies. Solids. Debye interpolation formula. Thermal expansion of solids. Phonons. Non-ideal gases. Deviation from ideal gas behavior. Van der Waals formula. Phase balance. Phase equilibrium conditions. Clausius-Claiperon relation. Critical point. System with different particles. Phase rule. Weak solutions. Mixture of ideal gases. Mixture of isotopes. Chemical reactions. The condition of chemical equilibrium. The law of active masses. Heat of reaction. Ionization equilibrium. Fluctuations. Gaussian distribution. Fluctuations of basic thermodynamic quantities. Fluctuations in an ideal gas. Poisson formula.

7. Physical Kinetics

Gibbs Ensemble. Distribution function. Liouville equation. Boltzmann equation. Fokker-Planck equation. H-theorem. Statistical entropy. Ideal liquid. Continuity equation. Euler equation. Collisionless plasma: self-consistent field, quasi-neutral plasma, two-temperature plasma hydrodynamics.

8. Mathematical methods of physics

Theory of functions of a complex variable. Calculation of integrals by residues. Solving equations using contour integrals (Laplace's method). Calculation of asymptotics of integrals. Special functions (Legendre, Bessel, elliptic, hypergeometric, gamma functions).

Reference

1. Ландау Л.Д., Лифшиц Е.М. Механика. М.: Физматлит, 2001.
2. Ландау Л.Д., Лифшиц Е.М. Теория поля. М.: Наука, 1988.
3. Давыдов А. С. Квантовая механика. М.: Наука, 1973.
4. Ландау Л.Д., Лифшиц Е.М. Квантовая механика. Нерелятивистская теория. М.:Физматлит, 2001.
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6. Ландау Л.Д., Лифшиц Е.М. Электродинамика сплошных сред. М.: Физматлит, 2001.
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23. Киттель Ч. Введение в физику твердого тела. М.: Наука, 2000.
24. Абрикосов А.А., Горьков Л.П., Дзялошинский И.Е. Методы квантовой теории поля встатистической физике. М.: Физматгиз, 1962.
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26. Смирнов В.И., Курс высшей математики, Лань, СП. 2008.
27. Бейтмен Г., Эрдейи А., Высшие трансцендентные функции, Лань, СП, 2001.

RADIOPHYSICS SECTION

1. Vibration theory

1.1. Linear oscillating systems with one degree of freedom. Power and parametric effects on linear and weakly nonlinear oscillating systems.

1.2. Self-oscillating system with one degree of freedom. Energy ratios in self-oscillating systems. Methods for calculating self-oscillating systems.

1.3. Influence of a harmonic signal on self-oscillatory systems. Synchronization. Tightening and damping phenomena in vibrations. Applying a tightening to stabilize the frequency.

1.4. Analytical and qualitative methods of the theory of nonlinear oscillations. Analysis of possible motions and bifurcations in the phase space: small parameter method, Van der Pol method, Krylov-Bogolyubov method. Abridged equations. Averaging in systems containing fast and slow motions.

1.5. Oscillatory systems with two and many degrees of freedom. Normal fluctuations. Forced vibrations.

1.6. Self-oscillatory systems with two or more degrees of freedom. Mutual synchronization of oscillations of two generators.
1.7. Parametric amplification and parametric generation. Parametric amplifiers and generators. Frequency division.
1.8. Stability of stationary regimes of autonomous and non-autonomous oscillatory systems. Temporal and spectral methods for assessing stability.
1.9. Natural and forced oscillations of linear distributed systems. Eigenfunction of a system (modes). Expansion of forced oscillations in terms of the eigenfunction of a system.
1.10. Distributed self-oscillatory systems. The laser as an example of such system. Conditions for self-excitation. Single-mode and multi-mode generation modes.
1.11. Chaotic oscillations in dynamical systems. The concept of a chaotic (strange) attractor. Possible ways of stability loss in regular oscillations and transition to chaos.

2. Wave theory
2.1. Plane homogeneous and inhomogeneous waves. Plane acoustic waves in a viscous heat-conducting medium, elastic longitudinal and transverse waves in a solid, electromagnetic waves in a conductive medium. Energy flow. Polarization.
2.2. Signal propagation in a dispersive medium. The simplest physical models of dispersive media. Wave packet in the first and second approximations of the dispersion theory. Phase and group velocities. Parabolic equation for the envelope. Spreading and compression of pulses. Field in environments with temporal. Kramers-Kronig dispersion relations and the principle of causality.
2.3. Properties of electromagnetic waves in anisotropic media. Optical crystals, Fresnel equation, ordinary and extraordinary waves. Magnetoactive media. Plasma permittivity tensor in a magnetic field; normal waves, their polarization.
2.4. Waves in periodic structures. Mechanical chains, acoustic and optical phonons. Bandwidth and Opacity. Electrical chains, continuous medium with weak periodic inhomogeneities. connected waves.
2.5. Approximation of geometric optics. Eikonal equations. Differential equation of light rays. Rays and wave field in layered inhomogeneous media.
2.6. Electromagnetic waves in metal waveguides. Dielectric waveguides, light guides. Lens lines and open resonators. Gaussian beams.
2.7. Kirchhoff's method in the theory of diffraction. Green's functions. Radiation conditions. Diffraction in the Fresnel and Fraunhofer zones. Characteristics of the field at the focus of the lens.
2.8. Waves in non-linear media without dispersion. Faulting. Shock waves. Burgers’ equation for a dissipative medium and properties of its solutions. Generation of harmonics of the original monochromatic signal, the effects of nonlinear absorption, saturation and detection.
2.9. Korteweg-De Vries equation and sine-Gordon. Stationary waves. The concept of solitons. Interactions of plane waves in dispersive media. Second-harmonic generation. Parametric amplification and generation.
2.10. Self-action of wave beams. Self-focusing of light. Approximations of nonlinear quasi-optics and nonlinear geometric optics. Wave front reversal. Intense acoustic beams; parametric sound emitters.

3. Statistical radiophysics
3.1. Random variables and processes, methods of their description. Stationary random process. Statistical and time averaging. Ergodicity. Measurement of probabilities and averages.
3.2. Correlation and spectral characteristics of stationary random processes. The Wiener–Khinchin theorem. White noise and other examples of spectra and correlation functions.

3.3. Models of stochastic processes: Gaussian process, narrow band stationary noise, impulsive stochastic processes, shot noise.
3.4. Linear system response to noise impacts; Green's function, Duhamel's integral. Effect of noise on the oscillatory circuit, noise filtering. Nonlinear transformations (frequency multiplications and amplitude detection of narrow band noise).
3.5. Markov's and diffusion processes. Fokker-Planck equation.
3.6. Brownian motion. Fluctuation-dissipation theorem. Thermal noise; classical and quantum versions of the Nyquist formula. Blackbody radiation.
3.7. Random fields. Spatial and temporal coherence. Diffraction of random waves. Van Cittert–Zernike theorem. Diffraction of a regular wave by a random phase screen. Thermal electromagnetic field. Reciprocity theorem.
3.8. Scattering of waves in randomly inhomogeneous media. Born approximation, smooth perturbation method. Scattering of waves on a rough surface. The concept of the inverse scattering problem.
3.9. Interaction of random waves. Generation of the second optical harmonic, self-focusing and self-modulation of partially coherent waves. Transformation of noise wave spectra in non-linear media without dispersion.

4. Principles of amplification, generation and control of signals
4.1. The principle of operation, device and parameters of lasers (examples: helium-neon laser, ruby laser, semiconductor laser).
4.2. Optical cavity. Fabry-Pérot interforometer, confocal and concentric resonators. Unstable resonator. Longitudinal and transverse types of vibrations. Frequency spectrum and radiation divergence. Q factor.
4.3. Operating modes of lasers: continuous generation mode, resonator Q-switching mode, mode locking. Ultrashort pulses. Noise of lasers, Townes formula and limiting frequency stability. Optical compressors and obtaining femtosecond pulses.
4.4. Molecular generator. Quantum standards of frequency (time).
4.5. Waveguides, long lines and resonators. Critical frequency and critical length of the waveguide. TE-, TH- and TEM-waves. Dielectric waveguides. Periodic structures and slow systems. Wave resistance.
4.6. Microwave amplifiers (resonator, traveling wave). The bandwidth of the traveling wave amplifier.
4.7. Generation of waves in the microwave range. The principle of operation and the device of a traveling and reverse wave lamp, a magnetron and a klystron. Negative differential resistance and microwave generators based on field-effect transistors, tunnel diodes, Gunn diodes and avalanche transit diodes. Josephson effect.
4.8. Interaction of space charge waves with an acoustic field, acousto-electric effect. Principles of operation of acousto-electronic devices (ultrasound amplifiers, delay lines, filters, convolvers, memory devices).
4.9. Interactions of light with sound. Bragg and Raman-Nath diffraction. Operating principles of acousto-optic devices (light modulators and deflectors, light-signal converters, acousto-optic filters), spectrum analyzers and correlators.
4.10. Linear electro-optical and magneto-optical effects and their application to light control.

5. Antennas and radio wave propagation
5.1. Dipole antenna. Near and far zones. Radiation pattern. Gain and scattering coefficient of the antenna. Antennas for LW, MW and microwave bands. parabolic antenna. Phased antenna arrays. Effective area and noise temperature of the receiving antenna.
5.2. Geometric and diffraction approximations in the analysis of radio wave propagation. Influence of unevenness of the earth's surface. Terrestrial and tropospheric radio waves. Scattering and absorption of radio waves in the troposphere. Fading effect. Tropospheric

waveguide. Propagation of radio waves in the ionosphere. Dispersion and absorption of radio waves in ionospheric plasma. Ionospheric refraction. Ray path in the underwater sound channel and tropospheric radio waveguide.

6. Extracting signals against the background of interference

6.1. Problems of optimal signal reception. Posterior probability density. Likelihood function. Statistical testing of hypotheses. Bayes, Neyman-Pearson and Wald tests of hypotheses.

6.2. A priori information about the signal and noise. Observation and communication. Problems of interpolation, filtering and extrapolation.

6.3. Linear Kolmogorov–Wiener filtering based on error variance minimization. The principle of orthogonality of error and observation. Realizable linear filters and the Wiener-Hopf equation. Separation of signal from noise. matched filter.

6.4. Linear Kalman-Bucy filter. Stochastic equations for the message and noise model. Differential filter equations. Equation for a posteriori information in the form of the Riccati equation. Comparison of filtration by the Kolmogorov–Wiener and Kalman–Bucy methods.

6.5. The main tasks of nonlinear filtering and systems synthesis.

Reference

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22. Зверев В.А. Радиооптика. М.: Сов. радио, 1975.
23. Букингем М. Шумы в электронных приборах и системах. М.: Мир, 1986.
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OPTICS SECTION

1. Laws of geometric optics. corpuscular theory. Wave nature of light. Quantum properties of light. Photons. Energy and momentum. Scale of electromagnetic waves.
2. Solution of Maxwell's equations for an idealized dielectric medium. Polaritons. Polarization of an electromagnetic wave in a material medium. Expressions for the permittivity and linear polarizability. Electromagnetic waves in ferroelectrics and in plasma. Soft modes near points of structural phase transitions.
3. Coherent wave sources. The phenomenon of interference. Interference schemes. Interference filters and antireflection coatings. Multilayer dielectric mirrors.
4. Diffraction from slits and round holes. Microscope and telescope. Diffraction grating. Holographic gratings.
5. Reflection and refraction of light at the boundary of isotropic dielectrics. Fresnel equations. Total internal reflection. Brewster's angle. Reflection and refraction of light at the boundary: vacuum-photonic crystal.
6. Emissivity and absorption capacity. Kirchhoff's law. Completely black body. Rayleigh-Jeans formula. Planck formula. Stefan Boltzmann's law. Wien's displacement law. Thermal radiation of a photonic crystal.
7. Emission spectra of atoms, molecules and condensed media. Electroluminescence. Radioluminescence. Photoluminescence. The duration of the luminescence. Phosphorus. Luminescence spectroscopy and analytical methods. Vavilov-Cherenkov radiation. Transition and synchrotron radiation.
8. Inverse population and methods for its creation. The principle of the laser operation. Solid-state lasers. gas lasers. Control of laser radiation parameters. Generation of ultrashort pulses.
9. Spectrographs and monochromators. Raman spectrometers. Luminescence spectroscopy. Luminescent microscope. Compound microscope. Fourier spectrometers. Acousto-optical spectrometers. Polychromators. radiation receivers. Gating systems. Processing of spectral information.
10. Spontaneous and stimulated emission. Einstein coefficients. The concept of the strength of oscillators. Transitions of different multiplicity, selection rules for electric dipole, magnetic dipole and electro quadrupole radiation. Widths of energy levels and spectral lines.
11. Coherent interaction. Кesonant approach. Hamiltonian of an atom in an electromagnetic field. Dynamic field broadening. Nutations. Coherent damping. Slowly varying envelope approximation.
12. Photon echo and self-induced transparency. Polarization when exposed to two short resonant pulses. Reversible skew. The duration of the echo signal. The sine equation of Gordon. Automated solution. Solitons.
13. Spectra of hydrogen and alkali metals. Energy levels and spectra. Fine level structure. vacuum shift. Spectral series of alkali metals. Quantum defect. Doublet structure of levels.
14. Approximation of the central field. Electrostatic and magnetic interaction of electrons. Link types. LS connection. Definition of a set of terms for configurations with non-equivalent and equivalent electrons. Initial terms. Multiplet structure of terms. Connection type jj, connection type jl.
15. Diatomic molecules. Born-Oppenheimer adiabatic approximation for describing the nuclear and electronic subsystems of molecules. Potential energy curves and electronic terms of the molecule (bound and repulsive). Structure of rotational- vibrational energy levels. Multiplet terms: cases a, b, c and d. Symmetry of molecular terms. Predissociation. Radiation of diatomic molecules (electronic, vibrational and rotational spectra). Selection rules. Franck-Condon principle. Isotopic effect.

16. The concept of low-temperature plasma, problems of diagnostics. Equilibrium plasma: energy distributions of particles, densities of neutral and charged particles, thermal radiation. Equilibrium models and related parameters: local thermal equilibrium, partial local thermal equilibrium, coronal model, collisional-radiative model. Optical spectrum and plasma parameters.
17. Dense High-Temperature Plasma and Inertial Controlled Synthesis. Cross sections of thermonuclear reactions. Inertial thermonuclear fusion. Pinch. Adiabatic compression. Bennett equilibrium. Relationship between current and pinch plasma temperature.
18. Charged particle accelerators. Classification. Applications. High current accelerators. charged plasma. Basic Concepts and characteristic values. description methods. The need for a self-consistent approach.
19. High-current electron and ion accelerators. Nodes of high-current accelerators. Diagrams of diodes for the formation of beams with different parameters. Physical models. The main factors affecting the characteristics of diodes and the choice of models.
20. Physical processes on the surface. Types of emission: thermionic, autoelectronic, explosive electronic, photoelectronic, secondary electronic emissions, emission from the surface of ferroelectrics.
21. High-current beams in gas and plasma. Conditions for the occurrence of current beam neutralization in plasma. Characteristic scales of processes. Non-stationary phenomena during beam injection into plasma. Nonstationary ionization during beam injection into a neutral gas. Physical processes during the interaction of a beam with a neutral gas. Charge and current neutralization of a beam in a gas.
22. Monochromatic electromagnetic radiation of relativistic particles. Condition of Cherenkov resonance. Formation length. Radiation of a relativistic oscillator. Normal and anomalous Doppler effect. Directivity and frequency spectrum of radiation of relativistic particles in distributed waveguide structures.
23. Radiation of a uniformly moving charge. Vavilov-Cherenkov radiation in a homogeneous dispersive medium. Radiation in a magnetized plasma waveguide. Transition radiation. Natural waves in periodic structures and their excitation by a moving charge. Cherenkov radiation in periodic structures.
24. Free electron laser. FEL oscillator: the structure of the field in an optical resonator. Gain and self-excitation threshold. Steady-state oscillations and output power. FEL amplifier: saturation and diffraction effects. Waveguide properties of an electron beam. Amplification mode of spontaneous emission in a continuous beam and in a short bunch.
25. Electromagnetic theory of light
    Maxwell's equations. The Umov-Poynting vector. Wave equation. Plane and spherical waves. Phase and group speeds of light. Polarization of light. Stokes parameters. Poincaré sphere. Types of polarizing devices. Reflection and refraction of light at the interface between isotropic media. Fresnel formulas. Total internal reflection. Complex permittivity. Reflection of light from the surface of a conductor. Penetration depth when reflecting light. Light propagation in anisotropic and gyrotropic media. Wave surfaces in crystals. Ray and wave normal. Fresnel ellipsoid. Optical properties of uniaxial and biaxial crystals. Double refraction. Electro-optical Kerr and Pockels effects. optical activity. Faraday effect. Optics of moving media. Fizeau’s and Michelson’s experiments. Lorentz transformations. Longitudinal and transverse Doppler effects.
26. Geometric optics. Asymptotic solution of the wave equation. Geometric-optical approximation. The eikonal equation. Scope of ray approximation. Fermat's principle. Homocentric bundles. The concept of an optical image. Paraxial approximation. Refraction on a spherical surface. Spherical mirrors and lenses. Formation of caustics in optical systems. Geometric aberrations of the third and higher orders. Chromatic aberration. Types of optical devices.
27. Interference and diffraction of light waves

Interference phenomena in optics. Complex degree of coherence. Van-Cittert-Zernike theorem. Double-beam and multi-beam interference. Shear and speckle interferometry. Multilayer coatings. Diffraction. Diffraction integrals of Kirchhoff-Huygens. Fresnel and Fraunhofer diffraction. Influence of diffraction on the resolving power of systems forming an image. Diffraction grating. Inverse problems of the theory of diffraction. Synthesis of optical elements.

28. Theory of radiation and interaction of light waves with matter

    Classical theory of interaction of radiation with matter. Resonant approximation. Kramers-Kronig relations. Optical nutation. Optical Stark effect. Photon echo and self-induced transparency. Solitons. Relaxation processes. The equation for the density matrix. Self-consistent equations for the field, polarization, and population difference. Saturation effect. The laws of thermal radiation. Planck formula. Photoelectric effect. Field quantization. Creation and annihilation operators of photons. Hamiltonian of the quantized field. Commutation relations of field operators. Single-photon and multi-photon processes. Probabilities of spontaneous and forced transitions. Einstein coefficients. cooperative effects. Superradiance. Coherent and Raman scattering. Propagation of waves in a nonlinear medium. Synchronization condition. Generation of optical harmonics. Self-focusing of light. Stimulated Raman scattering. Stimulated Mandelstam-Brillouin scattering. Four-wave interaction. Wave front reversal. Substance in an ultrastrong light field.

29. Statistical optics

    Temporal and spatial coherence of light fields; correlation functions of the first and higher orders. Spectral representation. Wiener-Khinchin theorem. Bose-Einstein distribution. Field degeneracy parameter. Poisson, sub-Poissonian and super-Poissonian photon statistics. Relation between photon and photocount statistics, Mandel's formula for the distribution of photocounts. Shot noise. Spontaneous parametric scattering of light. Biphotons. Entangled states of light. Optical realization of qubits and their transformations. Bell states. EPR- paradox. Bell's inequalities.

30. Spectroscopy

    Atomic spectra. Systematics of spectra of multielectron atoms. Types of electron bonds. Definition of a set of terms. Multiplet structure. Selection rules. Spectra of molecules. Adiabatic approximation. Symmetry groups of molecules. Vibrational spectra. Classification of normal vibrations according to symmetry types. Selection rules in vibrational absorption and Raman spectra. Rotational structure of vibrational bands. Electronic spectra of molecules. Classification of electronic states of diatomic molecules. Franck-Condon principle. Communication types of electronic motion and rotation. Spectroscopy of a rigid body. Transitions under the action of light in an ideal crystal. Absorption in the infrared region of the spectrum and the interaction of light with the phonon subsystem. Absorption of light in metals. Forbidden band and transparency region in dielectrics. Transitions from the main levels. Auger and Fano effects. Effects at core absorption edges: EXAFS and XANES. The concept of polaritons. Spectroscopy of defect states in crystals. Luminescence. Classification of luminescence according to the duration of the glow and the method of its excitation. Molecular and recombination luminescence. Stokes-Lommel law. Levshin's mirror symmetry rule for absorption and luminescence spectra. Vavilov's law. Triplet states of molecules and their role in the processes of degradation and migration of electronic excitation energy. Terenin-Lewis scheme. Luminescence quenching. Radiative energy transfer of electronic excitation. Luminescence of molecular crystals.

31. Experimental and applied optics

    Sources of optical radiation. Thermal, gas-discharge and laser sources. Synchrotron radiation. Optical materials. Characteristics of radiation receivers: spectral and integrated sensitivity, noise, inertia. Spectroscopy technique. Light filters, prism and diffraction spectral devices, interferometers. Fourier spectroscopy. Main characteristics of devices: hardware function, resolution, luminosity, dispersion. Laser spectroscopy. Recording and processing of optical information. Fiber optics. Types of fiber light guides. Fiber communication lines. Nonlinear effects in optical fibers.

32. Laser optics

    The principle of operation of the laser. Pumping schemes. Lamb's theory. Frequency pulling and hole burning effects. Lamb failure. Optical resonators. Modes of optical resonators. Properties of laser beams. Types of lasers. Solid-state lasers. Gas lasers: neutral atom lasers, ion lasers, molecular lasers, self-terminating lasers. Chemical lasers. Semiconductor lasers. Color center lasers. Operating modes of lasers. Continuous and pulse modes. Peak mode. Q modulation. Synchronization mod. Generation of ultrashort pulses.

33. Nanophotonics

    Near field interactions. Optics of evanescent waves. Plasmonics. Field distribution in the metal-dielectric system. Giant amplification of the electromagnetic field near metal nanostructures. Nonlinear properties of nanosized structures. Near-field nonlinear optical processes. Photonic materials with bandgap. Photonic crystals. Nanoscale light sources. Metamaterials. Superlens. Photovoltaics. Surface characterization. Scanning probe microscopy. Electron microscopy.

Reference

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CONDENSED MATTER PHYSICS SECTION

1. Bonding forces in solids.
   Electronic structure of atoms. Types of bonding forces in a condensed state: van der Waals bond, ionic bond, covalent bond, metallic bond. Examples of crystal structures corresponding to close packings of spheres: simple cubic, bcc, fcc, hcp.
2. Symmetry of solids
   Crystalline and amorphous solids. Translational invariance. Basis and crystal structure. Elementary cell. Wigner-Seitz cell. Bravais lattice. Designations of knots, directions and planes in a crystal. Reciprocal lattice, its properties. Brillouin zone. Crystal symmetry elements: rotations, reflections, inversion, inversion rotations, translations. Operations (transformations) of symmetry.
3. Defects in solids.
   Point defects, their formation and diffusion. Vacancy and interstitial atoms. Linear defects. Edge and screw dislocations. The role of dislocations in plastic deformation.
4. Diffraction in crystals.
   Propagation of waves in crystals. Diffraction of X-rays, neutrons and electrons in a crystal. Elastic and inelastic scattering, their features. Bragg reflections. Atomic and structural factors.
5. Lattice vibrations.

Vibrations of the crystal lattice. Equations of motion of atoms. Simple and complex one-dimensional chains of atoms. Dispersion law of elastic waves. Acoustic and optical vibrations. Quantization of vibrations. Phonons.

6. Thermal properties of solids.
   Heat capacity of solids. Lattice heat capacity. Electronic heat capacity. Temperature dependence of the lattice and electron heat capacities. Classical theory of heat capacity. The law of uniform distribution of energy over degrees of freedom in classical physics. Limits of justice of the classical theory. Quantum theory heat capacity according to Einstein and Debye. Limit cases of high and low temperatures. Debye temperature.
7. Electronic properties of solids. Electronic properties of solids: basic experimental facts. Conductivity, Hall effect, thermoEMF, photoconductivity, optical absorption. Difficulties in explaining these facts on the basis of the classical Drude theory. Basic approximations of the zone theory. Born-von Karman boundary conditions. Bloch's theorem. Bloch functions. Quasi-momentum. Brillouin zones. Energy zones. Bragg reflection of electrons moving through a crystal. Approximation of strongly bound electrons. Relationship between the width of the allowed zone and the overlap of the wave functions of atoms. Dispersion law. Inverse effective mass tensor. Approximation of almost free electrons. Bragg reflections of electrons. Filling of energy bands with electrons. Fermi surface. Density of states. Metals, dielectrics and semiconductors. Semimetals.
8. Magnetic properties of solids. Magnetization and susceptibility. Diamagnets, paramagnets and ferromagnets. Curie and Curie-Weiss laws. Paramagnetism and diamagnetism of conduction electrons. The nature of ferromagnetism. Phase transition to the ferromagnetic state. The role of exchange interaction. Curie point and susceptibility of a ferromagnet. Ferromagnetic domains. Reasons for the emergence of domains. Domain boundaries (Bloch, Neel). Antiferromagnets. Magnetic structure. Neel point. Susceptibility of antiferromagnets. Ferrimagnets. Movement of the magnetic moment in constant and alternating magnetic fields. Electronic paramagnetic resonance. Nuclear magnetic resonance.
9. Optical and magneto-optical properties of solids. Complex permittivity and optical constants. Absorption and reflection coefficients. Kramers-Kronig relations. Absorption of light in semiconductors (interband, impurity absorption, absorption by free carriers, lattice). Determination of the main characteristics of a semiconductor from optical studies. Magneto-optical effects (Faraday, Focht and Kerr effects). Penetration of a high-frequency field into a conductor. Normal and abnormal skin effects. Skin layer thickness.
10. Superconductivity
    Superconductivity. Critical temperature. High temperature superconductors. Meissner effect. Critical field and critical current. Superconductors of the first and second kind. their magnetic properties. Abrikosov vortex. Depth of penetration of the magnetic field into the sample. Josephson effect. Cooper pairing. coherence length. Energy gap.

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PLASMA PHYSICS SECTION

1. Plasma thermodynamics
   The concept of plasma, quasi-neutrality, microfields, Debye radius, ideal and non-ideal plasma. Condition of thermodynamic equilibrium, thermal ionization, Saha formula, coronal equilibrium, reduction of ionization potential. Plasma degeneracy, Boltzmann and Fermi-Dirac statistics, Thomas-Fermi model.
2. Elementary processes
   Collisions of charged particles, long-range action, collision frequencies, collisions of electrons with atoms (elastic and inelastic), collisions of heavy particles. Ionization, recombination, recharge and sticking. Excitation and dissociation of molecules by electron impact.
3. Physical kinetics
   Boltzmann and Vlasov equations, collision integral, maxwellization time and temperature equalization rate of different plasma components. The rate of ion formation and recombination of electrons and ions, the formation and destruction of excited atoms (ions). Transport phenomena in plasma, electrical conductivity, diffusion and thermal conductivity of particles in the presence and absence of a magnetic field. Kinetics of excited molecules in plasma.
4. Dynamics of charged particles in electric and magnetic fields
   Movement in crossed electric and magnetic fields. Drift approximation, varieties of drift motion. Charged particle in a high-frequency field. The concept of an adiabatic invariant.
5. Plasma magnetic hydrodynamics
   Equations of plasma motion in a magnetic field, penetration of a magnetic field into a plasma, freezing-in of a magnetic field. Conservation laws in an ideal single-fluid MHD. Two-fluid approximation.
6. Plasma instability
   Equilibrium plasma configurations in magnetohydrodynamics, pinch. Plasma instability, types of instability, overheating and ionization instabilities. Energy principle of MHD stability.
7. Oscillations and waves in a plasma
   The main types of oscillations and waves in plasma: Langmuir electronic and ionic, electromagnetic, ion-acoustic, magnetosonic, Alfvén’s. Plasma refractive index, spatial and temporal dispersion, phase and group velocities of plasma waves.
8. Interaction of charged particles with waves in a plasma
   Excitation and damping of waves in plasma, Cherenkov radiation, Landau damping. The buildup of plasma oscillations by beams. Quasilinear approximation.
9. Interaction of electromagnetic waves with plasma
   Propagation of electromagnetic waves in an inhomogeneous plasma, geometric optics, plasma resonance, cyclotron resonance, linear transformation. Basic nonlinear processes of wave interaction, plasma instability in a strong electromagnetic field. Scattering and transformation of waves.
10. Plasma radiation
    Elementary radiation processes, intensity of spectral lines, continuous spectra, stimulated emission. Radiation ranges, radiation transfer in a medium, optically transparent and opaque plasma, radiative thermal conductivity.
11. Plasma diagnostics
    Probe technique, optical methods, microwave methods, corpuscular methods, laser scattering, magnetic measurements.
12. Electric discharge in gases
    The main types of discharge: glow discharge, spark, electric arc, HF, microwave and optical discharge. Discharge stationarity conditions, emitting discharge in dense plasma, beam-plasma discharge.

13. Hydrodynamic and thermal phenomena in plasma
    Shock waves in plasma, shock wave, relaxation layer, radiation of shock waves, nonlinear thermal conduction waves. Current layers.
14. Applied problems of plasma physics
    Controlled thermonuclear fusion, magnetic confinement and plasma heating in magnetic traps and inertial systems. Geophysical and astrophysical plasma phenomena - the Earth's ionosphere, interplanetary plasma, stars. Plasma radiation sources, plasma microwave electronics. Converting thermal energy into electrical energy: MHD converters, thermal converters. Interaction of plasma with the surface of solids. Plasma technologies.

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PHYSICS OF ELEMENTARY PARTICLES AND ATOMIC NUCLEI SECTION

PART 1

1. Quantum field theory

1.1. Elementary particles and fields.

Types of fundamental interactions: gravitational, electromagnetic, strong, weak. Classification of particles: hadrons and leptons, photon and intermediate bosons. Classification of hadrons, baryons and mesons. Quantum numbers characterizing elementary particles. Additive and multiplicative quantum numbers. Spin, P-, C- and T-parity. Isotopic invariance of strong interactions. The concept of isotopspin. Relations between the amplitudes of various processes. Kinematic restrictions in reactions of interaction of elementary particles. SU(3)-invariance of strong interactions. Strangeness and SU(3)-multiplets of elementary particles. Composite structure of hadrons. Gell-Mann-Zweig model of fractionally charged quarks. Three generations of leptons and quarks. Generalization of the Gell-Mann – Nishijima formula for quantum numbers c,b and t. S-matrix. Relationship of process probability with matrix elements of S-matrix. Feynman rules. Feynman propagator, gauge invariance. Compton scattering. Klein-Nishima formula for section. Scattering ee $\rightarrow$ ee in QED. Four-fermionic weak interaction. β-decay of the neutron and hyperons. Fundamentals of the Weinberg-Salam electroweak theory. Spontaneous symmetry breaking. The emergence of masses of gauge bosons W and Z. Neutral currents. Properties of W, Z-bosons, decays W $\rightarrow$ lν and Z $\rightarrow$ $\nu\nu$. The number of neutrino varieties from the Z-boson decay width into invisible modes. Higgs boson and its properties. Coupling constants and decay width H $\rightarrow$ ll. Running coupling constants of fundamental interactions $\alpha 1$, $\alpha 2$, $\alpha 3$. The main ideas of the Grand Unified Theory (GUT).

1.2. Quantum fields

Introduction (Lagrangian formalism, symmetries, Noether's theorem). Free real scalar field. Lagrangian, field equations, properties of classical solutions. Complex scalar field. Massive vector field. Lagrangian and solutions. Features of the electromagnetic field. Dirac field. Construction of equations of motion, γ-matrices, relativistic covariance, spin representation of the Lorentz group. Solution properties. Lagrangian formalism. Massless spinor field. Principles of quantization of wave fields. Canonical quantization. Operator quantization. Schrödinger and Heisenberg picture. Relativistic quantization scheme. Permutation relations. Fermi-Dirac and Bose-Einstein quantization. State amplitude in the Fock representation. Quantization of a free scalar field. Quantization of a free massive vector field. Peculiarities of electromagnetic field quantization. Dirac free field quantization. Charge conjugation. CPT theorem. Lagrangian formalism in the theory of interacting fields. Principles of constructing Lagrangians. Gauge symmetry. Higgs mechanism. Quantization of interacting fields. Interaction representation. S-matrix, T-product of operators, properties of S-matrix. Wick's theorems. Green's functions of free fields. Feynman diagrams. Feynman diagrams in QED and ø4 -theory. Calculation of transition probabilities. Green's functions in quantum field theory. Method of generating functionals. Methods for calculating Feynman integrals. γ -representation and method of Feynman parameters. Ultraviolet divergences of loop integrals. Regularization methods.

Pauli-Villars regularization. Dimensional regularization. Spinors and γ-matrices in a space of arbitrary dimension. Examples of Feynman integrals calculation. Introduction to renormalization oscillation. The standard renormalization scheme. Scheme of subtractions on the surface of a surface in scalar theory (one-loop approximation). The BPHZ renormalization scheme. Introduction to renormalization of multiloop diagrams. Method for calculating the degrees of divergence. Renormalizable and non-renormalizable theories. Scheme of minimal subtractions. Features of the minimum subtraction scheme. Renormalization in quantum electrodynamics. Gauge invariance and renormalizations. Ward's identities. Calculation of electron form factors. Renormalization group. Renormalization group equation. Calculation of renormalization group coefficients. Applications of the renormalization group. Analysis of the asymptotic behavior of Green's functions. Weinberg's theorem. Leading logarithms. Effective mass and coupling constant. Varieties of high-energy and low-energy behavior. Asymptotic freedom. Spectral representations of Green's functions. Optical theorem. The Källén-Lehmann representation. Renormalization of compound operators. Anomalies in quantum field theory. Axial anomaly.

2. Physics of elementary particles and cosmology

2.1. Classical theory

Fundamentals of the theory of groups and Lie algebra. Non-Abelian global and gauge symmetries. Spontaneous symmetry breaking. The Higgs phenomenon in non-Abelian gauge theories. Standard model of elementary particle physics.

2.2. Quantum theory

Functional integral in quantum mechanics. Properties of the functional integral. Quantum field theory in functional formulation. Quantization of gauge fields in functional formulation. Renormalization of gauge theories. BRST symmetries and Ward identities.

2.3. Cosmology

Early Universe and observational data. The "hot" model of the Universe (Robertson-Walker metric, Friedman equation, history of evolution of the "hot" model of the Universe). Inflation. Reheating the Universe after inflation. Phase transitions. Baryogenesis. Relic neutrinos. Nucleosynthesis. Relic thermal radiation. Formation of the large-scale structure of the Universe.

3. Physics of atomic nuclei

3.1. Nucleus structure

Basic properties of atomic nuclei. Symmetry principles in the physics of the atomic nucleus. Nuclear forces. Nucleus models. Effective nucleon-nucleon interaction in nuclear matter. Non-nucleon degrees of freedom of the nucleus. Delta isobar in the core. Meson currents. The simplest nuclear transformations. Thermodynamics of nuclear matter. Phase transitions.

3.2. Nuclear reactions

Statement of the problem of particle scattering. Cross section of interaction. Central symmetric potential. Partial scattering amplitudes. S-matrix. Born approximation. Rutherford scattering. Scattering of slow particles. Inelastic collisions of hadrons with complex nuclei. Reaction channels. Fundamentals of the multiple-scattering theory by composite scatterers. Diffraction interaction of fast hadrons and nuclei with nuclei. Glauber-Sitenko model. Nuclear reactions proceeding through the stage of the compound nucleus, and direct processes. Resonances in nuclear interactions. The idea of describing the meson-nuclear interactions in the framework of the quantum theory of many-body systems. Green's function method. Scattering of hadrons on low-nucleon systems. Spin-orbit interaction of incident nucleons with a target nucleus. Spin density matrix. Investigation of the structure of nuclei using electron scattering. Neutrino-nucleus scattering. Photonuclear reactions. Reactions of knock-out nucleons from nuclei under the influence of gamma quanta, electrons and hadrons. Research on beams of unstable nuclei. Nuclear-nuclear interactions at intermediate and high energies. Interaction of unstable particles and antinucleons with nuclei. Hadronic atoms. Hypernucleus. Astrophysical applications. Fundamentals of relativistic nuclear physics.

3.3. Experimental nuclear physics

3.3.1. Basic physical quantities for describing nuclear processes. Method of spectrometry of charged particles. Dispersion compensation method for creating spectrometers. Total absorption Cherenkov spectrometers. Threshold Cherenkov detectors and ring imaging Cherenkov detectors. Neutral mesons spectra measurements. Detection and spectrometry of high-energy muons. Methods for obtaining polarized particles beams. Polarized and oriented nuclear targets. Installations for the study of the production of pi mesons. Technique for studying the scattering of pi mesons by nuclei. Temporal features at high beam intensities. Installations with high geometric efficiency. Creation of installations for studying collisions of relativistic nuclei.

3.3.2. Nuclear reactions on beams of gamma-quanta. Methods for monochromatization of photon beams. Interaction of electrons with nuclei at medium and high energies. Determination of nuclear radii, density and shape of nuclei. Resonant nuclear reactions on proton beams of intermediate energies. Interaction of pi mesons with nuclei. Study of pion-nucleon resonances in nuclei. Reactions with polarized particles. Methods for obtaining polarized protons beams and deuterons. Methods for obtaining polarized targets. Features of the study of processes with the emission of neutral pi mesons and – mesons. Introduction to the physics of the interaction of relativistic nuclei. Birth of strange particles in collisions of nuclei. Subthreshold production of antiprotons. The birth of vector mesons in the collision of high-energy nuclei. The program for the search for quark-gluon plasma at the LHC accelerator, the ALICE facility.

3.4. Monte Carlo method in nuclear physics Introduction to the Monte Carlo method. Continuous and discrete random variables. Methods for modeling random variables with a given distribution law. Calculation of integrals by the Monte Carlo method. Some typical modeling problems in nuclear physics. Registration of simulation results. Modeling of many-particle processes.

4. Neutrino Physics and Astrophysics

4.1. Neutrino Physics

Dirac equation. Classical theory of weak interaction. Interactions of neutrinos with nuclei. Quasi-elastic interactions of neutrinos with nucleons. Neutrino properties. Inelastic interactions of neutrinos with nucleons. Neutrinos in gauge theories of weak interaction. Neutrino and cosmology. Experimental searches for neutrino oscillations. Neutrinos in the atmosphere. Extraatmospheric sources of high-energy neutrinos. Thermonuclear reactions in the Sun's interior and neutrinos. Neutrinos from supernova explosions. Study of neutrino properties in accelerator experiments. Investigation of the properties of elementary particles in experiments on hadron and electron colliders.

4.2. Methods for detecting ultra-high energy cosmic neutrinos (particles and astrophysics)

4.2.1. Possible mechanisms of particle acceleration to superhigh energies. Energy spectra and chemical composition of primary cosmic rays. Superheavy particles (maximons), mini-black holes, cosmic strings as possible sources of superhigh-energy cosmic rays (topological defects). Possible upper limit of the energy spectrum. Astrophysical sources of high-energy gamma-quanta. Cygnus X-3; gamma quanta and neutrons from Cygnus X-3. The Fly's eye experiment. Atmospheric muons and neutrinos; features of their spectra. Direct muons and neutrinos from the decay of charmed particles. Astrophysical sources of neutrinos.

4.2.2. Strong, electromagnetic, weak interactions. Decays of particles. Muons and neutrinos interaction cross sections.
4.2.3. Deep underground experiments in South Africa, India, Italy, Japan. Baksan neutrino observatory. Search for neutrino oscillations in underground experiments.
4.2.4. Standard Model of the early Universe. The expansion of the Universe. Friedman model. Critical density.
4.2.5. The Grand Unified Theory of strong (colored), electromagnetic and weak interactions. Association scale. Superheavy gauge bosons. Decay of the nucleon. Magnetic monopole. Relic particles and their search. The problem of the missing mass of the Universe.
4.2.6. Deep-sea neutrino detection (NESTOR projects, Baikal). Acoustic method for detecting superhigh-energy neutrinos (SADKO project). Radio wave method for detecting neutrinos (RAMAND project in Antarctica).

5. Acceleration of charged particles
5.1. Fundamentals of physics and technology of charged particle acceleration
Physical foundations of the acceleration of charged particles. The main types of accelerators and their features. Fundamentals of electrodynamics of accelerating systems. Particle dynamics in linear resonant accelerators. Space charge effects in linear accelerators. Dynamics of particles in cyclic accelerators. Radiation effects in cyclic electron accelerators. Space charge in cyclic accelerators. Accelerator magnets and their power. Accelerating systems of cyclic accelerators. Application of superconductivity. Storage installations. Injection and extraction of particles. Beam diagnostics and accelerator control systems. Application of accelerators for physical research. Projects of new generation accelerators. New (collective) acceleration methods.
5.2. High frequency electrodynamics
Maxwell’s equations. Monochromatic fields and complex amplitudes. Wave equation. Potentials of the electromagnetic field. Flat waves. Skin effect theory. Shchukin-Leontovich boundary condition. Cylindrical waves. Waveguides of rectangular and round sections. Waveguides with a doubly connected cross section. Losses in waveguides. Slow waves. Diaphragm waveguide. Resonators of simple shapes. General theory of resonators. Spherical waves and their excitation; Lorentz lemma. Green’s function and integration of inhomogeneous Maxwell’s equations. Excitation of waveguides and resonators. Scattering matrix. Inhomogeneities in waveguides and resonators. Methods of the theory of functions of the complex variable in electrodynamics (Wiener-Hopf-Fock method, Riemann-Hilbert problem).
5.3. Linear accelerators
Areas of application of linear accelerators. General review of the history of development of linear resonant accelerators and their systems. Sources of charged particles. Accelerating system. Accelerating systems with traveling and standing waves. Superconducting accelerating structures. HF power supply systems for linear accelerators. Microwave generators and amplifiers. Focusing system for klystrons. Vacuum system. High current linear accelerators for neutron sources. Application of accelerators in nuclear power engineering. The method of colliding beams. Linear colliders. ERL.

6. Study of matter
6.1. Neutron sources and research on neutron beams
Proton-neutron model of the nucleus. Neutrons and cosmogony. Neutron and the Grand Unification. Investigation of the properties of nuclei with the help of neutrons. Properties of the neutron. Nuclear reactions with the emission of neutrons. Energy spectra of neutrons. Neutrons slowing down. Diffusion of neutrons. Heavy nuclei fission. Fission chain reaction. Cascade evaporation process. Canadian project. Photofission as an intense source

of neutrons. The breakup of deuterons on light nuclei as a source of neutrons. Thermonuclear fusion reaction. Time-of-flight technique in neutron research. Russian area of research in the creation of intense pulsed neutron sources. Pulsed sources of slow neutrons based on proton accelerators and negative hydrogen ions. First and second generations of pulsed neutron sources. Hybrid source schemes based on boosters. Giant single neutron pulses. Practical application of neutrons. Fundamentals of experimental technology. Permissible radiation doses.

6.2. Interaction of radiation with matter

6.2.1. The passage of heavy particles through matter: the relationship between range and energy; relationship between energy loss and ionization; dispersion of runs, determination of the average run by extrapolated run; elastic and inelastic scattering of heavy particles by atoms.

6.2.2. Passage of β-particles through matter: energy losses; intensity and angular distribution of radiation emitted by fast electrons; secondary electrons; elastic scattering of electrons by atoms; multiple scattering of charged particles; passing through foils, energy measurement.

6.2.3. Passage of γ-radiation through matter: photoelectric effect; Compton scattering; pair formation; total absorption cross section; other effects.

6.3. Radiation physics research

Crystal structure of solids. Point and extended defects. Defect formation energy. Basic ideas about the interaction of nuclear radiation with matter. Primary processes. Transfer of energy to atoms of the irradiated medium. Atomic displacements cascades. The rate of radiation damage in metals irradiated in beams of protons and neutrons. Non-equilibrium solutions of point defects in irradiated metals. Formation of the simplest complexes. The problem of the origin and growth of clusters. Diffuse decomposition kinetics of supersaturated solid solutions. Vacansion swelling of metals under irradiation. Kinetics of formation of dislocation loops in irradiated metals. Stochastic fluctuations in an open dissipative system of radiation defects. Self-organization processes in metals and alloys under irradiation. Pore lattice in irradiated metals. Processes of radiation-induced segregation in alloys. Phase transformations in alloys under irradiation. Numerical methods for modeling radiation damage. Problems of radiation materials science of nuclear and thermonuclear reactors. Key problems of nuclear energy. Opportunities to study on benches and nuclear research facilities.

6.4. Neutron methods for studying condensed matter

Physical prerequisites for the use of neutrons in condensed matter physics. Features of the interaction of neutrons with matter, the wave properties of the neutron. Nuclear and magnetic scattering of neutrons. Doubly differential neutron scattering cross section. Coherent and incoherent neutron scattering. Correlation functions. Advantages and disadvantages of neutron scattering in comparison with other types of radiation and particles (electrons, photons, muons). Physical problems solved with the help of neutron scattering. Features of neutron sources used to study the condensed state. Formation of beams of unpolarized and polarized neutrons. Single-crystal and ToF installations. The main types of neutron instruments are: diffractometers, inelastic neutron scattering spectrometers, reflectometers, small-angle scattering setups, spin-echo spectrometers. Basic concepts of condensed matter physics important for neutron research: Crystal structures. Direct and reverse lattice. Quasiparticles and elementary excitations in condensed media. Methods for studying quasiparticles. Conditions on a sample in neutron studies of condensed matter. A technique for obtaining high pressures, low and high temperatures, high magnetic fields. Structural and magnetic neutron diffractometry. Experimental technique for neutron diffraction. Methods for the analysis of neutron diffraction patterns. Neutron spectroscopy. Fundamentals of the technique of experiment on ToF spectrometers. Triaxial crystal spectrometer: a universal tool for studying the spectra of elementary excitations of crystals. Neutron spectroscopy with high energy resolution. Using neutrons to study atomic vibrations. Determination of the density function of phonon states in matter. Investigations of dispersion curves for phonons in crystals. The use of neutrons for research on the dynamics of the magnetic moment in various materials. Spectroscopy of magnetic excitations in magnetically ordered and paramagnetic media. Magnetic form factor. Physical problems solved with the help of polarized neutrons. Methods for separating the nuclear and magnetic components in experimental neutron spectra. Prospects and directions of development of neutron methods in solid-state physics. Using neutron scattering to study systems with strong electronic correlations. Heavy fermion materials, unstable valence, unusual superconductivity, low-dimensional magnetism. The main directions of development of neutron methods for the study of matter. Improvement of the experimental base. Complementarity with other methods.

PART 2

1.The Dirac equation and its free solution.
2. Lagrangian and quantization of the electromagnetic field.
3. S-matrix and Feynman rules for QED.
4. QED radiation corrections.
5. Infrared catastrophe and its elimination.
6. Gauge invariance in Abelian and non-Abelian theories.
7. Structure of weak currents. Left charged currents. Universality of the weak interaction. Neutral currents.
8. Spontaneous SU(2)-symmetry breaking and generation of masses of fermions and vector bosons.
9. Standard Model Lagrangian.
10. The Grand Unified Theory.
11. Supersymmetry.
12.Experimental determination of the elements of the CKM matrix.
13. Observation of oscillations of B0, Bs and D0 mesons.
14. Experiments to search for neutrino oscillations from various sources.
15. Experimental study of CP violation in B- and K-mesons.
16. Experimental verification of the Standard Model in CERN experiments (LEP, SPS accelerators).
17. Spectroscopy of hadrons containing heavy quarks.
18. Study of the properties of the tau. Muon g-2.
19. Structural functions and deep inelastic scattering.
20. Discovery of the Higgs boson.
21. Neutrino mass. Hierarchy of neutrino masses. Beta decay.
22. Search for processes beyond the boundaries of the Standard Model.
23. Passage of charged particles through matter. Ionization. Vavilov-Cherenkov effect. Transition radiation.
24. Passage of electrons and photons through matter. Electromagnetic showers.
25. Passage of hadrons through matter. Hadron showers.
26. Photodetectors. Classification. Main characteristics and field of application.
27. Gas detectors. Classification. Main characteristics and field of application.
28. Silicon detectors. Classification. Main characteristics and field of application.
29. Detectors of Cherenkov radiation. Classification. Main characteristics and field of application.
30. Electromagnetic calorimeters. Classification. Main characteristics and field of application.
31. Track detectors. Classification. Main characteristics and field of application.
32. General principles of the design of a modern detector in high-energy particle physics.
33. General principles of the design of a modern low-background detector

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Teaching materials and books written by the staff of the department

1. В.А. Бережной, В.Н. Курдюмов. Лекции по высокочастотной электродинамике. Учебноепособие. Второе издание, исправленное и дополненное. ИЯИ РАН, 2013.
2. Д.С. Горбунов, В.А. Рубаков. Введение в теорию ранней Вселенной: Теория горячегоБольшого взрыва. М.: ЛКИ, 2008.
3. Д.С. Горбунов, В.А. Рубаков. Введение в теорию ранней Вселенной: Космологическиевозмущения. Инфляционная теория. — М.: КРАСАНД, 2010.
4. В.Б. Копелиович. Учебно-методическое пособие «Введение в физику элементарныхчастиц. Часть 1.» Второе издание, исправленное и дополненное. ИЯИ РАН, 2012.
5. В.Б. Копелиович. Учебно-методическое пособие «Введение в физику

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6. Э.А. Коптелов. Радиационные эффекты в твёрдых телах. Лекционный курс. ИЯИ РАН,2001.
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8. Ю.Г. Куденко. Основы экспериментально физики элементарных частиц. ИЯИ РАН, 2007.
9. Н.М. Соболевский. Метод Монте-Карло в задачах о взаимодействии частиц с веществом.Учебное пособие. ИЯИ РАН, 2007.

LASER PHYSICS SECTION

1. Main processes of interaction of laser radiation with matter
   The main processes arising from the interaction of low-intensity radiation with atomic particles. Free electron in the wave field. Perturbation of the structure of atomic particles under the action of a laser radiation field. Multiphoton processes and fundamental laws of quantum physics. Multiphoton excitation of atomic particles. Theory of the process of nonlinear ionization of atomic particles. Non-resonant process of multiphoton ionization of atomic particles. Resonance process of ionization of atomic particles. Tunnel ionization of atomic particles. Nonlinear scattering of laser radiation by atoms. Pressure of laser radiation on atomic particles. Orientation of molecules in the field of laser radiation. Dissociation of molecules in the field of laser radiation. Plasma formation during the interaction of laser radiation with a gas.
2. Basic concepts of quantum mechanics
   The Schrödinger equation and the wave function interpretation. Photoelectric effect in atoms. Surface and volume photoelectric effect in metals. Multiphoton excitation and ionization of atoms. Composite matrix elements, dynamic Stark effect, dynamic polarizability of an atom. Two-level system in a resonant field. Approximation of a rotating wave. Rabi frequency and oscillations.
3. Self-action of radiation with matter
   Effects of self-action of light with matter, self-phase modulation. Nonlinear interaction of intense radiation with matter. Nonlinear dependence of polarization on the field strength of a light wave. Nonlinear susceptibility. Electronic nonlinear susceptibility, Kerr-lens effect, electronic Kerr effect, Kerr orientation effect. Electrostriction, electrocaloric effect, thermal effect. Forced scattering. Stimulated Raman scattering (SRS). Stimulated Mandelstam-Brillouin Scattering (SBS). Nonlinear refraction. Self-focusing of laser radiation. Critical self-focusing power, self-focusing length. Self-modulation of laser radiation in nonlinear media.
4. Lasers
   Basic laser circuit. Active medium, population inversion. Energy level systems. Three-level scheme of laser generation, four-level scheme. Self-limiting transition, its features. Pumping processes: electron impact, chemical, gas dynamic, optical. Peculiarities and differences between optical pumping by means of injection lasers and lamp pumping. Optical resonators. Types of resonators. Stable resonators, stability diagram of a real resonator. Plane-parallel resonator, concentric resonator, confocal and semi-confocal resonator.
5. Generation of short pulses
   Principles of ultrashort pulse generation. Mode locking method (active and passive). Mechanisms of action of a fast and slow saturable absorber. Artificial (inertialess) absorber. Spatial and temporal coherence, measurement methods and examples of the use of laser sources with different degrees of coherence. Peculiarities of temporal coherence of radiation from continuous-wave femtosecond pulse lasers. Nonlinear effects of self-action of intense pulses in a medium.
6. Laser spectroscopy

CARS spectroscopy. Spectroscopy of two-photon absorption in media with and without a center of symmetry. Raman spectroscopy and Raman amplification (attenuation) in media with and without a center of symmetry.

7. Fundamentals of fiber optics
   Structure, main parameters and types of fiber light guides. Photosensitivity of fiber light guides and fiber refractive index gratings. Nonlinear phenomena in fiber light guides. Stimulated Raman scattering of light in glass fiber light guides. The phenomenon of electrostriction in fiber light guides. Main applications of fiber light guides.
8. Nanostructures
   What are nanostructures, their classification, the most common properties, manufacturing methods. Semiconductor quantum wells. Semiconductor quantum threads and dots. Nanostructures based on carbon (fullerenes, nanotubes). Methods for experimental study of nanostructures (optics, magnetooptics, electron and STM microscopy).
9. Thermal effect of laser radiation
   Thermoelastic deformations created by laser radiation. Influence of solid-liquid phase transitions on the dynamics of laser heating. Heterogeneous chemical reactions stimulated by laser radiation. Laser cleaning. Laser ignition of metals. Laser ablation. Laser chemical vapor deposition (LCVD).
10. Phase and group velocity of light. Group velocity dispersion. Formation of the refractive index in the medium. Theory of light dispersion. Normal and anomalous dispersion. Effective field and polarizability of the medium. Dielectric permittivity and refractive index of the medium.
11. Optics of metals. Plasma frequency. Drude formula and its applications to plasma and metals. Generalizations of the Drude formula. Dispersion relations for plasmons in a metal. Surface plasmon polaritons.
12. Propagation of light in isotropic and anisotropic media. Spatial dispersion. Uniaxial and biaxial crystals. Ordinary and extraordinary waves. Rotation of the plane of polarization.
13. Interference phenomena in optics. Spatial and temporal coherence of light. Double-beam and multi-beam interference. The resolving power of an optical device. Rayleigh resolution criterion.
14. Diffraction phenomena in optics. Huygens-Fresnel principle. Kirchhoff integral theorem. Fresnel and Fraunhofer diffraction. Limit cases. Fundamentals of the exact theory of diffraction.
15. Resonators and waveguides. Standing electromagnetic waves in resonators. Natural oscillation frequencies in resonators. Propagation of TM and TE waves in waveguides. Critical radius of the waveguide. Lower frequency limit for wave propagation in waveguides. Main wave in a coaxial waveguide.
16. Energy levels and spectra of hydrogen-like atoms. Rydberg formula. Specificity of highly excited states of the atom. Fine and hyperfine structure of atoms. Characteristic scales of energies, frequencies and wavelengths of transitions in atoms and ions.
17. Basic concepts of the theory of molecules. The Born-Oppenheimer approximation. Electronic and nuclear wave functions of a diatomic molecule. Electronic terms. Energy spectrum of a diatomic molecule. Characteristic scales of energies, frequencies and lengths of wave transitions. Linear, striped and continuous spectra.
18. Electronic-vibrational-rotational structure of the spectra of a diatomic molecule. Harmonic oscillator and rigid rotator approximations, their generalizations. Selection rules for electronic, vibrational and rotational transitions.
19. Atom in an external field. Zeeman and Stark effects. Linear Stark effect in the hydrogen atom. Random degeneration and transitional case.
20. Thermodynamic distributions. Gibbs, Maxwell, Boltzmann, Planck distributions. The law of mass action. Detailed equilibrium relations for particles in discrete and continuous spectra. Saha and Saha-Boltzmann formulas. Statistical weight of the continuous spectrum.

21. Specificity of the optical range. Dipole approximation. Fields in the near and far zones. The intensity of the dipole radiation. Decomposition of fields in multipoles. Magneto-dipole and electro-quadrupole radiation. Multipole radiation.
22. Classical oscillator with damping in the field of an electromagnetic wave. The force of radiation friction and the damping constant of the oscillator. Dispersion formula of classical electrodynamics on the example of an oscillator in an external field. Dynamic and static polarizability of an atom. Natural line width. Classic and quantum expression for Δωrad and Δλrad. Lorentzian intensity distribution radiation under radiative line broadening.
23. Self-oscillation in fields. Placement of the electromagnetic field by the effects of waves. Hamiltonian method in electrodynamics. Canonical variables. Free field quantization. Rules for switching generalized coordinates and impulses. Creation and annihilation operators of photons; operator of number of units Energy and impulsive quantum field
24. Coherent and compressed states of light. Quantum noises of the light field in various quantum states: coherent, N-photon, squeezed, thermal. Photon statistics.
25. Hamiltonian of the system: atom + field. Interaction operator of a field with a moving charge. General expressions of perturbation theory for the probabilities of single-photon emission and absorption of light. Spontaneous and forced emission. Einstein coefficients. Probabilities and intensities of dipole radiation. The principle of conformity.
26. Forces of transition oscillators. Theorem on the sum of oscillator strengths. Spectral distribution of the Einstein coefficient. Effective cross sections for absorption and stimulated emission. Contours of spectral lines. Dependence of the sections in the center of the line on its width. Integral over the line and over the entire spectrum of the absorption cross section. Coefficient of light absorption at a bound-bound transition.
27. Mechanisms of spectral lines broadening. Homogeneous and inhomogeneous broadening. Doppler broadening. Impact and quasi-static broadening. Impact broadening by neutral particles (power law model). Lorentzian line contour in the shock limit. Weiskopsoff radius and frequency. Limits of applicability of shock and quasi-static limits. Quasi-static and anti-static wings of the line.
28. Quantum formulas for the cross sections of impact broadening and shift of spectral lines. Line broadening and shift in gases at transitions between highly excited and weakly excited atomic levels. Asymptotic expressions for widths and shifts of Rydberg levels. Fermi's law.
29. Types of freebound radiative transitions involving atoms and molecules. Photoionization of the atom and photorecombination. Photodetachment of an electron from a negative ion. Photodissociation of molecules. Free-free photo transitions. Bremsstrahlung of an electron in a Coulomb field.
30. Elastic and inelastic scattering of light by atoms and molecules. Classical theory of elastic light scattering. Dispersion formula of classical electrodynamics and its limiting cases. Rayleigh and Thomson limits. Resonant fluorescence.
31. Spontaneous and stimulated Raman scattering. Kramers-Heisenberg formula. Scattering on molecules. Stokes and anti-Stokes components. Scattering tensor. Selection rules for light scattering.
32. Theory of two-photon emission and absorption of light. Dependence of the probability of two-photon emission on the frequencies of the emitted photons. Comparison of the probability of one-photon and two-photon emission. Coefficient of two-photon absorption.
33. Nonlinear polarization of matter. Classification of nonlinear phenomena, characteristic light intensities. Generation of the second harmonic. Phase matching conditions: angular and frequency matching. Transfer of energy to the harmonic and vice versa. Generation of sum and difference frequencies.

34. Parametric generation and amplification of light. Parametric luminescence and amplification. Parametric light generation. Four-wave mixing. Connection of four-wave mixing with known mechanisms of nonlinearity.
35. Interaction of a two-level atom with a field. Bloch's equations. Rabi oscillations under the action of a monochromatic field. Response of an atom to the action of a laser pulse (pulse area). Photon echo. Self-induced transparency.
36. Quantum features of nonlinear optical phenomena (second-harmonic generation, parametric generation of light and generation of squeezed states, sub-Poissonian-light generation).
37. Collisional processes. Elastic and inelastic scattering. Effective section. Scattering in the central field. Optical theorem and its consequences for the scattering of waves and particles. Excitation section. Semiclassical and Born approximations.
38. Femtosecond laser pulses. Femtosecond laser. Self-focusing and self-phase modulation. Nonlinear parabolic equation. Applications of femtosecond lasers.
39. Laser cooling of atoms and ions. Optical molasses, Doppler limit. Sub-doppler cooling.
40. Methods for capturing charged particles. Paul trap. Methods for capturing neutral particles. Magnetic, optical dipole traps. Magneto-optical trap.
41. Physical foundations of subwavelength optics and near-field microscopy. The passage of light through a small ($a \ll \lambda$) hole in the screen. Bethe formula for the far-field transmittance of light. Obtaining localized light fields in narrowing metallized waveguides with a subwavelength aperture (near-field optical probes).
42. Gaussian beams: transverse structure, longitudinal structure. Relationship between focus angle and waist radius. Transformation of a Gaussian beam by an ideal lens.
43. Resonator modes; state of stability (relationship with diffraction). Frequencies of longitudinal and transverse modes. Longitudinal mode locking (femtosecond light pulses).
44. The structure of fiber light guides; single mode and multimode fibers. Effective wave vector; cut-off wavelength. Causes of radiation losses.
45. The principle of operation of lasers. Methods for creating population inversion. Relaxation processes. The width of the transition line. Gain. Saturation effect.
46. Single and multiphoton ionization of atoms and molecules. Tunnel and over-barrier ionization of atoms and ions.
47. Multiphoton dissociation of molecules in a laser field. Laser separation of isotopes. Optical stimulation of chemical reactions.

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33. Д. Маркузе. Оптические волноводы (Мир, Москва, 1974).
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12. А. Ярив, П. Юх. Оптические волны в кристаллах, (Мир, Москва, 1987).
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THERMAL PHYSICS AND THEORETICAL HEAT ENGINEERING SECTION

1. General system of hydrodynamics motion equations and heat transfer equations. Ideal liquid
1.1. Subject of hydrodynamics. Laws of conservation of mass, momentum and energy. Derivation of the general system of equations of motion of a non-ideal fluid (continuity, Navier-Stokes and heat transfer equations). Boundary conditions.
1.2. Ideal liquid. System of equations of motion and boundary conditions. Hydrostatics. Isentropic flows. Vorticity. Thomson's theorem.
1.3. Potential flow. Incompressible liquid. Bernoulli equation. Potential flow around an incompressible fluid. D'Alembert's paradox.
1.4. Applicability conditions for the incompressible fluid approximation. Gravitational waves. Sound.

2. Viscous liquid
2.1. Navier-Stokes equation. Problems on the simplest types of viscous fluid flow. Poiseuille flow. Oscillatory motion of a viscous fluid.
2.2. Similarity laws. Reynolds, Froude and Strouhal numbers.
2.3. Flows at low Reynolds numbers. Stokes' law.
2.4. Laminar flows at high Reynolds numbers. Laminar trail. Drowned jet. Laminar boundary layer. The power of resistance.

3. Turbulence
3.1. The problem of the stability of stationary motion. Rayleigh-Taylor and Kelvin-Helmholtz instabilities. Transition to turbulence.
3.2. Developed turbulence. The Kolmogorov-Obukhov model.
3.3. Turbulent jet. Turbulent trail. Logarithmic velocity profile for turbulent flow along an unbounded flat surface.
3.4. Turbulent boundary layer. Turbulent flow in pipes. Drag coefficient. Drag crisis in turbulent flow past solids.

4. Surface phenomena
4.1. Laplace's equation. Mechanical equilibrium of contacting bodies.
4.2. Capillary waves. Resorption of a periodically modulated liquid surface profile.

5. Forced convection heat transfer
5.1. Heat transfer equation. Thermal conductivity in an incompressible fluid. Convection.
5.2. The law of similarity for heat transfer. Heat transfer in the boundary layer. Turbulent temperature fluctuations.
5.3. Heat transfer during laminar flow in pipes and channels.
5.4. Heat transfer during turbulent flow in pipes and channels.

6. Free convection in a liquid without internal heat sources
6.1. Thermal expansion. Free convection. Similarity laws. Laminar free-convective boundary layer on a vertical wall.
6.2. Turbulent free-convective boundary layer. Free-convective jets.
6.3. Convective instability of a horizontal plane-parallel liquid layer heated from below. Rayleigh-Benard convection.
6.4. Turbulent Rayleigh-Benard convection. Soft and hard turbulence.
6.5. Heat transfer accompanied by phase transformations. Radiation heat transfer.

7. Convective heat transfer of the energy-releasing liquid

7.1. Methods and the current state of the study of heat transfer of the energy-releasing liquid. Method of analytical estimates.
7.2. Energy-releasing liquid heat transfer regimes. Heat transfer in the asymptotic regime.
7.3. Limiting angular characteristics of heat transfer of the energy-releasing liquid.
7.4. Energy-releasing liquid heat transfer in quasi-two-dimensional geometry.
7.5. Features of heat transfer of a cooling liquid without internal heat sources in a quasi-stationary regime.

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INSTRUMENTATION AND METHODS OF EXPERIMENTAL PHYSICS SECTION

1. Methods for measuring basic physical quantities
1.1. Time measurement methods, measurement errors, standards. Accounting for the effects of the general theory of relativity (dependence of the clock rate on acceleration and gravity).
1.2. Measurement of frequencies in the radio range. Frequency standards.
1.3. Methods and errors of measurements of coordinates, angles, lengths. World standards and benchmarks.
1.4. Methods for measuring thermodynamic quantities.
1.5. Radiospectroscopy (Zeeman effect, nuclear magnetic resonance, tomography).
1.6. Electromagnetic measurements (methods of registration of radio emission, methods of registration in the optical range: photodiodes, photomultipliers, Cherenkov detectors).
1.7. Registration of particles and radioactive emissions (ionization chambers, gas discharge counters, proportional counters, spark and streamer chambers, semiconductor detectors, scintillation counters, bubble chambers, Cherenkov counters, nuclear emulsions).
1.8. Noise and interference in the measurement of electrical, acoustic and optical quantities.
1.9. Differential, interferometric and other measurement methods.
1.10. Nanotechnologies in measuring technology.
1.11. Dosimetric measurements and dosimetric units; coefficients taking into account the effect of radiation on living organisms, equivalent dose.

2. Measurements
2.1. Systems of units. International system of units (SI). Universal constants and natural systems of units. Derived units and standards.
2.2. Direct, indirect, statistical and dynamic measurements. Estimates of errors in indirect measurements. Conditional measurements. The problem of correlations and balancing of conditional measurements. Fundamental limitations on measurement accuracy (physical limits).
2.3. Methods for measuring physical quantities in the area of physics under study.

2.4. Basic principles for constructing instruments for measuring physical quantities in a given area of physics.
2.5. Fundamental noise in measuring devices.
2.6. Thermal noise. Nyquist formula. Cullen-Welton theorem. Shot noise in electronic and optical devices. $1/f$ noise.
2.7. Quantum effects in physical measurements. Conditions when the classical approach becomes inapplicable.
2.8. Uncertainty relations. The role of the reverse fluctuation effect of the device. Standard quantum limits. Quantum nonperturbing measurements. Quantum standards of units of physical quantities (examples). Josephson effect and superconducting quantum interferometers.

3. Criteria for measurement accuracy
3.1. Random events. The concept of probability. Conditional probabilities. Probability distribution. Probability density. Moments.
3.2. Special probability distributions and their use in physics. Binomial distribution, Poisson distribution (shot noise), exponential distribution. Normal distribution and the central limit theorem.
3.3. Multivariate probability distributions. Correlations of random variables.
3.4. Random processes. Ergodicity. Correlation function of a random process. Stationary random processes. Spectral density. The Wiener–Khinchin theorem.
3.5. Estimation of the parameters of random variables. Sample means and variances. Sampling distributions. Student's t-distribution, chi-square - distribution.
3.6. Determination of the average values of the measured parameters and their errors in direct and indirect measurements.
3.7. Technique for estimating parameters for different distributions of measurement errors. Mean and probable values of variables. Parameter estimation technique for asymmetric error distributions. Summation of the results of various measurements. Robust estimates. Parametric and nonparametric estimates.

4. Methods of analysis of physical measurements
4.1. Analytical approximation of results and measurements. Interpolation (linear, quadratic, cubic, etc.).
4.2. Fourier analysis. Discrete Fourier transform. Fast Fourier Transform. Wavelet analysis.
4.3. Statistical testing of hypotheses. Goodness-of-fit criteria and methods of their use. Chi-square, Smirnov-Kolmogorov, Kolmogorov criteria.
4.4. Direct and inverse problems. Incorrect tasks. Inverse problems in the analysis of measurement results and methods for their solution.
4.5. Maximum likelihood method and its application.
4.6. Least square method.

5. Modeling of physical processes
5.1. Analytical description of physical processes.
5.2. Experiment planning, choice of method and technical means, methods for evaluating the expected results and their errors.
5.3. Method of statistical tests, methods of its application.
5.4. Using models of physical processes.
5.5. Accounting for the influence of the device on the measurement results. Modeling taking into account the features of the used detectors.

6. Automation of the experiment
6.1. Creation of complex installations. General requirements. Information processing on-line.

6.2.Methods for converting measurements for long distance transmission.
6.3.Control of measurement processes in real time.
6.4.Ways to display information in real time. Accumulation of experimental data, creation of databanks.

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2. Ю.П. Добрецов. Ускорители заряженных частиц в экспериментальной физике высокихэнергий. МИФИ, 2004.
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https://www.python.org/

ASTROPHYSICS AND STELLAR ASTRONOMY SECTION

1. General part: astrometry, celestial mechanics
1.1.Fundamentals of motion mechanics.
1.2.Law of gravity, Kepler's law. Two-body problem, types of movements in the two-body problem. Orbital elements. The concept of disturbing forces in the two-body problem.
1.3.Movement of artificial Earth satellites and characteristics of their orbits.

2. Some general astronomy questions
2.1.Definition of the main planes: horizon, celestial equator, ecliptic, galactic equator. Systems of celestial coordinates. Precession, nutation, aberration (daily and annual). Principles of

constructing coordinate systems. Principles of gyrostabilization and astroorientation of space instruments (gyroscopes, stellar and solar sensors).

2.2. Definition of time. World time, sidereal time, solar time (true, mean, standard, daylight savings).

2.3. Fundamentals of mathematical statistics. Poisson, Gaussian distributions. Methods for testing hypotheses and estimating parameters. Least square method. Calculation of standard deviations. Transferring errors.

3. Observational and experimental methods of astrophysics

3.1. Astronomical optics. Aberrations of optical systems. Telescopes and their main parameters (resolution, field of view, penetrating power). The main types of telescopes (refractors, reflectors, mirror-lens systems, telescopes with adaptive optics). Types of telescope mounts. Astroclimate.

3.2. Radio telescopes. The main types of antennas (dipole, horn, mirror antennas, arrays, aperture synthesis antennas). The main parameters of antennas (effective area, radiation pattern, noise temperature). Radio astronomy receivers. Radiometric calibration. Bolometric and heterodyne reception in radio and IR ranges.

3.3. The main parameters of spectral instruments (resolution, luminosity, geometric factor). Light filters. Prism spectrographs and spectrometers. Diffraction spectral devices. Flat and concave diffraction gratings.

3.4. Receivers for optical, ultraviolet and infrared radiation. Photographic emulsion. Photoelectric receivers. CCD matrices. Thermal receivers. The main parameters of the receivers (sensitivity, spectral response, noise, frequency response). Factors limiting the signal detection threshold in different ranges.

3.5. Methods of extra-atmospheric astronomy. Detectors and optics for ultraviolet and X-ray ranges (proportional counters, microchannel plates, oblique incidence telescopes, honeycomb and modulation collimators, coded aperture telescopes). Semiconductor detectors. Scintillation detectors. Solid state (germanium) detectors. Calorimeters. Spark chambers for the gamma range.

3.6. Planetary surface temperature measurements (IR radiometry, radio astronomical methods). Measurements of pressure, density and temperature in planetary atmospheres using space technology (direct methods, deceleration of artificial satellites, spectroscopy, radio translucence).

4. General astrophysics

4.1. Stars: magnitude scale, photometric systems, U, B, V system and its continuation. Apparent and absolute stellar magnitudes. Methods for determining distances to stars. Color index, color excess. The temperature of the stars, the scale of stellar temperatures. Spectra of stars and their classification. Hertzsprung-Russell diagram. Determination of the masses of stars. Double stars.

4.2. Variable stars and their classification. Cepheids, period-luminosity dependence. New stars. Supernova, their types and causes of explosions. The role of radioactive radiation in the formation of supernova light curves.

4.3. Proper motions of stars, radial velocities of stars, motion of the solar system in the galaxy.

4.4. The Milky Way and its structure. Star clusters. Open and globular clusters. Interstellar medium. Galactic nebulae; light and dark. Interstellar absorption of light.

4.5. Theory of galactic rotation. Spiral structure of the Galaxy. Properties of gas in clouds and intercloud space. Stellar population types and their kinematics.

4.6. Galaxies and their classification, methods for determining distances in the Metagalaxy. Redshift.

4.7. Radio galaxies, quasars, active galactic nuclei. Unification of active galactic nuclei.

4.8. Clusters of galaxies. Visible and hidden mass. Hot gas in galaxy clusters. The Sunyaev-Zeldovich effect and the determination of the Hubble constant.

5. Solar system

5.1. Sun (dimensions, mass, luminosity, temperature, spectrum). Photosphere, chromosphere, the Sun’s corona (spectrum, physical conditions). Radio and X-ray radiation from the Sun. Solar activity. Sunny wind.

5.2. Earth as a planet. Earth's atmosphere, its composition, vertical section. General circulation in the atmosphere. Upper atmosphere, ionosphere, exosphere.

5.3. Surface and shape of the earth. Earth's magnetic field, elements of terrestrial magnetism. The concept of the internal structure of the Earth.

5.4. Terrestrial planets and their satellites. Moon: dimensions, features of movement, surface structure, composition and structure of the soil. Mercury (surface, rotation, atmosphere).

5.5. Terrestrial planets: Mars and Venus. Comparative analysis of the chemical composition of the atmospheres. Venus (rotation, its atmosphere, cloud layer, ionosphere, heating mechanisms). Mars (its surface, atmosphere, ionosphere). Magnetic fields and the internal structure of the terrestrial planets. Pluto.

5.6. Giant planets. Jupiter. Atmospheric structure, atmospheric dynamics, cloud layer. Jupiter radio emission, magnetic field and magnetosphere.

5.7. Saturn. Uranus. Neptune. Fundamentals of the theory of the internal structure of the giant planets.

5.8. Small bodies of the solar system: satellites of planets, rings, asteroids, comets, meteorites, interplanetary dust, zodiacal light.

6. Theoretical astrophysics

6.1. Atomic spectra. The nature of spectral terms. Spectrum of the hydrogen atom, 21 cm line. Spatial quantization. Spin, fine structure. Spectrum of a hydrogen molecule. Spectra of alkali metals. Spectra of atoms and ions with two electrons. Transition probabilities. Oscillator strength, Einstein coefficients. Zeeman effect. Stark effect. Isotopic displacement. Superfine structure.

6.2. Molecular spectra. Rotational and rotational-oscillatory bands. Electronic spectra. Molecular radiospectroscopy. isotopic effects. Line intensity. Rotational temperature. Maser radiation.

6.3. Theory of stellar photospheres. Continuous spectrum. Basic concepts about the theory of radiation (coefficients of absorption and radiation, various mechanisms of absorption in the continuum). Transfer equation. Eddington approximation. LTE hypothesis. The law of limb darkening. Excitation and ionization of atoms in stellar atmospheres, scattering and true absorption, free-free transitions, negative hydrogen ions. Deviations from LTE (the Sun’s corona, planetary nebulae). The concept of a gray atmosphere. Albedo.

6.4. Formation of absorption lines in the spectra of stars. Transfer equation for the conservative case. Accounting for true absorption. Doppler broadening and true attenuation. Pressure effects, line broadening due to atomic collisions.

6.5. Fundamentals of the theory of growth curves. Methods for constructing growth curves from observations. Turbulent velocities in stellar atmospheres, damping constant. Influence on the profile of rotation lines of stars. Changing the contours of the lines from the center to the edge. Influence of the acceleration of gravity (the difference between the spectra of giants and dwarfs).

6.6. Ionization of atoms by radiation and electron impact. Fundamentals of the theory of ionization of the Sun’s corona. Coronal lines and their identification. Continuous spectrum of the Sun’s corona (F and K components).

6.7. Forbidden lines in astrophysics. The mechanism of the glow of planetary nebulae. Zanstra method for determining the temperatures of the cores of planetary nebulae. Behavior of

Balmer and forbidden lines in planetary nebulae. Lc and L• radiation and its diffusion in planetary nebulae.

6.8. Areas of molecular, atomic, ionized hydrogen and their radiation. Recombination time and cooling mechanisms of the HI and HII regions. Strömgren radius. Nonstationarity of HII regions.

6.9. Basic mechanisms of cosmic radio emission and main characteristics. Bremsstrahlung, radiation of optically thin and optically thick plasmas. Synchronous radiation and practical application to sources. Recombination radio lines. Fundamentals of radio spectroscopy of molecules, electronic, vibrational and rotational transitions, maser radiation.

6.10. The concept of the internal structure of stars and their evolution. Degenerate electron gas. Structure of main sequence stars. Red giants and white dwarfs. Fundamentals of the theory of evolution of stars with constant mass. Connection of the theory of evolution with the observed spectrum-luminosity diagrams in open and globular clusters.

7. Special questions of astrophysics

7.1. The remnants of supernova explosions. Their classification. Crab nebula (spectrum, glow components, basic theory). Stellar remnants: neutron stars and black holes. Pulsars. Neutron star stability limit and determination of the mass of a compact object in a binary system by measuring the Doppler shift of spectral lines.

7.2. Fundamentals of the theory of accretion onto neutron stars and black holes. Spherically symmetric and disk accretion. The boundary layer of the accretion disk and the layer of matter spreading over the surface of the star. Hot coronas and emission spectrum of the accretion disk.

7.3. Rayleigh scattering. Scattering, absorption and attenuation by small particles.

7.4. Interstellar medium. Methods for studying the gas and dust components. Molecules in the interstellar medium. Cosmic rays and magnetic fields in the Galaxy.

7.5. Mechanisms of X-ray and gamma radiation (bremsstrahlung and recombination radiation of hot optically thin plasma, synchrotron radiation, fluorescence, inverse Compton effect, pion decay). Interaction of X-ray and gamma radiation with matter (ionization losses, photoabsorption, Compton scattering, pair production). Comptonization and formation of spectra of compact X-ray sources.

7.6. Classification of observed compact sources of cosmic X-ray and gamma radiation (supernova remnants, double X-ray sources, bursters, X-ray pulsars, X-ray transients and novae, black hole candidates, soft gamma repeaters, magnetars).

7.7. Isotropic x-ray and gamma background. extragalactic sources of x-ray radiation. logN-logS diagram. Cosmic gamma-ray bursts. Gamma-ray burst afterglows. Neutrino astronomy (Sun and supernova).

7.8. The study of dust. IR radiation from star-forming regions of molecular dust clouds, HII zones of planetary nebulae and circumstellar shells. Diffuse glow of the plane and the center of the Galaxy. IR excesses in the spectra of stars and active galaxies. Infrared background.

7.9. Fundamentals of cosmology. Observational foundations of cosmology: homogeneity of the distribution of matter on the largest scales; Hubble law. Theory of the expanding Universe (Newtonian equations for a homogeneous isotropic Universe, expansion law, critical density). Friedman's models of the expanding Universe: curvature of 3-dimensional space (closed, open, flat world).

7.10. Theory of the hot Universe. Relic radiation. Early stages of expansion. The concept of an expanding universe. Behavior of radiation and matter in the early stages of the expansion of the Universe. recombination of matter. Gravitational instability. The emergence of the structure of the universe. Dark matter and dark energy. Accelerated expansion of the Universe (methods of measurement).

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2. Кононович Э.В., Мороз В.И. Общий курс астрономии. М.: УРСС, 2011.
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6. Гинзбург В.Л. Распространение электромагнитных волн в плазме. М.: Наука, 1967.
7. Горбунов Д. С., Рубаков В. А. Введение в теорию ранней Вселенной: Теория Горячегобольшого взрыва. М.: Изд-во ЛКИ/URSS, 2008.
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10. Есепкина Н.А., Корольков Д.В., Парийский О.Н. Радиотелескопы и радиометры. М.:Наука, 1973.
11. Засов А.В., Постнов К.А. Общая астрофизика: Учебное пособие. М.: МГУ – Фрязино,2011, 573 с.
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13. Зельдович Я.Б., Новиков И.Д. Строение и эволюция Вселенной. М.: Наука, 1975.
14. Каплан С.А., Пикельнер С.Б. Физика межзвездной среды. М.: Наука, 1979.
15. Краус Д.Д. Радиоастрономия. М.: Сов. радио, 1973.
16. Мартынов Д.Я. Курс практической астрофизики. М.: Наука, 1977.
17. Москаленко Е.И. Методы внеатмосферной астрономии. М.: Наука, 1984.
18. Новиков И.Д. Эволюция Вселенной. М.: Наука, 1990.
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21. Физика космоса: Маленькая энциклопедия. Ред. Р. А. Сюняев. М.: Сов. Энциклопедия,1986.
22. Шкловский И.С. Звезды: их рождение, жизнь и смерть. М.: Наука, 1984.
23. Шкловский И.С. Сверхновые звезды и связанные с ними проблемы. М.: Наука, 1976.
24. Шапиро С., Тьюколски С. Черные дыры, белые карлики и нейтронные звезды. М.:Мир, 1985.
25. Лонгейр М. Астрофизика высоких энергий. М.: Мир, 1984.

LOW TEMPERATURE PHYSICS SECTION

1. Refrigeration cycles
   Ideal gas liquefaction process and minimal liquefaction work. Liquefaction of hydrogen and helium. Cooling by pumping 3He and 4He vapors by dissolving 3He into 4He. Cooling using the Pomeranchuk effect and adiabatic demagnetization. Thermometry at low temperatures.
2. Thermodynamics and statistical physics
   Gibbs, Maxwell, Boltzmann distributions. The second law of thermodynamics. Thermodynamic potentials, relations between their derivatives. Thermodynamic functions of an ideal gas. The theorem of equipartition of energy over degrees of freedom. Phase equilibrium condition. Clausius-Clapeyron equation. Critical point. Phase transitions of the second kind. Change of symmetry and order parameter. Heat capacity jump. Critical

indices. Bose and Fermi distributions. Degeneration temperature. Order of magnitude of the heat capacity of a degenerate Fermi gas.

3. Symmetry, crystallography
   Crystal systems. Bravais lattice. Reciprocal lattice, Brillouin zone. Crystal structures of simple substances. Liquid crystals. Magnetic symmetry.
4. Thermal properties of dielectrics.
   Heat capacity: Debye's law, Dulong Petit's law. Debye temperature. Laws of conservation of energy and quasi-momentum in the interaction of phonons. Thermal conductivity of dielectrics. Temperature dependence. The role of transfer processes.
5. Magnetic properties of dielectrics
   Atom in a magnetic field. Diamagnetism. Paramagnetism. Curie law. The Heisenberg Hamiltonian. Magnetically ordered substances. Ferromagnets. Curie-Weiss law. Antiferromagnets. AFM Longitudinal and transverse susceptibility. Ferrimagnets. Magnetics in weak and strong magnetic fields. Spin waves. Dispersion law for ferro- and antiferromagnets. Temperature dependence of the magnetic contribution to the heat capacity and magnetization of a ferromagnet in the approximation of the theory of spin waves. Resonances. NMR, RCS, FMR, AFMR. Regions of resonance frequencies.
6. Normal metals
   Model of free electrons. Energy, momentum, velocity, Fermi temperature. Form of dependence of energy on quasi-momentum for electrons in a periodic lattice field. Closed and open Fermi surfaces. Density of states. Quasiparticles. Elementary formulas for conductivity and thermal conductivity. Electron free path length. Electron-phonon collisions (conditions for conservation of energy and momentum). Temperature dependence of conductivity and thermal conductivity. Wiedemann-Franz law. Landau diamagnetism and Pauli paramagnetism. Anomalous skin effect. Cyclotron resonance. Quantum oscillations of magnetic moment and resistance.
7. Superconductors
   Change in free energy, entropy, heat capacity during the transition of a metal from a normal state to a superconducting state in a magnetic field. BCS relations for Tc and gap. Electronic energy spectrum of excitations in a superconductor and a normal metal. Relation between the gap width and Hc at T = 0. Temperature dependence of the heat capacity and thermal conductivity of superconductors at T<< Tc. Coherence length and penetration depth. Expression of these quantities in terms of the gap width, Fermi velocity, mass and density of electrons. Magnetic flux quantization. Josephson effects. Superconductors of the I and II kind. Curves of magnetization. Structure of superconductors in a mixed state. Abrikosov vortex.
8. Helium-4 and helium-3.
   Phase diagram of 4He and 3He. The energy spectrum of superfluid 4He and the critical Landau velocity. Temperature dependence of the phonon and roton contributions to the heat capacity. Thermomechanical effect. 1st and 2nd sounds. Vortices in superfluid 4He. Fermi liquid: degeneracy temperature, heat capacity, viscosity, thermal conductivity.

Reference

1. Киттель Ч. Введение в физику твердого тела. М.: Наука, 1978.
2. Ашкрофт Н., Мермин Н. Физика твердого тела. Т. I, II. М.: Мир, 1979.
3. Уэрт Ч., Томсон Р. Физика твердого тела. М.: Мир, 1969.
4. Займан Дж. Принципы теории твердого тела. М.: Мир, 1974.
5. Шмидт В.В. Введение в физику сверхпроводимости. МЦ НМО, М., 2000.
6. Л. Д. Ландау, Е.М. Лифшиц. Статистическая физика, М, Наука, Физматлит, 1995.
7. Л.Д. Ландау, Е.М. Лифшиц. Электродинамика сплошных сред, М, Наука, Физматлит,2001.

HIGH ENERGY PHYSICS SECTION

1. Experimental methods in high energy physics

1.1. Interaction of radiation with matter

1.1.1. Ionization loss

The Fermi model for the Coulomb interaction of a charged particle with atomic electrons. The spectrum of recoil electrons. Bethe-Bloch formula. MIP concept. Limits of applicability. density effect. Fermi plateau. Limited losses. Loss fluctuations. Landau distribution. Ionization losses as the main mechanism for particle detection.

1.1.2. Cherenkov and transition radiation

Cherenkov distortion as an interference effect. Threshold character of Cherenkov distortion. Kinematic interpretation of Cherenkov distortion. Spectrum, angular distribution and polarization of Cherenkov distortion. Cherenkov distortion as a part of ionization losses. Identification of particles by registering Cherenkov distortion. Transition radiation from the media interface. Transition radiation from foil and slit. Transition radiation from the regular structure. Optical transition radiation and X-ray transition radiation. Saturation of transition radiation as a function of the Lorentz factor of a particle. Identification of particles by registration of FIR.

1.1.3. Multiple scattering.

Rutherford scattering. The concept of radiation length. Angular scattering distribution.

1.1.4. Bremsstrahlung and pair production.

TI in the field of the nucleus. Shield length. critical energy. Creation of electron-positron pairs by -quantum in the field of the nucleus. Bethe-Heitler formulas. Electromagnetic cascade. Cascade model. Longitudinal cascade. The approach of Rossi. Molière radius.

1.1.5. Additional questions of radiation and interaction with matter. Synchrotron radiation. Absorption of low-energy -quanta by matter: Compton scattering; photoelectric effect; Rayleigh scattering. Interaction of very high energy muons with matter. Interaction of hadrons with matter, its general characteristics. Nuclear cascade.

1.2. Particle and radiation detectors

1.2.1. Gas particle detectors.

Physical processes in gas: primary and total ionization; -electrons; drift and diffusion of charged particles; gas amplification; breakdown; photoionization and photoabsorption. Ionization chamber. Waveform. Inductive effect. Cylindrical proportional counter. Multi-wire proportional chamber, drift chamber, drift tube, GEM. Time is a projection camera. dE/dx iparticle identification.

1.2.2. Semiconductor detectors.

Band structure of a semiconductor. Intrinsic and impurity conductivity; ionization; thermalization; drifting; recombination. Noises in p / conductor. The need semiconductor detectors or impoverishment. Transfer capacity. PIN detector. Formation of a signal in semiconductor detectors. Permission. Spectrometric and track semiconductor detectors. Vertex detector.

1.2.3. Scintillators and photodetectors.

Types and properties of scintillators, main characteristics; scintillation mechanisms. Birks effect. Synchronous motor structures. Vacuum PMT, main processes and characteristics: photo- and thermal emission from a semiconductor photocathode; secondary issue; optical and ionic feedback; bulk charge. PMT noise. Semiconductor photodetectors. Cellular avalanche photodiode.

1.2.4. Cherenkov and transition radiation detectors. Cherenkov counters. Threshold, differential and multi-channel counters. Cherenkov radiation ring detector. Transition radiation detectors (TRD). Radiator, detecting elements.

1.2.5. Calorimeters and installations.

Types of calorimeters. Electromagnetic calorimeter. Resolution factors: charge and sample collection fluctuations, leakage, noise. Linearity. Radiation resistance of the calorimeter. Hadron calorimeters: additional energy (and spatial) resolution factors. Designs of calorimeters. Main detectors and typical arrangements of installations in high energy physics.

Reference

1. К.Н. Мухин. Экспериментальная ядерная физика. М.: Энергоатомиздат, 1985.
2. Ю.К. Акимов. Полупроводниковые детекторы в экспериментальной физике. М.:Энергоатомиздат, 1989.
3. Ю.К. Акимов Фотонные методы регистрации излучений. Дубна: ОИЯИ, 2006.
4. А.И. Абрамов, Ю.А. Казанский, Е.С. Матусевич. Основы экспериментальных методовядерной физики. М.: Энергоатомиздат, 1985.
5. Ю.А. Будагов и др. Ионизационные измерения в физике высоких энергий. М.:Энергоатомиздат, 1988.
6. К. Клайнкнехт. Детекторы корпускулярных излучений. М.: Мир, 1990.
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8. Walter Blum,Werner Riegler, Luigi Rolandi. Particle Detection with Drift Chambers. Springer,2008. e-ISBN: 978-3-540-76684-1.

Additional literature

1. C. Grupen. Particle Detectors. Cambridge: University Press. 1992.
2. В.Л. Гинзбург. Теоретическая физика и астрофизика. М.: Наука, 1981.
3. Л.Д. Ландау, Е.М. Лифшиц. Электродинамика сплошных сред (г.VHI). М.: Наука, 1982.
4. А.И. Ахиезер, Н.Ф. Шульга. Электродинамика высоких энергий в веществе: М. Наука,1993.

2. Statistical and numerical methods for data analysis

2.1. Use of grid computing in high energy physics.

2.1.1. Characteristics and types of grid systems

Grid resources and virtual organizations. Grid architecture. Middleware. European Grid Infrastructure.

2.1.2. Organization of practical work in Grid.

Tasks in Grid. Task types. Launch, getting results. Basic principles of working with data in Grid. Concepts SURL, TURL, LFN. Information system in Grid.

2.2. Statistical Methods in high energy physics.

2.2.1. Confidence interval and confidence limits.

Frequency approach. On the example of a normal distribution. Bayesian approach on the example of Poisson distribution with non-zero background. Maximum likelihood method on the example of the Poisson distribution.

2.2.2. Hypothesis testing.

Accounting for systematic errors. Hypothesis testing. Statistical software in problems of high energy physics.

2.3. Neural networks

2.3.1. Neural networks

Mathematical model of a neuron. Activation functions of neural elements. Training with a teacher. Delta rule for adjusting weights. Single-layer and multilayer neural networks. Signal propagation in multilayer networks. Backpropagation algorithms for learning multi-layer neural networks.

2.4. Application software in high energy physics.

2.4.1. ROOT programming environment

Setting and building graphs and functions, working with a graphics editor, an introduction to random number generators. Types of histograms: 1D, 2D and profile.

2.4.2. Modeling in the ROOT environment

Monte Carlo simulation method. Classes for working with 4-vectors. Basic data fitting methods. Modeling the decay of a pion into 2 gamma quanta. Basic methods of working with data arrays. Extraction of information from objects of type TTree and their analysis. Simulation of the operation of an electromagnetic calorimeter. Event generators on the example of the PYTHIA generator. Simulation of the process of formation of a lepton pair in pp collisions.

2.4.3. Application of databases and Internet technologies in high energy physics.

Databases on the example of MySQL. Basic MySQL commands. Formation of queues of requests to the database. Familiarity with Internet technologies - HTML, PHP.

2.5. Main methods of reconstruction and analysis in high energy physics.

2.5.1. Basic methods of reconstruction and analysis and physical processes in high energy physics. Basic components of interaction modeling. Main types of generators. Acquaintance with the program for modeling detectors and processes in them GEANT. Methods for determining the parameters of charged particles. Basic algorithms for determining jet parameters. The problem of double counting for jets and methods for its solution. Basic ideas of b-tagging.

Reference

1. Б. Эккель. Философия С++. Практическое программирование. СПб. Питер, 2004.
2. С. Прата. Язык программирования С++. Москва, DiaSoft, 2005.
3. Д.Худсон. Статистика для физиков. Москва, Мир, 1970.
4. Е.Бюклинг, К.Каянти. Кинематика элементарных частиц. Москва, Мир, 1973.
5. http://root.cern.ch
6. С. Осовский; Нейронные сети для обработки информации, М: Финансы и статистика,2002.
7. В.В. Круглов, "Искусственные нейронные сети", Телеком, 2001.
8. G. Cowan, Statistical Data Analysis, Oxford Univ. Press, 1998.
9. R. J. Barlow, Statistics, J. Wiley, 1989.
10. С. Битюков, Н. Красников, Применение статистических методов для поиска новой физикина Большом Адронном Коллайдере, e-Print -- arXiv: 1107.3974 [physics.data- an], 2011.
11. Jacob, Bart; et.al.Introduction to Grid Computing. IBM. http://www.redbooks.ibm.com/abstracts/sg246778.html?Open
12. GEANT - Detector Description and Simulation Toolhttp://wwwasd.web.cern.ch/wwwasd/ geant/
13. Pythia event generator http://root.cern.ch/root/html/tutorials/pythia/index.html

3. Fundamentals of accelerators physics

3.1. Principles of accelerators operation

3.1.1. Importance of accelerators in physical sciences and technologies

Classification of accelerators. Application of accelerators. Colliding beams, luminosity, modern colliders. Electronic and ion sources of charged particles. Linear accelerators: direct high voltage accelerators, Van-de-Graaff accelerator, tandem accelerators, cascade accelerators, linear accelerators. Cyclic accelerators with constant orbit: betatron, synchrotron. Cyclic accelerators with installation into orbit: cyclotron, microtron.

3.1.2. Resonant acceleration

Resonance principle of acceleration. Linear accelerators of electrons, ions (Alvarez accelerator), RFQ accelerator, meson factories. Synchrotrons with combined and separated functions of the magnetic structure. Examples of high-energy synchrotrons: Dubna, Booster IHEP, U-70, LHC, accelerating-storage complex, Omega project at IHEP.

3.1.3. Synchrotron: device and principle of operation

The concept of focus. Reference orbit. Change in the magnetic field, coefficient of expansion of the orbit. Acceleration in the synchrotron: principle of autophasing, synchronous energy and synchronous phase, critical energy, equations of synchrotron motion, synchrotron oscillations.

Reference

1. А.А. Коломенский, А.Н. Лебедев. Теория циклических ускорителей. М., Физматгиз, 1962.
2. А.А. Коломенский. Физические основы методов ускорения заряженных частиц.Издательство Московского университета, 1980.
3. А.Н. Лебедев, А.В. Шальнов. Основы физики и техники ускорителей. М., Энер-гоатомиздат, 1991.

4. Fundamental interaction theory
   - 4.1. Quantum electrodynamics
     - 4.1.1. Distribution function
     - 4.1.2. Electromagnetic field
     - 4.1.3. Free relativistic particles with mass
     - 4.1.4. Free particles with spin 'A
     - 4.1.5. Electron Green's function
     - 4.1.6. Matrix elements of scattering amplitudes
     - 4.1.7. Interaction with a photon of an electron and a scalar particle
     - 4.1.8. Scattering of a photon by an electron and a scalar particle (Compton effect)

4.1.9. Electron-positron annihilation

4.1.10. Scalar particles annihilation

4.1.11. Weizsäcker-Williams formula

   - 4.2. Weak interactions
     - 4.2.1. Structure of weak currents
     - 4.2.2. Muon decay
     - 4.2.3. Leptonic decays of hadrons
     - 4.2.4. Neutral K mesons, decays and mixing
     - 4.2.5. CP violation
     - 4.2.6. Tau lepton decays
     - 4.2.7. Decays of charmed particles
     - 4.2.8. Quark mixing matrix
     - 4.2.9. Gauge invariance
     - 4.2.10. Standard model of the electroweak interaction
     - 4.2.11. Spontaneous symmetry breaking
     - 4.2.12. Properties of intermediate bosons
     - 4.2.13. Properties of the Higgs bosons

Reference

1. М. Пескин, Д. Шредер, «Введение в квантовую теорию поля», Addison-WesleyPublishingCompany (русский перевод: Научно-издательский центр «R&C Dynamics», Москва-Ижевск, 2001 г.)
2. В.Н. Грибов, «Квантовая электродинамика», Научно-издательский центр «R&C Dynamics», Москва-Ижевск, 2001г.
3. Р. Фейнман, «Квантовая электродинамика», издательство «Мир», Москва, 1964 г.
4. Л.Б. Окунь, «Лептоны и кварки», Москва, «Наука», 1981 г.

Additional literature

1. Дж.Д. Бьёркен, С.Д. Дрелл, «Релятивистская квантовая теория (в 2х томах)», И: Наука, 1978 г.

5. Introduction to high energy physics
   5.1. What does high energy physics study and how
   Masses of particles. Particle sizes. Natural units. Types of fundamental interactions. Section. Luminosity. Typical experiments. Kinematics of reactions. Reaction thresholds. Binary reactions. Distribution transformations. two-body decays. Three-body decays. Inclusive and exclusive responses.
   5.2. Scattering theory
   Expression of scattering amplitude in terms of phases. Optical theorem. Breit-Wigner formula. Diffraction scattering. Baryon and meson resonances.
   5.3. Isotropic symmetry
   Hadrons. SU(2) symmetry. Clebsch coefficients. SU(2) symmetry in strong and weak interactions. Violation of SU(2)-symmetry.
   5.4. Scattering of electrons on nucleons and nuclei
   Derivation of the Rutherford formula. Form factor. Møller and Rosenblat formulas. Nucleon form factors.
   5.5. Rigid processes (1)
   e+e- into hadrons. Full section. Jets. Color.
   5.6. Systematics of hadrons
   Quark model, SU(3)f symmetry, color. Mesmons, baryons, heavy quarkonia.
   5.7. Rigid processes (2)
   Deep inelastic interaction. Kinematics. Scaling. Parton model.
   5.8. Discrete symmetries
   P, C, T -symmetry. Identity of particles. Relationship between spin and statistics
   5.9. Dirac equation. Wave function of particles with spin U. Particles and antiparticles.
   Weak interactions
   5.10. Decays of leptons. P-parity violation. Current-current interaction. Fermi constant. Decays of hadrons. Universality of the weak interaction.
   5.11. Quark mixing
   Quark mixing matrix. CP violation. Experiments to study the decay of heavy quarks.
   5.12. Neutrino
   Neutrino masses. Dirac and Majorana neutrinos. Interaction of neutrino with matter. Oscillations.
   5.13. Intermediate bosons

Birth of intermediate bosons in hadronic interactions. Birth of Z-bosons in e+e- interactions. Masses, widths, decay probabilities.

5.14. Information about the standard model

Problems of the Fermi model. Gauge theories. Higgs model. Properties of the Higgs boson.

Reference

1. Д. Перкинс. Введение в физику высоких энергий. Энергоатомиздат, 1991.
2. Ф. Клоуз. Кварки и партоны. М.: Мир, 1988.
3. Ф. Хелзен, А.Мартин. Кварки и лептоны. Москва, Мир, 1987.
4. Л.Б. Окунь, Лептоны и кварки, Наука,М., 1981.
5. Л.Б. Окунь. Физика элементарных частиц. М.: Наука, 1988.

6. Phenomenology in high energy physics

6.1. Electromagnetic interactions

6.1.1. Higher orders in QED. Lamb shift. The contribution of hadrons to ae. Anomalous magnetic moment of the muon. Measurement of the muon's anomalous magnetic moment

6.1.2. Electromagnetic properties of hadrons. Relative widths of V—>ll- decays in the quark model. Relative widths of V—Py decays in the quark model. Vector meson dominance model. Primakov's reactions. Approximation of equivalent photons.

6.1.3. Experiments to measure the quantum numbers of hadrons. Spatial parity of the pion. Pion spin. C-parity of a pion. Examples of allowed and forbidden (suppressed) reactions.

6.1.4. Experiments to test C, P, T invariance. How different quantities are transformed in P and T inversions. Comparison of cross sections for forward and backward reactions. Observation of P-parity non-conservation in weak interactions. Combined parity.

6.1.5. Measurement of the electric dipole moment of the neutron.

6.2. Strong interactions

6.2.1. QCD Lagrangian

Local transformation SU(3)c. Eight massless gluons. Self-action of gluons. Non-Abelian. QCD Lagrangian

6.2.2. Asymptotic freedom, confinement. Evolution of as with q2. Asymptotic freedom. Confinement

6.2.3. Hadron models. Potential model. Bag model. Tubes. Heavy quarkonium

6.2.4. Exotic hadrons

What states can be realized in a non-relativistic model. Glueballs. Hybrid Mesons and baryons. Multiquark states. Pentaquark baryons. X, Y, Z states.

6.2.5. Chiral symmetry, quark masses. Chiral symmetry SU(2)L x SU(2)R. The pion as a pseudo-Goldstone boson. Chiral symmetry SU(3)L x SU(3)R. Masses of u and d - quarks

6.2.6. Jets

Factorization of hard and soft processes. Detection of jets in experiments on e+e colliders. Jet selection algorithms (cone, kt...). Jets characteristics. Jet energy calibration methods.

6.2.7. Multiple processes

Rapidity and pseudorapidity. Ladder model. Fragmentation and recombination. Counting rules for processes with small pt.

6.2.8. Reggistics

Dispersion relations. Unitarity. Cross symmetry. Chew-Frautschi diagram. Pomeron. Phenomenology of binary reactions.

6.2.9. Quark-gluon plasma. Phase diagram. Critical temperature. Collective properties

6.3. Standard model

6.3.1. Structure of weak interactions at low energies, parity nonconservation. Current-current Interaction. The versatility of the charged current. Fermi constant. Left charged currents. Neutral current. Muon decay. Muon decay experiments.

6.3.2. Pion decay Cabibbo angle. Conservation of the vector current. Experiments to study pion decay.

6.3.3. P-decay of the neutron. General view of the vector and axial currents. Vector form factors. Axial form factors. Partial conservation of the axial current Experiments on the study of neutron decay.

6.3.4. Decays of kaons. Nonleptonic decays.

6.3.5. Neutral kaons. Transitions K°<^K°. The difference between the masses of K1 and K2. Oscillations of strangeness. GIM mechanism. Regeneration.

6.3.6. Non-preservation of CP. Decays K-l+l-. Phenomenology of CP violation. CP - non-invariant effects. Experiments to study CP violation in kaon decays.

6.3.7. Tau lepton

Lepton decays. Semi-hadron decays. Experiments to study the decays of the tau lepton.

6.3.8. Decays of heavy quarks Mesons with d and b quarks. Lepton decays. Nonleptonic decays. Top quark.

6.3.9. CP-parity nonconservation in heavy quark decays. CCM matrix Measurement of constants V ij. Triangle CCM.

6.3.10. Neutrino interactions. Interaction of a neutrino with an electron. Interaction of neutrinos with nucleons Experiments on direct measurement of neutrino mass.

6.3.11. Neutrino oscillations Oscillations for a system of two neutrinos. Oscillation experiments. Interaction with matter. General view of the mixing matrix for three neutrinos.

6.3.12. Lagrangian of the standard model. Properties Z,W. Masses of W and Z bosons. Weak charges of neutral currents. Masses of leptons and quarks. Experiments to measure the parameters of W and Z bosons.

6.3.13. Properties of H bosons. Restrictions on the mass of the Higgs boson. The role of the Higgs boson at high energies. Interaction of the H-boson with quarks. Interaction of the H-boson with gluons and photons. Discovery of the Higgs boson.

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