**STATE FINAL CERTIFICATION**

1. **GENERAL CHARACTERISTIC OF THE DISCIPLINE**

The programme of the discipline is disegned in accordance with the Federal State Educational Standards of Higher Education

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| Degree Code | Degree/Specialty | Requisites of the Order of the Ministry of Education and Science of the Russian Federation on Approval and implementation of the FSES of Higher Education |
| Date | Order No |
| 03.06.01 | Physics and Astronomy/01.04.02 – Theoretical Physics | 30.07.2014As amended on30.04.2015 | 867Amendments464 |

**1.1 The purpose of the State Final Certification**

The purpose of the State Final Certification is to test the graduate's ability and readiness to perform professional tasks in the field of professional activity and compliance of his preparation with the requirements stated in the passport of the Main Curriculum of the Higher Education. Within the framework of the State Final Certification, the maturity level of the following learning outcomes declared in the academic programme is checked:

Learning outcomes -2: The ability to conduct scientific research in the field of theoretical physics;

Learning outcomes -3: The ability to analyse and present the results of scientific research in the field of theoretical physics.

As a result of the State Final Certification, the graduate student should master the following competencies:

**general professional competences:**

* the ability to independently carry out research activities in the relevant professional field using modern research methods and information and communication technologies (General Professional Competencies-1);

**professional competences:**

* the ability to freely master the fundamental sections of physics necessary to solve research problems in the field of theoretical physics (Professional Competencies -1);
* the ability to use the knowledge of modern problems of physics, the latest achievements of physics in their research activities (Professional Competencies -2);
* the ability and readiness to apply in practice skills of drawing up and registration of scientific and technical documentation, scientific reports, reviews, reports and articles (Professional Competencies -3);
* the ability to use the search engines of scientific information in the state and foreign languages (Professional Competencies -4).

**1.2 The structure of the State Final Certification:**

* preparation for sitting and passing the state examination
* presentation of a scientific report on the main results of the prepared scientific and qualification work (thesis)

**1.2.1 The form of the state examination**

Oral

**1.3. The workload of the State Final Certification**

The total workloadof the State Final Certification is 9 credits.

* 1. **Time of the State Final Certification**

The state examination - the seventh semester

Presentation of the scientific report – the eighth semester

* 1. **Requirements for the procedure of the State Final Attestation**

Requirements for the procedure for planning, organizing and conducting the State Final Attestation, for the structure and layout of documents on the organization of the State Final Attestation are formulated in the documented procedure of the State Final Certification of Graduates (QMS-DP-8.2А-02-2010) approved in UrFU.

The requirements for the order of execution and registration of graduation paper at the Institute of Natural Sciences are formulated in the Regulations on the Order of Execution, Registration and Submission of Bachelors`, Graduates`, Masters` and Postgraduates` Graduation Papers for Presentation at the Institute of Natural Sciences of the Ural Federal University (approved by the Methodological Council of the UrFU Institute of Natural Sciences, Minutes No. 6 of 23.03.2012, as amended on 20.03.2015, Minutes No. 36).

**1.6 Requirements for the assessment of the results of completing the degree programme within the framework of the State Final Certification.**

An objective assessment of the level of compliance of learning outcomes with the requirements for completing the degree programmeis ensured by a system of developed criteria (indicators) for assessing the acquisition of knowledge, the formation of skills and the experience of performing professional tasks.

Assessment criteria were adopted at the meeting of the Educational and Methodological Council of the UrFU Institute of Natural Sciences of April 3, 2014, Minutes No. 24 and approved at the meeting of the Academic Council of the Institute of Natural Sciences of April 21, 2014, Minutes No. 4.

**2. REQUIREMENTS TO THE CONTENT OF THE STATE FINAL CERTIFICATION**

**2.1 Subject matter of the scientific paper**

The topic of the scientific paper is directly related to the scientific activity of the graduate chair and other profile enterprises with which agreements on cooperation were concluded.

**2.2 The subject matter of the state examination**

**1. Theoretical and group methods**

Symmetry and conservation laws. Symmetry groups. The Wigner theorem. The method of irreducible tensor operators of the rotation group. The Wigner-Eckart theorem. Fundamentals of the Jucys-Levinson graphic technique. Point groups. The method of irreducible tensor operators of the cube group. Spatial groups of crystals. Irreducible representations. Groups of magnetic symmetry.

**2. The theory of phase transitions and critical phenomena.**

Elements of the thermodynamic description of the condensed matters. Generalised susceptibilities. Spontaneous symmetry breaking, quasi-average and anomalous Green's functions. The Landau theory of phase transitions of the second kind, order parameters, fluctuations, functional integration. Critical indexes and scaling. Wilson's renormalization group. Epsilon- and l / n-decomposition for critical indices. Symmetry of crystals and phase transitions. Lifshitz`s criteria. Orientational phase transitions. Peculiarities of the behaviour of susceptibilities in phase transitions.

**3. Elements of quantum statistical mechanics.**

The satistical operator and thermodynamic functions. Statistical operators of particle complexes. The Wick-Bloch-de Dominicis theorem. Degeneracy of states and quasi-averages. Methods of the quantum field theory at T = 0. Green's functions, physical meaning, analytical properties. Basic principles of the diagram technique, rules for constructing diagrams for various types of interactions. The Dyson equation, the vertex part, Green's many-particle functions, ground-state energy. The diagram technique at finite temperatures. Green's temperature (Matsubara) functions, connection with the Green's time functions. The diagram technique for various types of interaction. The thermodynamic potential. Fundamentals of the Keldysh technique. Green's two-time functions. Delayed, leading and causal functions of Green. Spectral representations and sum rules. Chains of equations of motion and methods of uncoupling. The reaction of the system to the external action, the Kubo formula.

**4. Micron-electron atoms in crystals \***

Classification of the states of a free atom. Electrostatic interactions. Spin-orbit interaction. Theory of the crystal field (CF). Many-electron configurations in the scheme of a strong cubic CF. High and low-spin states of ions with an unfilled 3d shell. The scheme of the average CF. Crystalline 28 + 1G terms. Scheme of the weak CF. The method of the Stevens equivalent operators. The theory of the single-ion magnetic anisotropy of rare-earth ions and ions of the iron group. Ultrafine interactions. Interaction of atoms in crystals. Exchange and exchange-relativistic interactions. Spin models of Heisenberg, Ising, Dzyaloshinski-Moriya . Non-Heisenberg spin Hamiltonians.

**5.The electronic theory of metals.**

Fundamentals of the Fermi-liquid theory. The Landau phenomenological formulation. The proof of the main relations of the Fermi-liquid theory by the Green's function method. Coulomb systems and screening, small and high density approximations. The Boltzmann kinetic equation for electrons in a metal. Electrical conductivity of metals. Scattering of electrons in metals by impurities, phonons and electrons. Temperature dependences of electrical conductivity and electronic thermal conductivity. Matissein's rule. The Kondo effect. The influence of the topology of the Fermi surface on the electrical conductivity of the metal. The Lifshitz formula. Electronic properties of metals in a magnetic field. Landau levels. Oscillation of magnetic susceptibility. The Einstein - de Haas and Shubnikov effects. The cyclotron resonance. The longitudinal magnetoresistance. Strong and weak magnetic fields. The influence of the topology of the Fermi surface on the electrical conductivity of metals in a magnetic field. Galvanomagnetic effects. Transverse magnetoresistance. Magnetooscillation effects. The classical and quantum Hall effects.

**6. Methods of the band theory of crystals.**

Hamiltonian systems of electrons and ions. Approximations of the model. Adiabatic approximation. The Hartree-Fock method. Approximation of a strong and weak connection. Brillouin zones. The Fermi surface. Methods of calculating the band structure, the method of attached plane waves. Pseudopotentials. Fermi surfaces of *d* and *f* metals. The theory of the electron density functional (DFT). The approximations of LDA, LSDA, LDA + U. The theory of the dynamic mean field.

**7. Vibrations of lattices, phonons.**

Symmetry of crystals and classification of phonon modes. Acoustic and optical phonons. The dispersion law of phonons. Elements of the kinetics and thermodynamics of the phonon gas at low temperatures. The kinetic Boltzmann equation for the phonon gas. Approximation of the relaxation time. Normal processes and umklapp processes. The phonon gas in an ideal dielectric. The second sound, the conditions of its occurrence. The potential of intermolecular interaction. Phonon heat capacity and thermal conductivity. Spectroscopy of phonons. Quantum crystals. The stability condition of the crystalline state. The de Boer parameter. Quantum diffusion. Vacancions. Impuritons. The model of hard ions and the shell model of a crystal. Electronic-vibration interactions. Hamiltonian. Electron-lattice relaxation. The theory of screening effects. The theory of the Jahn-Teller effect. The polarons. Orbital ordering. Cooperative Jahn-Teller ordering.

**8. The theory of superconductivity.**

The Meissner effect. The critical field and the critical current. Thermodynamics of the phase transition from the normal state to the superconducting state. The depth of the magnetic field penetration into the sample. Quantization of the flow. The coherence length. The Ginzburg-Landau equation. Two kinds of superconductors. Abrikosov vortices. The theory of the Josephson effect. The microscopic theory of the stationary Josephson current. The non-stationary Josephson effect. The method of the tunnelling Hamiltonian. Electrodynamics of weak superconductivity. Quantum interference. The nonlinear wave equation. Interaction of electrons through virtual phonons, Cooper pairing. The Bardeen-Cooper-Schrieffer theory. Bogolyubov's n-v-transformation method. The Gor'kov equations. The energy gap. The superconducting transition temperature. Models of exciton superconductivity of Little and Ginzburg. Basic model theories of high-temperature superconductivity.

**9. Selected questions of the theory of low-dimensional systems.**

Two-dimensional electronic systems. Wigner crystallization.

Topology of two-dimensional systems. Spin 2D models. Topological defects. Whirlwinds, skyrmions. The theory of Berezinsky-Kosterditz-Thouless. 1D and 2D Ising model. Quantum magnets. Magnetic frustration. Incompatible structures. Spin-helical systems, helimagnets.

**10. Elements of the theory of disordered systems.**

Classification of disordered systems. Elementary excitations in disordered media. Methods of description. Density of states. Anderson`s basic ideas about localization, the scaling theory. General characteristics of the spectrum of elementary excitations in disordered media. Fluctuation boundaries of the spectrum. The structure of the spectrum near the fluctuation boundaries. Limits of mobility. Electrons in the field of random impurities, ladder approximation, quantum and Coulomb corrections. Phonons in disordered systems. Excitons in disordered systems. Spin glasses. The Edwards-Anderson model. The Parisi theory.

**11. Standard models and methods of the theory of strongly correlated systems.**

The Shubin-Vonsovsky s-d model. The Bogolyubov-Levdin model. The Anderson model. The Hubbard model. Approximations of the mean field (+ RPA). The Hartree-Fock approximation. Solving the simplest realizations of the Anderson and Hubbard models in the Hartree-Fock approximation. The Monte Carlo method. Classic and quantum options. Examples of solving problems in the theory of strongly correlated systems. Quantum magnets. Spin Hamiltonians, the localized and collectivized model. Representations of spin operators by secondary quantization operators. Wick's theorem for spin operators and the basis of the diagram technique. The method of the molecular field, spin waves. The Hubbard model, strongly correlated systems, the Mott transition. Pseudospin formalism in strongly correlated systems.

**3. EDUCATIONAL-METHODICAL AND INFORMATIONAL SUPPORT OF THE STATE FINAL CERTIFICATION**

**Recommended Literature**

13. P.A. Lee, T.V. Ramakrishnan. Disordered Electronic Systems. Rev.Mod.Phys. 57, No.2, 287 (1985).

16. Handbook of Magnetism and advanced magnetic materials, Volume I: Fundamentals and Theory, Eds. H. Kronmueller and S. Parkin, Wiley, 2007. 700 p.

**Additional Literature**

2. R.D. Mattuck. D. Johansson. Adv.Phys. 17, 509 (1968),

14. A.S. Moskvin, Spin and Pseudospin Models: Hamiltonians, Topological Excitations, The Physics of Metals and Metallography (ФММ), Vol. 95, Suppl. 1, 2003, p. 41.

**Databases, information and reference systems**

Electronic resourcesScienceDirect: http ://www. sciencedirect.com:

Electronic resources Web of Science: http://apps:webofknowled&e.com:

Electronic resources ScienceDirect: http://www.scifmder.com

Electronic resources Web of Science: http://reaxvs.org