APPROVED
at a meeting of the Academic Council of
NJSC «KazNU named after al-Farabi»
Protocol № 11 from 23. 05. 2025 y.

The program of the entrance exam for applicants to the PhD for the group of educational programs D101 - «Materials Science and Technology of New Materials»

I. General provisions

1. The program was drawn up in accordance with the Order of the Minister of Education and Science of the Republic of Kazakhstan dated October 31, 2018 No. 600 «On Approval of the Model Rules for Admission to Education in Educational Organizations Implementing Educational Programs of Higher and Postgraduate Education» (hereinafter referred to as the Model Rules).

2. The entrance exam for doctoral studies consists of writing an essay, an exam in the profile of a group of educational programs and an interview.

Блок	Баллы
1. Interview	30
2. Essay	20
3. Exam according to the profile of the group of the educational program	50
Total admission score	100/75

3.The duration of the entrance exam is 3 hours 10 minutes, during which the applicant writes an essay and answers the electronic examination ticket. The interview is conducted at the university premises before the entrance exam.

II. Procedure for the entrance examination

1. Applicants for doctoral studies in the group of educational programs D101 - «Materials Science and Technology of New Materials» write a problematic / thematic essay. The volume of the essay is at least 250 words.

The purpose of the essay is to determine the level of analytical and creative abilities, expressed in the ability to build one's own argumentation based on theoretical knowledge, social and personal experience.

Types of essays:

- motivational essay revealing the motivation for research activities;
- scientific-analytical essay justifying the relevance and methodology of the planned research;
- problem/thematic essay reflecting various aspects of scientific knowledge in the subject area.

2. The electronic examination card consists of 3 questions

Topics for exam preparation according to the profile of the group of the educational program:

Modern Materials Science

1. **Ultrafine and Nanostructured Materials. Applications. Nanopowders and Their Synthesis Methods.** Deposition, sol-gel method, reduction and thermal decomposition. Physical and mechanical methods for powder production. Chemical synthesis techniques.

2. **Bulk Nanostructured Materials and Their Production Methods.** Controlled crystallization of amorphous materials. Compaction of ultrafine powders. Severe plastic deformation of conventional-grained materials. Nanowires and nanofibers. Processing of metallic, ceramic, and diamond-based nanomaterials. Technologies for composite materials and nanostructured coatings. Structure and property analysis and control methods.

3. **Monocrystal Growth. Defect Formation in Dislocation-Free and Low-Dislocation Crystals.** Influence of impurities. Wafer manufacturing. Formation of device structures. Epitaxial growth. Silicon optoelectronics challenges. Thin-film structures based on hydrogenated amorphous silicon. Fullerenes as materials of the future.

4. **Metal Matrix Composites.** Composites with Al, Mg, Ti matrices. Immiscible metal-based composites. Copper-based systems. Laminated composites. Glass-fiber reinforced aluminum (SIAL). Heat-resistant composites from refractory metals. Carbon–carbon composites. Ceramic-metal composites (cermets). Transformation-toughened ceramics.

5. **Powder Production. Functioning, Purification, Mixing, Degassing.** Processing and application of modern inorganic powder materials. Powder compaction. Powder steels. Production of powder components. Structure and property control in powders and products.

6. **Structural Materials for Extreme Conditions.** Heat-resistant steels and superalloys. Applications and service conditions. Ni-, Fe-Ni-, and Co-based alloys. Single crystals, eutectics, permeable alloys, modern Ni-based disk alloys, intermetallics, titanium and iron-based alloys.

7. **High-Reliability Structural Steels and Alloys. High-Strength Steels.** Corrosion-resistant steels and special-purpose alloys. Shape memory alloys. Shape memory and superelastic effects. Superferritic and austenitic steels.

8. **Amorphous Metal Alloys. Production and Properties.** Mechanical, magnetic, and chemical properties. Thermal stability. Superplasticity: types and mechanisms. Superplastic ceramics and metallic glasses. Phase-transition-related superplasticity.

9. **Synthesis of High-Strength Polycrystalline Diamonds.** Use of complex alloyed catalysts. Ni-Cr, Ni-Cr-C systems. High-strength polycrystalline diamonds for tooling. Large diamond monocrystal growth. Applications in high-tech industries.

10. **New Magnetic Materials.** Hard magnets (Fe-Ni-Al-Co, Fe-Cr-Co, Mn-Al, Co-Pt, Fe-Pt systems). Sintered and film permanent magnets. Soft magnetic materials, electrical steels, precision alloys (Fe-Ni, Fe-Co), amorphous and nanocrystalline alloys, ferrites (spinel, hexagonal, garnet structures).

11. **Superconductivity Phenomenon.** Superconducting state and major superconducting material groups. Composite superconductors and design principles.

12. **Physical Materials Science of Films and Multilayer Systems.** Surface property modification via coatings. Deposition technologies for inorganic coatings. Modern analytical and structural characterization techniques.

13. **Multicomponent Nanostructured Films.** Self-lubricating coatings for medical applications. Thermal-conductive, corrosion-resistant, and high-temperature oxidation-resistant coatings. Acousto-optic and microelectronic coatings. Multilayer optical coatings.

14. **Material Classification Approaches.** Structural vs. functional materials. Classification by functional properties.

15. **Semiconductor Quantum Dots as Replacements for Traditional Phosphors.** Heterostructures and superlattices. Applications in biology. Thermoelectric materials. Ternary semiconductors and heterostructures. Dye-sensitized solar cells (Grätzel cells), mesoporous oxide semiconductors, clathrates, and skutterudites.

Functional Materials and Coatings

16. **Substances, Phases, Defects. Band Structure of Crystals.** Dielectrics, semiconductors, metals. Catalysts, glasses, superconductors. Material formation principles. Phase transitions. Crystal growth and synthetic crystals. Whiskers. Thin film fabrication.

17. **Dielectric Structure and Polarization Mechanisms.** Ionic relaxation, ion migration, disordered dielectrics. Electrets, piezoelectrics, polycrystalline dielectrics.

18. **Diamond-like Semiconductors.** III-V and II-VI semiconductors, chalcogenides of group IV-V elements. High-temperature semiconductors. Crystal purification and growth from gas phase. Sublimation-condensation method. Doping. Oxide semiconductors.

19. **Film as a Composite: Interaction with Substrate.** Deposition conditions and morphology. Epitaxy. Film deposition techniques. Spectrophotometry. Applications of thin-film nanomaterials.

20. **Nucleation Theory and Film Formation.** Defect formation during growth. Surface adsorption and thermal accommodation. Interaction processes, etching, physical sputtering, cathodic sputtering. Film properties: adhesion, wear resistance, hardness, conductivity.

21. **Modern Material Characterization Methods.** Principles and capabilities of scanning electron microscopy (SEM), atomic force microscopy (AFM), transmission electron microscopy (TEM), Raman spectroscopy, and X-ray diffraction (XRD).

22. **Ceramic Materials.** Dielectric, magnetic, optical, chemical, and nuclear ceramics. Advanced ceramic composites. Si$_3$N$_4$-based materials. Solid electrolytes and electrode materials. High-temperature superconductors (HTS).

23. **Materials with Colossal Magnetoresistance.** Magnetic composites and spintronics. Recording and storage devices using ferroelectrics and ferromagnets. Magnetic fluids.

24. **Bioactive Glass-Ceramics and Carbon Implants.** Al$_2$O ceramics, hydroxyapatite and fluorapatite. Magnetic and radioactive bioceramics for cancer treatment. Nanomanganites in cancer therapy and drug delivery. Carbon ceramics for heart valves.

25. **Materials for Hydrogen Purification and Storage.** Composite membranes. Adsorptive storage with carbon nanostructures. Metal-organic frameworks. Chemical storage methods. Metal hydrides. Proton-conducting electrolytes (low- and high-temperature).

26. **Nanomaterials for Membranes.** Membrane classification and technologies. Polymeric membranes. Porous filtering elements.

27. **Nanostructured Crystals for Photonics.** Photonic crystals and synthesis methods. Application areas.

28. **Shape Memory Alloys (e.g., Nitinol) and Smart Polymers.** Conductive, piezoelectric, magneto/electrorheological, thermo- and photo-responsive polymers.

29. **Classical Superionic Conductors and Mixed Conductors.** Cathode/anode materials for lithium batteries. Proton conductors (e.g., barium cerate). Use of solid electrolytes.

30. **Ternary and Multicomponent Systems.** Conode, phase diagram usage. Building tie-lines in composition triangles. Triple four-phase equilibria. Gibbs phase rule.

III List of references

Main:

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