ANNOTATION

to the dissertation work of Ismagambetova Tomiris Nurlanovna

"Structural and thermodynamic properties of non-ideal quantum plasma", submitted for the degree of Doctor of Philosophy (Ph.D.) in the specialty "6D060400 - Physics"

General description of work. The dissertation presents the results of a study of the structural and thermodynamic properties of non-ideal quantum plasma based on effective particle interaction models.

Relevance of the topic.

The study of the interaction between particles in a dense plasma, as well as under extreme conditions, has both fundamental importance (for understanding the physics of giant planets and stars, warm dense matter (WDM)) and for practical applications, for example, for inertial confinement fusion (ICF). A dense plasma is defined as a plasma in which the average distance between particles becomes so small that it is necessary to take into account interparticle interactions. When the interparticle distance in a dense plasma decreases so much that it is comparable to the de Broglie wavelength, it becomes important to take into account the quantum nature of the interacting particles, and at least one of the plasma components (usually electrons due to their smaller mass than ions) becomes quantum degenerate and such a plasma is called quantum or degenerate.

Ground-based experiments that study quantum plasmas are carried out at facilities such as the NIF (The National Ignition Facility – National Complex for Laser Fusion Reactions) at the Lawrence Livermore National (LLNL) in the USA), magnetized Z-pinch and Z-machine at the Z Pulsed Power Facility at the Sandia National Laboratories (SNL) in the USA, FAIR (Facility for Antiproton and Ion Research) at GSI (GSI Helmholtz Center for Heavy Ion Research) in Darmstadt (Germany), IMP-Lanzhou and X- FEL (European X-Ray Free-Electron Laser Facility) at DESY (German Electron Synchrotron) in Hamburg (Germany).

Therefore, it is necessary to investigate and develop models for the interaction of quantum plasma particles, taking into account the influence of various quantum-mechanical effects of different components (electrons and ions) on the structural and other physical properties of such plasma.

The dissertation work aims to study the structural and thermodynamic properties of non-ideal quantum plasma.

The dissertation work was carried out in accordance with the plans of fundamental research work (R&D) of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan “Grant financing of scientific research” on the topics: “Study of the structural, transport and thermodynamic properties of a non-ideal multicomponent dense plasma with heavy ions” (2020-2022, code AP08856650, state registration number 0120RK00575); "Investigation of the properties of plasma and the interaction of the plasma column with intra-chamber materials in thermonuclear power reactors" (2020-2022, code AP09259081, state registration number 0121RK00295); “Investigation of the fundamental properties of a non-ideal complex plasma based on particle interaction models” (2018-2020, code AP05134366, state registration number 0118RK00603); "Models of particle interaction and fundamental properties of non-ideal plasma" (2015-2017, code 3086/GF4, state registration number 0115RK01046); "Relaxation and transport properties of dense plasma of an inertial thermonuclear fusion power reactor" (2013-2015, code 1573/GF3, state registration number 0113RK00392); "Investigation of the properties of complex plasma based on pseudopotential models" (2012-2014, code 1116/GF, state registration number 0112RK00977).

The goal of this work is to study the structural and thermodynamic properties of quantum hydrogen plasma based on various interaction models that take into account collective screening effects and quantum effects.

To achieve this goal, it was necessary to solve the following **tasks**:

1. Obtain an analytical expression for the effective screened interaction potential of semiclassical ions based on the dielectric response function method.
2. Calculate the radial distribution functions of particles in the framework of effective models of particle interaction in one-component and two-component hydrogen quantum plasmas.
3. Determine the thermodynamic properties of one-component and two-component hydrogen quantum plasma (internal energy and equation of state) based on the obtained radial distribution functions.

The object of research is non-ideal quantum hydrogen plasma.

The subject of research is radial distribution functions, and thermodynamic functions (internal energy and equation of state).

Research methods. When solving the problems necessary to achieve the set goals, the following methods were used: the method of linear dielectric response functions, and the method of integral equations for calculating the radial distribution functions. Effective interaction models were used to calculate the thermodynamic characteristics by determining the radial distribution functions of the system.

The novelty of the work. The novelty and originality of the dissertation work lie in the fact that for the first time in it:

- the effective potential of the interaction of ions in quantum plasma is obtained taking into account its screening by electrons and the influence of quantum effects of ion diffraction;

- based on the obtained ion-ion potential, the contribution of quantum effects of ion diffraction to the structural and thermodynamic properties of hydrogen quantum plasma was determined;

- the effect of spin orientation on thermodynamic properties was studied in the framework of the effective screened interaction potential of particles in a hydrogen plasma.

The theoretical and practical significance of the research. The results of the dissertation work are valuable both for understanding the evolution of the Universe and for practical applications. Knowledge of the interaction between particles that manifest their wave nature is important for understanding the properties of quantum plasma obtained by shock-wave compression using lasers, ion accelerators, and X-rays. In close ion-ion collisions, the occurring processes should be considered taking into account the wave nature of the target ion. An important problem is to take into account the nonideality of ions along with the partial or complete degeneracy of electrons, which can be solved using the obtained effective ion interaction potential. The study of the influence of quantum particle effects on the structural and thermodynamic properties of plasma makes it possible to determine the dynamic and transport properties necessary for modeling processes and designing targets in ICF, as well as for understanding the evolution of such astrophysical objects as neutron stars, white and brown dwarfs, and giant planets.

Thesis statements for defense:

1. Quantum effects of diffraction in the interaction potential of ions lead to a weakening of its shielding by electrons compared to the Yukawa potential, and the polarization of a degenerate electron cloud causes a decrease in the value of the potential at zero.

2. The contribution of quantum effects of ion diffraction to the thermodynamic characteristics of hydrogen plasma, in particular, to the correlation energy and correction to pressure, does not exceed 4% in the range of densities $6 \cdot 10^{25}\ см^{-3} \leq n_e \leq 1.6 \cdot 10^{30}\ см^{-3}$ (density parameter $0.01 \leq r_S \leq 0.3$) and temperatures $10^2\ K < T_i < 5.9 \cdot 10^7\ K$ (coupling parameter $2 < \Gamma_i < 600$).

3. The parallel orientation of electron spins in the range of densities $10^{21}\ см^{-3} < n_e < 10^{24}\ см^{-3}$ and temperatures $10^4\ K < T_i < 10^6\ K$ leads to a maximum positive contribution of +1.07% to the correction for nonideality to the pressure of the electronic component, and antiparallel orientation leads to a maximum negative contribution of –3.2%.

The author's contribution lies in the fact that the entire volume of the dissertation work, the choice of research method, solutions of tasks, and numerical calculations were performed by the author independently. The setting of tasks and discussion of the results were carried out jointly with the supervisors.

Reliability and validity of the obtained results.

The dissertation work used well-known physical models and proven mathematical methods. Also, the reliability and validity of the results obtained are confirmed by publications in foreign journals with impact factors and publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, and in the proceedings of international scientific conferences of near and far abroad.

Publications. Based on the materials of the dissertation work, 22 printed works were published: 3 in journals from the list of publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for the publication of the main results of dissertations for the degree of Ph.D. and 4 articles in foreign journals with an impact factor included in the international information resource Web of Knowledge (Thomson Reuters Clarivate Analytics, USA) Scopus (Elsevier, the Netherlands);

15 works in collections of international scientific conferences, including 11 materials of foreign conferences.

The volume and structure of the dissertation. The dissertation work consists of an introduction, 6 sections, a conclusion, and a list of 186 references, and contains 111 pages of basic computer text, including 35 figures.