ANNOTATION

to the dissertation work of Syzganbayeva Saule Askarovna

"Dynamic characteristics and optical properties of non-ideal plasma within the interpolation moment approach", submitted for the degree of Doctor of Philosophy (Ph.D.) in the specialty "6D060400 - Physics"

General description of work. The dissertation is devoted to the study of the dynamic and optical properties of a non-ideal plasma using a modified interpolation approach of the self-consistency method of moments. Theoretical methods have been tested, the numerical calculations and experimental data have been used to compare the results of the study.

Relevance of the research topic. Plasma physics is currently undergoing a period of intensive development. The interest shown in the properties of the so-called fourth state of matter is due to many reasons. One of the main of them is the solution of energy problems due to the reduction of natural fuel. As you know, there are several ways out of the impending crisis: renewable energy sources, nuclear energy and energy produced in thermonuclear fusion. The last, as it turned out, is the most profitable. Firstly, this energy can provide the bulk of world demand, secondly, the reactor in the CTF contains much less radioactive materials than a nuclear fission reactor, and therefore the consequences of an accidental release of radioactive products are less dangerous, thirdly, the CTF allows direct production of electricity. There are currently two ways to obtain energy in the CTF. The first is based on the magnetic confinement of a plasma heated to a temperature of several hundred million degrees. The second is the intense heating of thermonuclear fuel to high temperatures while simultaneously compressing it with intense electromagnetic radiation flows or heavy ion beams. As it is known, at the CTF in California it was recently possible to obtain more energy than was expended for heating and compressing the deuterium-tritium plasma. As such, experimental studies of dense plasma are rather complicated and require considerable financial expenditures; therefore, a number of theoretical methods of analysis have been developed that make it possible to obtain reliable data on the thermodynamic, optical, and electrodynamic properties of dense, high-temperature plasma.

"Indeed, besides the applications of controlled thermonuclear fusion, the spheres of application of non-ideal plasma, where the average potential energy of interaction between charged particles is on the order of or exceeds their average kinetic energy of thermal motion, have expanded explosively. These applications range from the interiors of stars and planets to the production of household appliances. Plasma can be used to environmentally-friendly incinerate urban waste, purify water, and even treat wounds. A recent trend is the emergence of powerful means of interacting with condensed matter. This has greatly expanded our capabilities for various realizations of non-ideal plasma with extreme parameters and the generation of a rich variety of phenomena. Among these are powerful femtosecond lasers and beams of heavy ions, which allow us to heat condensed matter superficially and volumetrically, and study various plasma effects. This represents a distinct field of physics, not to mention the powerful explosions traditionally used for generating non-ideal plasma."

As it was written above, the World has set a course line for the development of high-energy experimental devices, in particular inertial confinement fusion systems. But the problem is that the physical conditions (temperature and density) of the working fluid of future ICF reactors, where the target of hydrogen isotopes (deuterium and tritium) existing in nature is strongly compressed by external laser radiation or heavy ion beams to densities 5 orders of magnitude higher than those of metals, such that in such extreme under these conditions, traditional physical theories based on decompositions in some small parameters fail, and alternative non-perturbative theoretical approaches are needed to diagnose and control processes in the working body.

Recently, along with theoretical research, there has been rapid progress in computer technology, which allows for more complex and more sophisticated, so-called "direct" numerical modeling of complex physical processes in non-ideal plasma (the method of quantum molecular dynamics and quantum Monte Carlo, and etc.). The results of numerical simulation are among the most reliable, as they are based on the "first" principles. A certain place is also occupied by Particle-in-cell methods designed to simulate various physical systems as continuous media.

The construction of a consistent quantum mechanical theory for describing the characteristics of a non-ideal plasma using the Coulomb potential of interparticle interaction leads to computational problems. Consequently, so-called pseudo-potential models have appeared in the statistical theory of plasma, based on the replacement of the Coulomb interaction potential by some effective potentials that consider effects of various kinds. These potentials are finite at small distances, and at large distances they correspond with the Coulomb potential, i.e. they remain long-range.

A special place among the theoretical methods of studying systems with Coulomb interaction between particles is occupied by the method of moments. Its essence lies in the fact that the linear response function of the system is parameterized as a fractional-linear transformation of a parameter function with certain mathematical properties. The conversion coefficients are orthogonal polynomials calculated from the first moments of the imaginary part of the response function, which defines the response function itself through the Kramers-Kronig relations. The moments can be calculated independently and accurately within the framework of the theory of linear Kubo reaction by the method of secondary quantization. Self-consistent approach allows us to reconstruct the dynamic characteristics of the physical system that we study based on knowledge or by modeling static ones. The possibility of carrying out calculations for nonperturbative statistical systems of interacting charges at any degree of their imperfection makes it particularly attractive. At the same time, it is not necessary to carry out any decomposition according to the degree of non-ideality, as, for example, in kinetic theory.

Based on the above, it can be concluded that studies that allow obtaining reliable information about the dynamic and optical properties of non-ideal plasma by the method of moments seem relevant.

The aim of the work is to investigate the dynamic and optical properties of dense non-ideal plasma within the framework of the method of moments.

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

- calculate and analyze dynamic structural factors and compare the results with the data of numerical experiments;
- analyze the dispersion and decrement of attenuation of plasma modes;
- calculate the energy losses of charged particles in an electron gas;
- find and analyze expressions for the reflection coefficient of electromagnetic waves from dense plasma;

The object of the study is dense non-ideal plasma.

The subject of the study is dynamic and optical properties of dense non-ideal plasma.

Research methods. When solving the tasks necessary to achieve the set goals, the interpolation self-consistency method of moments will be used.

Novelty of the work. In the dissertation, the following novelties are presented for the first time:

- calculations of the reflection coefficient have been conducted without the use of fitting parameters, demonstrating good agreement with the results of a unique experiment and numerical simulations.
- the stopping power of an electron gas has been investigated within the framework of the interpolation self-consistency method of moment.
- dynamic structural factors in models of one-component plasma and electron gas have been calculated and analyzed, with the results being consistent with the findings of other authors.
- dispersion and attenuation of collective modes in the system have been studied.

Theoretical and practical significance of the research. The conducted research and the results obtained in the dissertation enable the prediction of the dynamic characteristics of experimentally studied plasma types encountered in controlled thermonuclear fusion facilities and astrophysical objects.

The research findings contribute to the development of the theory of dense Coulomb systems and hold practical value for plasma diagnostics.

Provisions submitted for defense

- The dielectric characteristics of plasma waves in a classical non-ideal one-component plasma (with a non-ideal parameter of $5 \leq \Gamma \leq 160$) agree with the data of numerical experiments with an accuracy of up to ~3.75%, so that the dielectric function satisfies the first five rules of sums.
- The polarization energy loss of the projectile charged particle in the electron gas is found in the framework of interpolation self-consistency method of moment in the density parameters $r_s \gtrsim 1,\ (n_e \gtrsim 10^{22}\text{см}^{-3})$, consistent with the data of modern numerical experiments with an accuracy of up to ~5% over the whole range of speeds.

- The values of the reflection coefficients from the shock-compressed plasma layer for r-polarized electromagnetic radiation in the wavelength range of 532-1064 nm, calculated using the method of moments in a wide range of incidence angles (from 0 to $\frac{\pi}{3}$) on the plasma without taking into account the width of the transition layer, are consistent with the data of real experiments with an error of up to ~5.5%, the value of which decreases with a perpendicular drop.

Reliability of the results of the work. The dissertation work used well-known and proven physical models using proven mathematical theorems. The obtained relations are based on well-known fundamental equations and mathematical expressions.

Connection with other studies. The dissertation is related to experimental work on inertial confinement fusion, modeling of physical processes and theoretical work in the field of dense non-ideal plasma.

Publications. Based on the materials of the dissertation work, 25 publications were published: 8 in journals from the list of the Committee for Quality Assurance in Education of the Ministry of Science, 6 articles in journals of foreign countries with an impact factor included in the international information resource Web of Science and Scopus, 11 papers in the materials of international scientific conferences.

The articles with an impact factor in the Thomson Reuters database or in publications included in the international scientific database Scopus:

- **S.A. Syzganbayeva**, J. Ara, A. Askaruly, A.B. Ashikbayeva, I.M.Tkachenko, and Y.V. Arkhipov// Collective phenomena in a quasi-classical electron fluid within the interpolational self-consistent method of moments// Europhysics Letters. –2022. –Volume 140. –Number 1. – 11001p.
- Yu.V. Arkhipov, A. Ashikbayeva, A. Askaruly, A.E. Davletov, D.Yu. Dubovtsev, Kh. S. Santybayev, **S.A. Syzganbayeva,** L. Conde, I.M. Tkachenko. Dynamic characteristics of three-dimensional strongly coupled plasmas// Physical Review E. –2020. –Vol.102(5). – P. 053215.
- Yu. V. Arkhipov, D. Yu. Dubovtsev, **S.A. Syzganbayev**a, I.M. Tkachenko. Optical properties of dense plasmas// Plasma Physics Reports. –2020. –V.46(1). – P.71-76.
- Yu. V. Arkhipov, A.B. Ashikbayeva, A. Askaruly, D. Yu. Dubovtsev, **S.A. Syzganbayeva**, I.M. Tkachenko. Stopping power of an electron gas: The sum rule approach // Contributions to Plasma Physics. –2019. –V.59(6). – P. e201800171.
- Yu. V. Arkhipov, A.B. Ashikbayeva, A. Askaruly, M. Bonitz, L. Conde, A.E. Davletov, T. Dornheim, D. Yu. Dubovtsev, S. Groth, Kh. Santybayev, **S.A. Syzganbayeva**, I.M. Tkachenko. Sum rules and exact inequalities for strongly coupled one-component plasmas // Contributions to Plasma Physics. – 2018. – V.58(10). – P. 967-975.
- Yu. V. Arkhipov, A.B. Ashikbayeva, A. Askaruly, A.E. Davletov, S. Syzganbaeva, I.M. Tkachenko. Dense Plasma Dynamic Structure Factor Simulation Data vs. the Method of Moments // Contributions to Plasma Physics. – 2015.- Vol. 55. – No.5. – P.381-389.

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.

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