ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD)
Specialty 6D060400 – Physics

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TRANSPORT AND OPTICAL PROPERTIES OF DENSE SEMICLASSICAL PLASMA BASED ON THE EFFECTIVE INTERACTION POTENTIALS

In the present dissertation work the results of calculation of collisional, transport, and optical properties of a dense nonideal plasma based on effective interaction potentials.

Relevance of the dissertation theme. At present, mankind faces an acute problem of developing such alternative energy sources, which, firstly, would allow meeting the growing energy needs with a large supply for the future, and, secondly, they would not lead to global consequences of warming. Such requirements are met the installation, realizing thermonuclear controlled fusion (TCF). In this regard, in recent decades, large expensive transnational and national projects have emerged (for example, ITER, NIF, etc.) associated with the development of thermonuclear power engineering, which allows to a large extent to solve these problems.

The study of the properties of dense semiclassical plasma is difficult, firstly, because of the inadequacy of the choice of particle interaction models and, secondly, the imperfection of the existing theoretical methods (often approximately analytical) to study the properties of such systems.

Thus, the development of models for the interaction of structural elements of the nonideal semiclassical plasma, methods of mathematical modeling, and the study on their basis of elementary collision processes, and then the kinetic, transport and optical properties of the system is not only of fundamental interest, but also important for the development of technologies of many practical applications, associated with the nonideal semiclassical plasma.

Collisional processes determine practically all properties of the plasma, its composition, thermodynamics, transport characteristics, electrodynamic properties, etc. Therefore, it is especially important to be able to conduct research at the level of elementary processes correctly and reliably. Traditionally, the study of elementary processes within a particular model begins with obtaining cross sections for elastic scattering, with the first estimates can and should be carried out on the basis of simple methods, to which the Born method applies.

The collision cross sections directly depend on the relative velocity of the colliding particles, it sits in the equations themselves, which allow the cross section to be calculated, but in most cases the interaction potential does not take into account this velocity. Such a formulation is not entirely correct and more consistent is the use of the dynamic potential of the interaction of particles in the study of their collisions.

The study of transport processes based on collisional characteristics is one of the important directions in the physics of nonideal plasma. Currently, this area of physics continues to develop intensively due to the key role of the transport processes in technical devices containing plasma (magnetogasdynamics and thermionic energy converters, gas-discharge lasers, gas-phase nuclear reactors, spacecraft, etc.), and in natural systems - the ionosphere of the Earth and the planets, the interstellar medium, the interior of the Sun, the core of the giant planets.

The interest in studying the optical properties of nonideal plasma is largely due to the use of lasers for compressing targets, as well as the prospects for optical contact-free diagnostics. Optical instruments allow a wide variety of measurements and studies, for example, temperature, plasma density, structure of plasma-dust formations, sizes and shapes of individual large particles and much more. The study of optical properties is thus not only an important theoretical task, but also capable of leading to the development of new technologies in the field of optical diagnostics of plasma.

The purpose of the dissertation

The main goal of the work is to study, using the effective interaction potentials, the collisional, transport, and optical characteristics of the dense nonideal plasma, such as: particle scattering cross sections, collision frequency, electrical conductivity, and reflectivity.

The object of research is the dense semiclassical plasma, realized in installations of controlled fusion with inertial confinement and in some astrophysical objects.

The subject of research is collisional (phase scattering, differential, total and transport scattering cross sections, collision frequencies), transport (static and dynamic conductivity of a hydrogen plasma) and optical (reflectivity of the dense nonideal xenon plasma) characteristics of dense semiclassical plasma.

To achieve this goal, within the framework of the effective interaction potentials of particles of the dense semiclassical plasma, it is necessary to solve the following problems:

– to develop the dynamic effective models of particle interactions of the dense semiclassical plasma

– to investigate collisional processes based on the static and dynamic effective interaction potentials

– to calculate and analyze the static and dynamic conductivities of dense semiclassical hydrogen plasma using the data obtained on collisional characteristics

– to calculate and analyze the reflectivity of the dense semiclassical xenon plasma using the data obtained on collisional characteristics.

The main provisions for the defense:

– Effective interaction potentials taking into account dynamic screening and diffraction effect, in case of high values of relative velocity, tend to the Deutsch potential (charge-charge interaction) or unshielded charge interaction potential with the atom.

– As a result, taking into account dynamic screening in the effective interaction potential of particles leads to an increase in the values of collisional characteristics (phase shifts, scattering cross section) as compared with data obtained taking into account static screening.

– Accounting for electron-electron collisions by means of the renormalization coefficient gives better agreement of the data on the dynamic conductivity with the results of the MD simulation in the long-wavelength limit.

– Better agreement of the reflection coefficient of radiation with p-polarization with experimental data, as well as with the results of MD simulation, is observed when taking into account dynamic screening.

Scientific novelty of the dissertation results.

In this paper, based on the effective interaction potentials, the following results were obtained for the first time:

– Efficient dynamic models of interaction of particles of dense semiclassical plasma, taking into account dynamic screening and quantum-mechanical diffraction effect, are constructed.

– New data on the collisional properties of the dense semiclassical plasma based on the effective interaction potentials were obtained.

– The dynamic electrical conductivity of the dense semiclassical hydrogen plasma was studied on the basis of the obtained collisional characteristics.

– The reflectivity of dense semiclassical xenon plasma was studied on the basis of the obtained collisional characteristics.

Practical importance of the dissertation. The results obtained in the dissertation are valuable for the development of both the pseudopotential theory and for the study of the kinetic and optical properties of the partially and fully ionized plasma. They can be used in calculating the parameters of partially and fully ionized plasma in a number of promising energy projects and real technical devices, including controlled thermonuclear fusion installations (CFB), since the pseudopotential models used adequately describe collective effects during static or dynamic screening and quantum effects in the interaction.

The theoretical importance of this work is related to the possibility of using the results obtained in studying the processes occurring in astrophysical objects (white dwarfs, the Sun, etc.). Also, the results obtained in the paper deepen the fundamental knowledge of the physics of dense plasma.

Validity and reliability of the results. In the dissertational research known physical models and proven mathematical methods were used. The results based on computer simulations are consistent with different theoretical approaches, such as the T-matrix method, method phase shifts, Born approximation of the first order. The results of the work are consistent with the experimental data, as well as with the results of computer simulation using the methods of molecular dynamics (MD). In the dissertation, well-known physical models and proven mathematical methods were used. Also, the reliability and validity of the results are confirmed by publications in foreign journals with high impact factors and in publications recommended by the Committee on the Control of Education and Science of the MES of RK, and in the works of international scientific conferences in the near and far abroad.

Personal contribution of the author: the author fulfilled the research, chose the methods of investigation, solved the problems and made numerical calculations. Formulation of the problems and their discussions were made together with scientific supervisors.

Publications. According to the materials of the dissertation, 25 published works were published: 3 in journals from the List of KKSON MES RK for publication of the main results of dissertations for the PhD degree and 5 articles in foreign journals with high impact factor included in the international information resource Web of Knowledge (Thomson Reuters , USA) and Scopus (Elsevier, The Netherlands); 17 papers in collections of international scientific conferences, including 13 in materials of foreign conferences.

Approbation of the dissertation. The results obtained in the dissertation were presented and discussed:

– at the International Conference «International Conference on Phenomena in Ionized Gases (ICPIG)» (2015, Iasi, Romania);

– at the International Conference «15th International Conference on the Physics of Non-Ideal Plasmas (PNP)" (2015, Almaty, Kazakhstan);

– at the International Symposium «21st International Symposium of Heavy-Ion Inertial Fusion (HIF)» (2016, Astana, Kazakhstan);

– at the International Conference «XXII Europhysics Conference on Atomic and Molecular Physics of Ionized Gases (ESCAMPIG)» (2016, Bratislava, Slovakia);

– at the International Conference «International Conference on Strongly Coupled Coulomb Systems (SCCS)» (2017, Kiel, Germany);

– at the International Conference «The International Conference on Research and Application of Plasmas (PLASMA)» (2017, Warsaw, Poland);

– at the International Conference «42nd European Physical Society Conference on Plasma Physics (EPS)» (2018, Prague, Czech Republic);

– at the International Conference «XV Russian conference (with international participation) on the thermophysical properties of substances (RCTP-15)» (2018, Moscow, Russia);

– at the International Scientific Conference «Modern achievements of physics and fundamental physical education» (2016, Al-Farabi Kazakh National University, Almaty, Kazakhstan);

– at the International Conference of Students and Young Scientists «Farabi Alemi» (2015, 2016, 2017, Al-Farabi Kazakh National University, Almaty, Kazakhstan);

– at scientific seminars of the Department of Plasma Physics, Nanotechnology and Computer Physics of the Kazakh National University. Al-Farabi, University of Rostock in Rostock, Germany.

discussed with professors: Reinholz H. (Germany), Röpke G. (Germany) in the framework of international cooperation.

Relation of the dissertation theme to the plans of scientific research. The dissertation was fulfilled in accordance with the plans of the following fundamental scientific research works (SRW) SC RK MES «Grant funding of scientific research» on the themes:

– «Elementary processes and optical properties of the complex plasma of inertial fusion» (2015-2017yy., No. 0115RK01037, code 3102/GF4);

– «Computer simulation of the complex magnetized plasma» (2015-2017yy., No. 0115RK01042, code 3087/GF4);

– «Study of dust-sound solitons in the complex magnetized plasma» (2018-2021yy., No. 0118PK00609, code AP05132665/GF);

– targeted financing programs «Investigation of the fundamental problems of plasma physics and plasma-like environments» (2018-2021yy., code BR05236730/GF).

Volume and structure of the dissertation. The dissertation work consists of the introduction, 4 chapters, conclusion and the list of references of 255 items. It contains 115 pages of basic computer text including 49 figures.