Investigation of the Coulomb Logarithm for transport coefficients in warm dense matter

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A perspective approach for the theoretical study of the dynamic and transport characteristics of dense plasma of inertial confinement fusion (ICF) is the pair collision approximation. When modeling the dynamic and transport characteristics of a dense ICF plasma, two approaches can be used. One of the is to calculate transport coefficients determined on the basis of particle scattering cross sections. In the second approach, a kinetic equation is solved, the collision integral of which contains a logarithmic divergent integral over the impact parameters, which is replaced by the Coulomb logarithm. The Coulomb logarithm is one of the fundamental parameters of plasma, which plays a decisive role in the study of transport and dynamic properties of plasma [1].

Whereas the Coulomb logarithm value is used in many plasma related studies and plays a key role in understanding the transport processes and behavior of plasma in various applications. Coulomb collisional processes in plasmas occur in many scenarios, ranging from particle and energy transport (e.g., self-diffusion, thermal diffusion, viscosity, thermal conduction, stopping power, temperature relaxation, and electrical conductivity) to wave damping, particulate drag, wake formation, and others. Central to the description of such processes is the Coulomb logarithm [2], which is usually defined as

$$\lambda = \ln \frac{b_{max}}{b_{\min}} \tag{1}$$

Here b_{max} and $b_{\min}$ are the maximum and minimum impact parameters, respectively. Most formulas describing energy transfer contain a Coulomb logarithm, in which the cutoff parameter is usually estimated from these values of the maximum and minimum collision parameters. The screening length (Debye length) is taken as the upper limit of integration b_{max}, since starting from distances of the order of the r_D, the particles are considered not to interact and do not scatter on each other. In reality, charged particles located at large distances from a certain scattering center are exposed to a large number of other scattering centers. Therefore, in plasma, even at moderate densities, it is necessary to take into account the effects caused by the interaction of a large number of particles, the so-called collective effects. Elimination of divergence at the lower limit is also carried out by choosing a finite value of the $b_{\min}$ that corresponds to a physically reasonable mechanism for eliminating close collisions:

$$b_{\min} = b_{\perp} = \frac{|q_1 q_2|}{m\upsilon^2} \tag{2}$$

Since any error in this term appears only within this logarithm and is usually accepted that it does not affect the result obtained by this formula. But this statement becomes unfair in the case when the argument is small, for example, in the case of dense plasma. Therefore, due to the long-range nature of the Coulomb interaction, the influence of density on plasma properties turns out to be more significant. In this area, which requires more precise formulation, it is desirable that all parameters be precisely defined. Therefore, to ensure the accuracy of results in plasma research, it is recommended to take into account important factors such as electronic screening, quantum mechanical effects, correlations between particles, etc [3-4]. In this regard, the Coulomb logarithm has been studied in many publications [5-7] and various approximations have often been used, taking into account screening by both electrons and ions, also based on the analysis of the obtained results of numerical modeling and experimental data [8], which are applicable for a specific problem and for different ranges of plasma parameters.

A study of dense nonideal semiclassical plasma has shown that taking into account quantum effects is important in a weakly coupled plasma, that is, for coupling parameters less than unity. At the same time, in the limit of weak coupling, quantum effects become insignificant. The discrepancy in the

Coulomb logarithm is due to the neglect of correlation: in a plasma, the collective effect of the surrounding plasma introduces Debye screening, which limits the interaction region.

The quantum mechanical approximation uses various approaches. In the Born approximation, it is mainly used at high velocities of incident particles or at large impact parameters [9]. In many works, the transport cross section for particle scattering in the quantum mechanical approximation is based on the calculation of scattering phases with different interaction potentials [10-12]. Another effect associated with the replacement of Maxwell-Boltzmann statistics with Fermi-Dirac statistics in the quantum approximation, i.e. at high densities or at low temperatures, which can be found in the article [13-14].

In this regard, to show the criterion for the applicability of various approximations: either the classical or quantum mechanical description used in the calculations of scattering cross sections is relevant and depends on the nature of the study. Here we limited ourselves to considering the electron-ion contributions to the transfer processes, and taking into account the contribution of the electron-electron interaction in the following works. In this work, the problem is considered in two cases: 1) when the quantum mechanical approximation is applicable to particle collisions and 2) when the collision process is quasi-classical. Comparisons are made of the electron-ion scattering cross section and, accordingly, the Coulomb logarithm in various degeneracy parameters and densities using classical theory and quantum mechanical theory.

In this work, we considered taking into account quantum mechanical effects during scattering and their influence on collision integrals and, accordingly, on the Coulomb logarithm, calculated on the basis of collision integrals. The obtained results are compared and the degeneracy parameters and density parameters at which the value of the Coulomb logarithm exactly coincides with each other within an error of 1% are shown. Calculations were carried out using classical and quantum mechanical theory.

Therefore, the analysis of these methods in classical and quantum plasma is of great interest. In this work, we consider comparisons of the results of two approximations when calculating the scattering cross section and Coulomb logarithms for different values of plasma parameters.

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