Equation of state and relaxation processes in dense plasma on the basis of effective potentials

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The relaxation processes in dense plasmas and equation of state were studied on the basis of effective interaction potentials taking into account quantum effects of diffraction at short distances and screening at large distances. The results obtained for the Coulomb logarithm, temperature relaxation times and equation of state for different plasma parameters are consistent with the results of other authors.

1. Effective potentials of dense plasma

It is known that in order to correctly describe static and dynamic properties of plasmas the collective screening effect is to be taken into account. In this work the dense plasma is considered for which quantum effects must be taken into account at short distances. In non-isothermal plasma a characteristic electron-ion temperature T_{ei} appears [1]. In [1] it was shown that for a correct description of plasma properties the electron-ion temperature is to be taken in the form:

$$T_{ei} = \sqrt{T_e T_i} \quad (1)$$

The effective potential was used from [2].

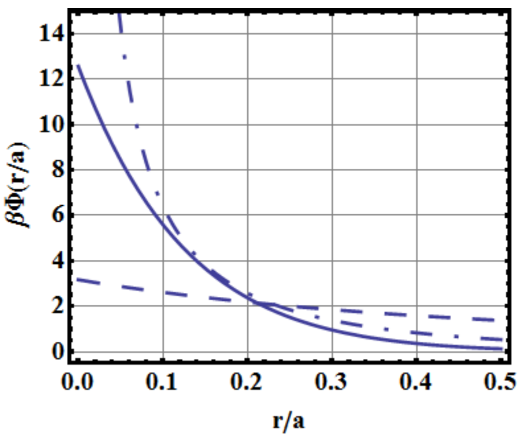

Fig. 1 – Effective interaction potential of electrons for $\Gamma=0.8$, $r_s=1$. Solid line is effective potential, dot line is Deutsch potential, dashed line is Debye potential

2. Equation of state for dense plasma

Thermodynamic expressions were evaluated based on RDFs, which were used for the solution of the Hugoniot equation. In this case, the plasma is formed by compression, acceleration and heating of matter in front of the shock wave. With the passage of gas through the shock wave its parameters change very rapidly and in a very narrow field.

Hugoniot equation is written as:

$$H(V,P,E) = E - E_0 + \frac{1}{2}(V - V_0)(P + P_0) = 0 , \quad (2)$$

where $P_0 = 0$, $\rho_0 = 0.171$ g/cm^3, E_0=-15.886 eV/atom, V_0 – volume of gas, V – volume of plasma.

Figure 2 represents pressure of hydrogen plasma on the basis of equation (2). The calculation results are compared and are in good agreement with those of other authors.

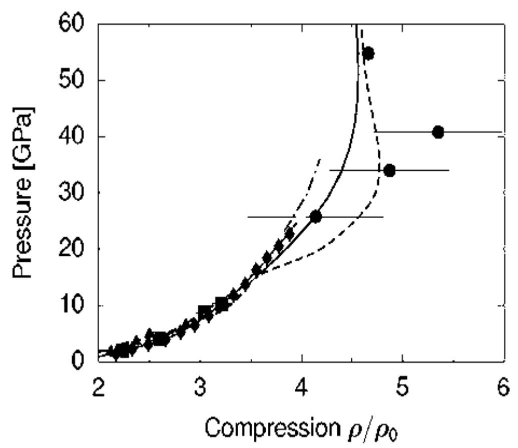

Fig. 2 – Pressure of partially ionized hydrogen plasma. Triangles - Dick and Curley (1980) [3], squares - Nellis (1983) [4], circles - Sano and others [5], dashed line - theoretical prediction of Curley model [6], dash - dotted line - molecular dynamics simulations [7], a straight line - a linear mixed model [8], diamonds - this work.

3. Relaxation processes in dense plasma

In this work the Coulomb logarithm is determined by the center-of mass scattering angle of particles:

$$\lambda = \frac{1}{b_\perp^2}\int_0^\infty \sin^2\left(\frac{\theta_c}{2}\right) b db, \qquad (3)$$

where the center-of-mass scattering angle can be obtained by the formula:

$$\theta_c = \pi - 2b\int_{r_0}^\infty \frac{dr}{r^2}\left(1 - \frac{\Phi(r)}{E_c} - \frac{b^2}{r^2}\right)^{-1/2}, \qquad (4)$$

here $E_c = 1/2\, m_{\alpha\beta}\upsilon^2$ is the energy of the center of mass, $b_\perp = Z_\alpha Z_\beta /(m_{\alpha\beta}\upsilon^2)$, $b_{\min} = \max\{b_\perp, \lambda\!\!\!^{-}_{\alpha\beta}\}$ is taken as the minimum impact parameter, the average distance between the particles $a = (3/4\pi n)^{1/3}$, the density parameter $r_s = a/a_B$, plasma frequency $\omega_p = \sqrt{4\pi n e^2/m_e}$. In formula (4) $\Phi_{\alpha\beta}(r)$ is the interaction potential, r_0 is the distance of the closest approach for a given impact parameter b:

$$1 - \frac{\Phi_{\alpha\beta}(r_0)}{E_c} - \frac{b^2}{r_0^2} = 0. \qquad (5)$$

The relaxation rate of the electron-ion temperature, i.e., the rate of energy exchange, is determined by the difference of the average energy or temperature:

$$\frac{dT_e}{dt} = \frac{T_i - T_e}{\tau_{ei}}, \quad \frac{dT_i}{dt} = \frac{T_e - T_i}{\tau_{ie}}, \qquad (6)$$

$$\tau_{ei} = \frac{3 m_e m_i}{8\sqrt{2\pi} n_i e^4 \lambda}\left(\frac{k_B T_e}{m_e} + \frac{k_B T_i}{m_i}\right)^{3/2}. \qquad (7)$$

The relaxation times of the temperature in the plasma were calculated for different density values on the basis of the Coulomb logarithm using the effective potential (Fig.3). It is seen that the equilibration rate increases with increasing density, which is caused by the increase in the frequency of collisions.

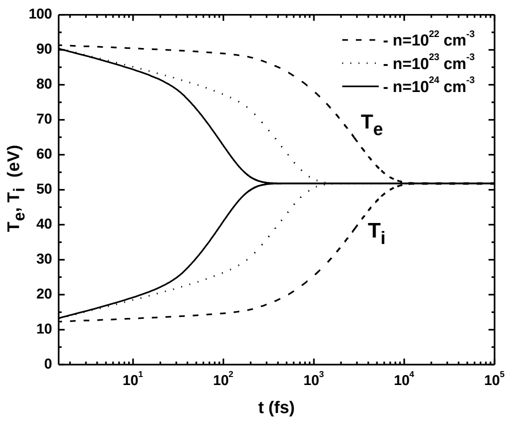

Fig. 3 – The relaxation time of temperature between electrons and ions

It was found that the relaxation has two stages. The final stage is characterized by the exponential decrease of the temperature difference of components. Figure 4 shows the comparison of the temperature relaxation time obtained on the basis of the effective potential with the results of MD at $r_S = 1$, $T_i = 10 eV$. It is seen that the relaxation time increases with increasing temperature. This is explained by the fact that the larger the temperature difference between electrons and ions, the more time is needed to come to an equilibrium state.

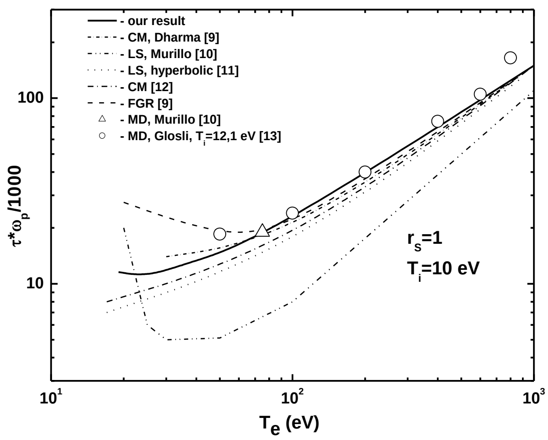

Fig. 4 – The relaxation time in units of plasma frequency

4. References

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