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AN INTERMEDIATE QUANTUM PLASMA
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DIELECTRIC RESPONSE AND ENERGY LOSS FOR AN INTERMEDIATE QUANTUM PLASMA


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1. INTRODUCTION: With the advent of the use of laser-driven pellets to obtain thermonuclear fusion, we have in the laboratory a plasma in which the electrons have a fugacity, \( Z = 1 \), the intermediate quantum regime. When a highly compressed deuterium plasma is obtained by laser compression, the final state of the system corresponds to particle number densities of \( \rho \approx 10^{26} - 10^{27} \) and temperatures \( T \approx 10^7 - 10^8 \) /K.

It is perhaps interesting to note that the ions in the deep interior of Jupiter correspondingly reach a fugacity regime around unity /3/. Using the above data, we find that the Fermi temperature, \( T_F \), is virtually equal to the system's temperature, \( T \). The temperature at which the fugacity of an electron gas reaches unity is \( T_0 = 0.93 T_F /4 \). Thus these laser-driven fusion conditions correspond to a plasma of intermediate (partially degenerate) electrons and classical ions. What is more, the plasma parameter

\[
\gamma = 4^{2/3} (4/3 \pi \rho)^{1/3} / m \varepsilon_0 \nu
\]

is, for the above values, such that

\[
10^{-2} \lesssim \gamma \lesssim 1.5
\]

Thus the particles to a first approximation are weakly coupled and also to a first approximation we can treat them using standard linear response theory.

Hore and Frankel /4/ have shown that all quantities which are thermodynamically averaged over the Fermi-Dirac distribution function can readily be expanded about the intermediate quantum region, \( Z = 1 \), using standard Mellin integral transform techniques. Hore and Frankel /5/ have also studied the dielectric response of the charged Bose gas about the condensation region, \( Z = 1 \). In this paper we report on similar calculations using the techniques of reference /5/ along with the expansions appropriate for a gas of fermions about \( Z = 1 \) given in reference /4/.

Work up to now on this region of compelling interest in fusion research has essentially only been accessible by numerical techniques /6/, /7/.

2. RESULTS: We give here a brief summary of results obtained by the above analytical techniques for: (a) the longitudinal dielectric response function, (b) plasma dispersion relationships, (c) the ion-acoustic sound, (d) the energy loss to collective modes, (e) the energy loss to binary collisions and (f) the electron-ion contribution to the thermal conductivity.

(a): Given the standard longitudinal dielectric response function \( \varepsilon(q, \omega) \) from linear RPA theory for an electron gas,

\[
\varepsilon(q, \omega) = 1 + \frac{\omega^2}{\omega^2 - \omega_0^2 - i \gamma (\omega_0 / \varepsilon_0) \nu / \rho} + O(\rho^0)
\]

where \( \lambda \) is the spin, \( \Omega \) the volume of the system and \( P_0(q) \) the Fermi distribution function

\[
F_0(q) = \frac{1}{\Omega} \left[ Z^{-1} e^{\gamma} \pi M \sqrt{1 + 1} \right]
\]

where

\[
\gamma = \frac{q^2}{4} \left( \frac{4}{3} \pi \rho \right)^{1/3} / m \varepsilon_0 \nu
\]

and

\[
\omega_0^2 = \omega_0^2 + \frac{3 \gamma^2}{\pi \rho} \left( \frac{\omega_0}{\gamma} \right) \left( \frac{\omega_0}{\gamma} - 5 \right) + \frac{20}{9} \left( \frac{\omega_0}{\gamma} \right) \left( \frac{\omega_0}{\gamma} - 4 \right) + \cdots + O(\rho^0)
\]

(b): From the analytical result given in (a) we have obtained the following dispersion relationship for electron oscillations in the small \( q \) region:

\[
\omega(q) = \omega(q) + i \gamma (q)
\]

where

\[
\omega(q) = \omega_0^2 + \frac{3 \gamma^2}{\pi \rho} \left( \frac{\omega_0}{\gamma} \right) \left( \frac{\omega_0}{\gamma} - 5 \right) + \frac{20}{9} \left( \frac{\omega_0}{\gamma} \right) \left( \frac{\omega_0}{\gamma} - 4 \right) + \cdots + O(\rho^0)
\]

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Y = -\omega_1'(\theta) \left( \frac{\omega_1(z)}{\omega_1(z)} \right) \exp(-\omega_1(z)) x \\
\times \left[ -\frac{x^2}{3} + \frac{\beta}{3} + \ldots \right] + O(\beta) \\
\chi[1.9944 - 1.0711 \beta - 1.3838 \beta^2 + O(\beta^3)] \\
\text{where all quantities are as in reference /12/.}

3. DISCUSSION: Detailed comparison will be given of the binary collision and collective energy loss rates in the final state of a laser-driven fusion electron-ion plasma. We will also make specific comparisons for the quantities presented in (a) and (f) above with their corresponding form in the cases Z = 0 (classical) and Z = \infty (totally degenerate).

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