PhD Open Days

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Thomas-Fermi Quasi-equilibrium in Ultra-cold Plasmas

APPLAuSE PROGRAMME

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INTRODUCTION

In order to reach plasma state, high temperatures are needed to sustain ionization. However, the development in atom cooling and trapping methods have enabled studies in a new domain of plasma physics. In this new regime, the requirement of high temperature to create the plasma is no longer necessary. These new type of plasma is known as ultra-cold plasma.

Usually, ultra-cold plasmas are formed through the ionization of atoms or molecules that have been cooled down to 1K [1] (typically, the temperature is of the order of micro kelvin in magneto optical traps [2, 3]). Such a cold initial sample is the exposed to a 10 ns laser pulse tuned near the ionization threshold, producing a plasma with a density ranging from 10^10 to 10^14 cm^(-3).

The main aim here is to present an introduction of the effects of the electron trapping leading to a model similar to the Thomas – Fermi model for heavy atomic systems [4]. In this case, when the trapped electron population dominates over the "free" electrons, the plasma qualitatively looks like a giant atom, where the ions play the role of a nucleus and the electrons compose the electronic cloud.

THE MODEL

We start describing the potential of the plasma

$$\nabla^2 \Phi = \frac{e}{\varepsilon_0}(n_e - n_i)$$

In the early stages of the plasma, the ions are approximately described by a Gaussian profile, associated with the neutral atoms confined in the MOT

$$n_i = n_0 \exp[-(r/\sigma)^2]$$

Combining both equations we obtain

$$\nabla^2 \phi = \frac{1}{\lambda_D^2}\left(\frac{n_e}{n_0} - \exp[-(r/\sigma)^2]\right)$$

where we have defined $\phi = \frac{e|\Phi|}{T_e}$.

The ions will create a positive electrostatic potential, in such a way that the classical energy of the electrons can be given by

$$E_e = \frac{1}{2} m_e v^2 - e\Phi(\boldsymbol{r})$$

When the potential energy of the ions overcomes the kinetic energy of the electrons, we have a trapping effect. The minimum velocity to escape the trapping potential is given by

$$v_t = \sqrt{\frac{2}{m_e} e|\Phi|}$$

The electrons that can escape the trapping potential follow a Boltzmann distribution associated to the energy presented before. On the other hand, the trapped electrons follow an uniform distribution, since they cannot leave the trapping radius.

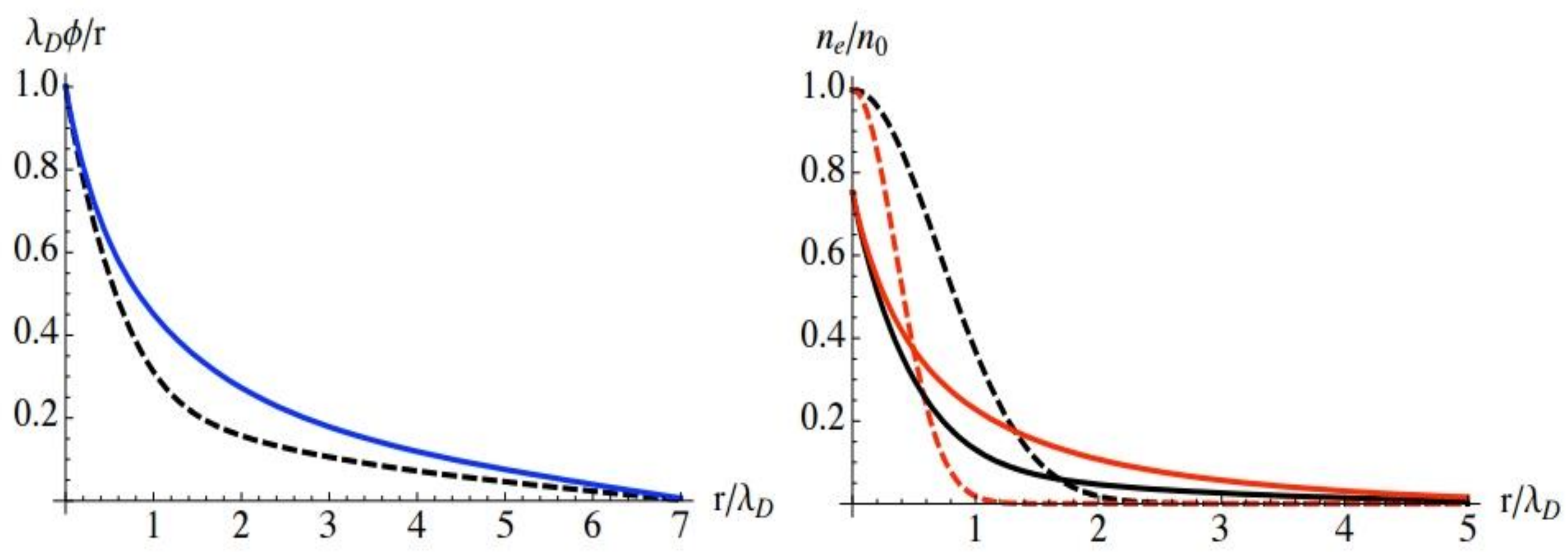

Figure 1: Left figure shows the Thomas – Fermi potential obtained in the strong confinement regime for two different Gaussian profiles. Right figure shows the ion (dashed lines) and electron (full lines) density profiles in the early stages of the plasma.

The electron density can be determined as follows

$$\frac{n_e}{n_0} = \frac{4}{\sqrt{\pi}}\left[\int_0^{u_t} u^2 du + \int_{u_t}^{\infty} e^{-(u^2-\phi)} u^2 du\right]$$

and the general expression for the electrostatic potential will be

$$\nabla^2 \phi = \frac{1}{\lambda_D^2}\left(\frac{4}{3\sqrt{\pi}}\phi^{3/2} - f(\phi) - \exp[-(r/\sigma)^2]\right)$$

where

$$f(\phi) = e^{\phi}\left(1 - \frac{4}{\sqrt{\pi}}\int_0^{\sqrt{\phi}} e^{-u^2}\, du\right)$$

We integrate in the strong confinement limit $\phi \gg 1$

$$\nabla^2 \phi = \frac{1}{\lambda_D^2}\left[\frac{4}{3\sqrt{\pi}}\phi^{3/2} - \exp[-(r/\sigma)^2]\right]$$

This expression is very similar to the Thomas-Fermi potential obtained for heavy atomic species. The numerical solution of the potential and the profiles of the densities are shown in Fig. (1) for a spherically symmetric potential.

REFERENCES

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