Contrib. Astron. Obs. Skalnaté Pleso **53/3**, 101 – 106, (2023)
https://doi.org/10.31577/caosp.2023.53.3.101

The development of simplified approach in describing of the ionic field to emitter interaction in stellar and laboratory plasmas

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Received: September 17, 2023; Accepted: October 9, 2023

Abstract. Dense plasma of moderate and strong non-ideality is of growing interest in physics related to stellar and laboratory plasma. Up until now the optical parameter of hydrogen plasma of mid and moderately high nonideality parameter could be described successfully, thus enabling the modeling of optical properties. But the model potential used does not include the correct plasma interaction in it's basic form. The influence of dense packing ionic structure onto the form of potential is investigated in this paper. The presented results are a step towards the more precise description of ionic field influence onto the plasma microfield when the dynamic of the ionic structure is neglected and the dense packing assumed.

Key words: optical properties – dense plasma – bond states – pseudopotential – modelling

1. Introduction

Nowadays, modeling of the optical properties of dense plasma is of growing interest in both astrophysical as well as laboratory plasma (Chabrier et al., 2002; Bardet et al., 2003; Vitel, 2004; Sultana & Schlickeiser, 2018; Chabrier et al., 2006). Since the known models of plasma emitter interaction do not describe this case well enough and precise simulation models are extremely computing time consuming the need for this research is required (see e.g. Agranat et al., 2007; Mazevet et al., 2005).

In the dense plasma the inter-particle Coulomb interaction becomes dominant over the thermal kinetic energy (Fortov et al., 2006). In such conditions a coupled system of particles behaves partially like a crystal. The simplified version, for hydrogen case, of non-ideality parameter Γ is given by

$$\Gamma = \frac{E_p}{E_k} = \frac{e^2}{kTr_{WS}} \sim e^2 N_e^{1/3}\beta, \qquad \beta = 1/kT, \qquad r_{WS} = \left(\frac{3}{4\pi N_e}\right)^{1/3}. \quad (1)$$

The simplified screening model of Debye is used to investigate screening influence, although it is not ideal for dense plasma, $r_D = \left(\frac{\varepsilon_0 k_B T_e}{n_e q_e^2}\right)^{1/2}$.

Models used for describing dense plasma

The usage of Cut-off Coulomb model potential was applied in the fully quantum mechanical solution for determining the optical properties of dense hydrogen plasma. Up until now the results were presented and used for instance see Dimitrijević et al. (2018); Srećković et al. (2018); Mihajlov et al. (2015, 2011); Ignjatović et al. (2017); Ignjatović et al. (2009). Both Coulomb as well as cut-off Coulomb potential is presented in Eq. 2,

$$U(r) = -\frac{e^2}{r}, \qquad U_c(r) = \begin{cases} -\dfrac{e^2}{r} + \dfrac{e^2}{r_c}, & : \; 0 < r \leq r_c, \\ 0, & : \; r_c < r < \infty \end{cases}. \quad (2)$$

The plasma-emitter interaction is roughly modeled by the cut-off radius r_c. The close vicinity of the emitter is described correctly by the shifted Coulomb potential in the vicinity of the emitter as well as constant plasma potential in the far field $r \gg r_c$.

2. Results and discussion

Since the strongly coupled Coulomb systems have small thermal mobility, the idea of was to use a dense packing of spheres to describe an influence of ionic field. The densest packing of the spheres is applied (see John Horton Conway, 1998). The calculations have been carried out to average a potential seen by the central particle of dense packing in accordance with the algorithm of integration on the sphere surface presented in Lebedev & Laikov (1999).

As first test a behavior of enlarging a number of charged ions layers is analyzed and presented in Fig. 1, in case of expected plasma parameters and then in model case of non-physical values of plasma density parameters and screening values (Fig. 2).

The influence of charged particle density as well as screening influence is shown in Fig. 3 and Fig. 4. It is expected to yield a semi-empirical form of describing plasma influence onto emitter potential and develop more precise plasma-emitter describing.

In order to describe the collective influence onto the emitter the ratio of the yielded potential and the Coulomb one is presented. It could be seen, from Fig. 1,

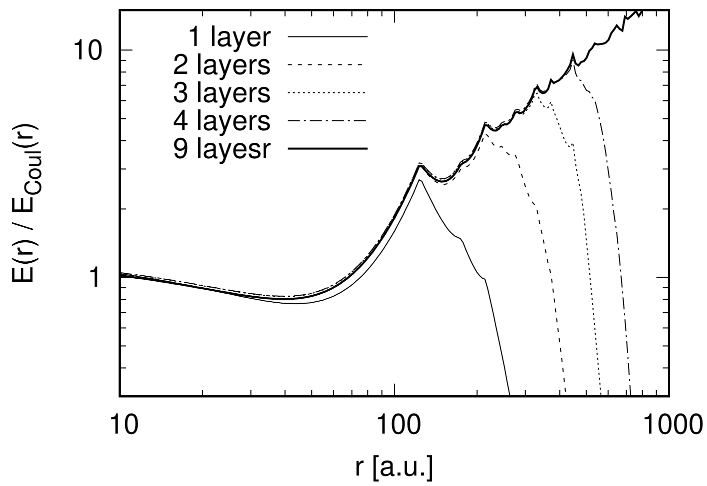

Figure 1. Investigation of the effect of number of layers of charged particles in realistic case, $N_e = 10^{19}$ cm^{-3}, $T = 10\,\mathrm{kK}$ giving estimated values of $r_D = 54.4\,a.u.$ and $r_{WS} = 41.2\,a.u.$.

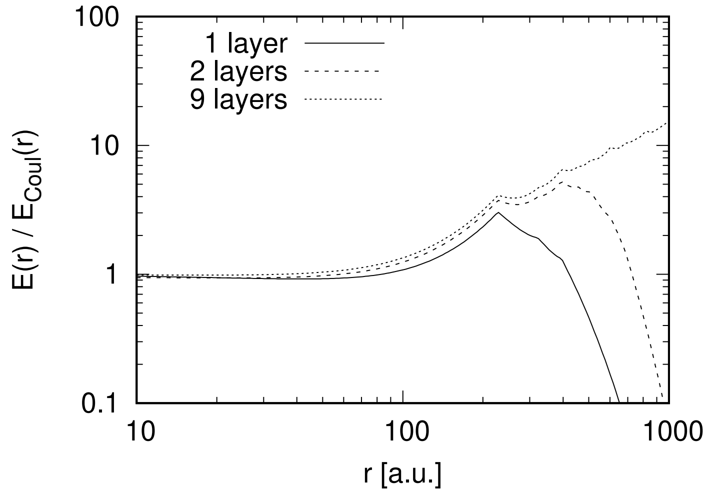

Figure 2. Number of layers effect on modeled case $r_D = 100\,a.u.$ and $r_{WS} = 100\,a.u.$.

and Fig. 2, that the enlargement of the charged particle layers lead to linear enlargement of the collective potential influence, the larger the layer count, the larger linear part is. So it is expected that in an ideal infinite case the linear enlargement of the collective potential could be a good candidate for

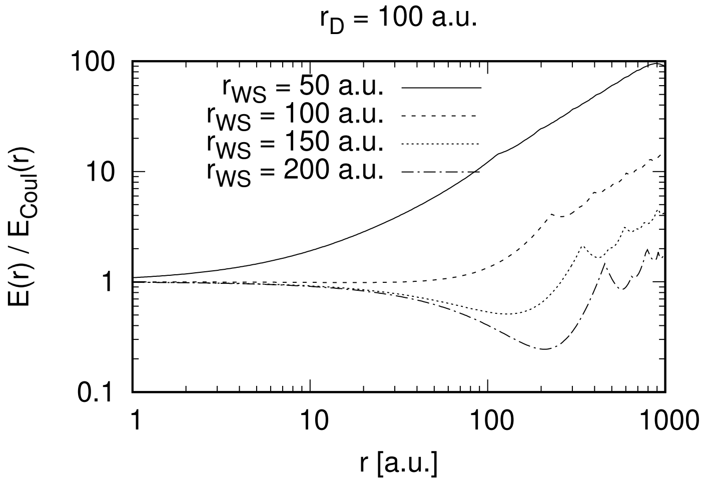

Figure 3. A modeling an effect of charged particle density variation, case of 9 layers.

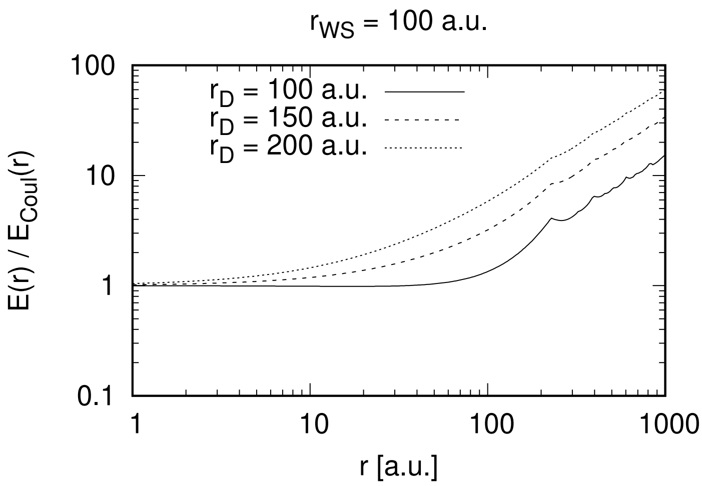

Figure 4. A modeling an effect of screening Debye-like parameter variation, case of 9 layers.

more precise description of the plasma influence onto the emitter. The inter-ionic distance influence is shown in Fig. 3, it is obvious that smaller inter-ionic distance is the faster plasma influence starts to be important, as expected. In Fig. 4 the screening influence is shown. It is expected that the plasma influence could be modeled with some form of analytical or semi-analytical form of pseudo-potential. This enables a more acceptable mechanism of broadening of the bond levels.

3. Conclusions

The simplification of plasma-emitter influence is needed, since the detailed approach with molecular dynamic code coupled with quantum mechanical solver is computing power intense method. The presented results are a step towards the more precise description of ionic field influence onto the plasma microfield when the dynamic of the ionic structure is neglected and the dense packing assumed. Although this approach is not ideal it could lead to a model both satisfactory in precision as well as with numerical simplicity.

The results that were obtained may be relevant to some astrophysical plasmas, such as the plasma of the solar atmosphere's inner layers and the plasmas of some other star atmospheres (such as those of some DA and DB white dwarfs).

Acknowledgements. This work is supported by the Ministry of Science, Technological Development and Innovations of the Republic of Serbia, through the project contract No.451-03-47/2023-01/200002 and 451-03-47/2023-01/200024.

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