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ELECTRICAL CONDUCTIVITY OF PLASMAS IN DB WHITE DWARF ATMOSPHERES

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Abstract. The calculation of the static electrical conductivity of non-ideal, dense, partially ionized helium plasma was carried over a wide range of plasma parameters: temperatures 10^4 K < T < 10^5 K and mass density 10^6 g/cm^3 < ρ < 2 g/cm^3 . Calculations of electrical conductivity of plasma for the considered range of plasma parameters are of interest for DB white dwarf atmospheres with effective temperatures $1\cdot10^4$ K < T_{eff} < $3\cdot10^4$ K. Electrical conductivity of plasma was calculated by using the modified random phase approximation and semiclassical method, adapted for the case of dense, partially ionized plasma.

1. INTRODUCTION

The data on electrical conductivity of plasma of stars with a magnetic field or moving in the magnetic field of the other component in a binary system could be of significant interest, since they are useful for the study of thermal evolution of such objects (cooling, nuclear burning of accreted matter) and the investigation of their magnetic fields. Moreover, electrical conductivity was particularly investigated for solar plasma, since it is of interest for the consideration of various processes in the observed atmospheric layers, like the relation between magnetic field and convection, the question of magnetic field dissipation and the energy released by such processes. Given the analogous role electrical conductivity plays in other stars as well, it is of interest to investigate its significance, to adapt the methods for research into stellar plasma conditions and to provide the needed data.

An additional interest for data on electrical conductivity in white dwarf atmospheres may be stimulated by the search for extra-solar planets. Namely Jianke, Ferrario and Wickramasinghe have shown in 1998, that a planetary core in orbit around a white dwarf may reveal its presence through its interaction with the magnetosphere of the white dwarf. Such an interaction will generate electrical currents that will directly heat the atmosphere near its magnetic poles. They emphasize that this heating may be detected within the optical wavelength range as Hα emission.

For investigation and modeling of such electrical currents, the data on electrical conductivity in white dwarf atmospheres will be useful.

We calculated here the static electrical conductivity of non-ideal, dense, partially ionized helium plasma within a wide range of temperatures and mass densities, of interest for the DB white dwarf atmospheres with effective temperatures between 10000 K and 30000 K. Electrical conductivity of plasma was calculated by using the modified random phase approximation (RPA) and semiclassical method, adapted for the case of dense, partially ionized plasma,

$$\sigma_0 = \frac{4e}{3m}\int_0^{\infty} E\omega(E)\frac{1}{\left[\frac{1}{t_{ee;ei}(E)}+\nu_{ea}(E)\right]}\frac{df_{FD}(E)}{dE}dE\,, \tag{1}$$

where m and e are the mass and the modulus of charge of the electron, ω(E) is the density of the single electron states in the energy space, $f_{FD}(E)$ is the Fermi-Dirac distribution function and $t_{ee;ei}(E) = t^{RPA}_{ee;ei}$ or $t_{ee;ei}(E) = t^{SC}_{ee;ei}$ is effective electron relaxation time given in Srećković et al. (2010). Finaly the electron-atom collision frequency ν_{ea}, in equation for σ_0, is given here by the known expression $\nu_{ea} = N_a \upsilon Q^{tr}_{ea}$ wher where N_a is the He(1s2) atom density, $v(E)=(2E/m)^{1/2}$- relative electron-atom velocity, and Q_{ea}^{tr} momentum transfer cross section calculated, following the previous papers Ignjatović & Mihajlov (1997) and Srećković et al. (2010) , using the potential U(r) (defined in Eq. 2 and Table 1).

$$U(r) = \begin{cases} U_0 = -\frac{Z}{r} + \frac{q}{r+r_0} + \frac{Z-q}{r_0}, & 0 < r < r_i \\ U_m = ar^2 + br + c, & r_i < r < r_f \\ U_{as} = -\frac{\alpha}{2(r^2+h^2)^2}, & r_f < r < \infty \end{cases} \tag{2}$$

Table 1. The parameter values of the model potential U(r) in atomic units.

Z	q	a	b	c	α	h	r_i	r_f	r_0
2	0.7	-0.59597652	2.2545472	-2.19405731	1.384	0.01	0.73	1.75	0.9

2. THE RESULTS

The developed method was then applied to calculation of plasma electrical conductivity for the models of DB white dwarf atmospheres presented in Fig. 1. The results of the calculations are shown in Fig. 3. First, let us note a regular behavior of the static electrical conductivity which one should expect considering the characteristics of DB white dwarf atmospheres.

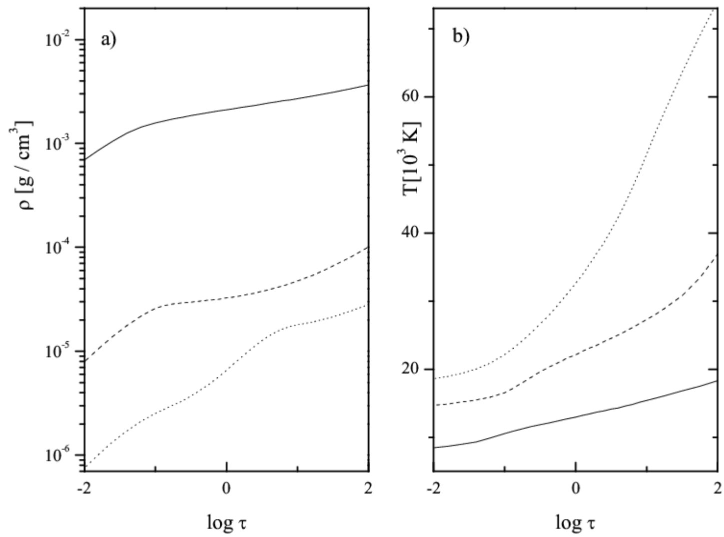

Figure 1: DB white dwarf atmosphere models with log g=8 and T_{eff}=12000K (full curve), T_{eff}=20000K (dashed curve) and T_{eff} =30000K (dotted curve) from Koester (1980): (a) The mass densities; (b) The temperatures, as functions of Rosseland opacity τ.

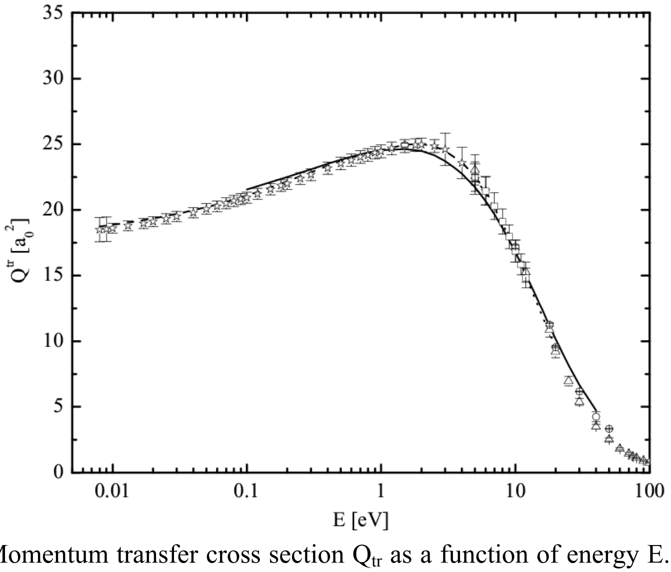

Figure 2: Momentum transfer cross section Q_{tr} as a function of energy E. Calculated data (full curve) for helium together with results of other authors see Srećković et al. (2010).

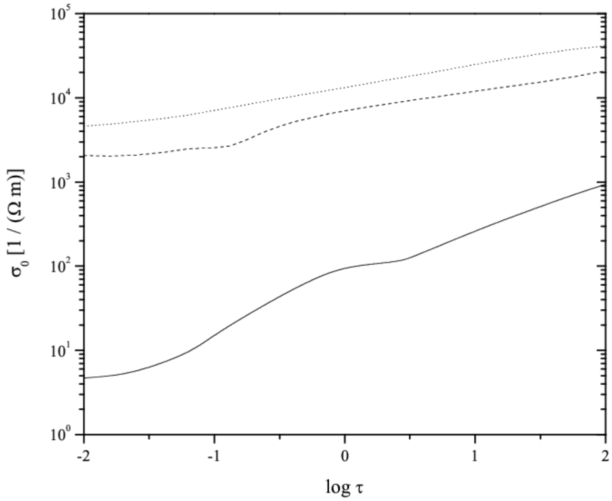

Figure 3: Static electrical conductivity σ_0 as a function of the logarithm of Rosseland opacity τ for DB white dwarf atmosphere models with log g=8 and T_{eff}=12000K (full curve), T_{eff}=20000K (dashed curve) and T_{eff}=30000K (dotted curve).

The method developed in this paper represents a powerful tool for research into white dwarfs with different atmospheric compositions (DA, DC etc.), and for the investigation of some other stars (M type red dwarfs, Sun etc.). Finally, the presented method provides a basis for the development of methods to describe the other transport characteristics which are important for the study of all the mentioned astrophysical objects, such as the electronic thermo-conductivity in the star atmosphere layers with large electron density, electrical conductivity in the presence of strong magnetic fields and high frequency electrical conductivity.

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