Proceedings of the VII Bulgarian-Serbian Astronomical Conference (VII BSAC)
Chepelare, Bulgaria, June 1-4, 2010,
Editors: M. K. Tsvetkov, M. S. Dimitrijević, K. Tsvetkova, O. Kounchev, Ž. Mijajlović
Publ. Astron. Soc. "Rudjer Bošković" No 11, 2012, 331-335

ELECTRICAL CONDUCTIVITY OF PLASMAS OF DB WHITE DWARFS ATMOSPHERES

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Abstract. The static 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 of DB white dwarf atmospheres. were performed for the range of plasma parameters of interest for DB white dwarf atmospheres with effective temperatures $1 \cdot 10^4\text{K} \lesssim T_{eff} \lesssim 3 \cdot 10^4\text{K}$.

1. INTRODUCTION

The data on electrical conductivity of plasma of stars with a magnetic field or moving in the magnetic field of other component in a binary system (see e.g. Zhang et. al., 2009; Potter and Tout, 2010; Rodriguez-Gill et al., 2009) 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. 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 (see e.g. Kopecký 1970 and references therein).

An additional interest for data on electrical conductivity in white dwarf atmospheres may be stimulated by the search for extra-solar planets. Namely Jianke et al. (1998) have shown 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. Jianke et al. (1998) emphasize that this heating may be detected within the optical wavelength range as H_α emission. For investigation and modelling of mentioned electrical currents, the data on electrical conductivity in white dwarf atmospheres will be useful.

One of the most frequently used approximations for the consideration of transport proprieties of different plasmas is the approximation of "fully ionized plasma" (Spitzer 1962, Radke et al. 1976, Adamyan et al. 1980, Kurilenkov and Valuev 1984, Ropke and Redmer 1989, Djurić et al. 1991, Nurekenov et al. 1997, Zaika et al. 2000, Esser et al. 2003). It was shown that the electrical conductivity of fully ionized plasmas can be successfully calculated using the modified random-phase approximation (RPA) (Djurić et al. 1991, Adamyan et al. 1994a,b) in the region of strong and moderate non-ideality, while the weakly non-ideal plasmas were successfully treated within semiclassical approximation (SC) (Mihajlov et al. 1993, Vitel et al. 2001). In practice, even the plasmas with the significant neutral component are treated as fully ionized ones because of simplification of the considered problems, (Ropke and Redmer 1989, Esser and Ropke 1998, Zaika et al. 2000, Esser et al. 2003). However, our preliminary estimations have shown that such an approach is not applicable for the helium plasmas of DB white dwarf atmospheres described in Koester (1980) where the influence of neutral component can not be neglected.

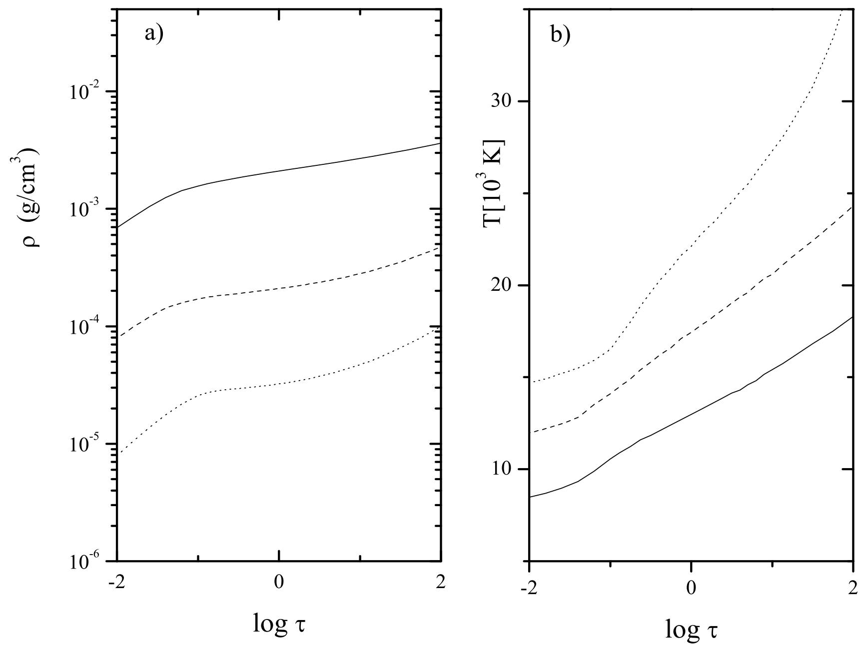

Figure 1. DB white dwarf atmosphere models with log $g = 8$ and T_{eff}=12000K (full curve), T_{eff}=16000K (dashed curve) and T_{eff}=20000K (dotted curve) from Koester (1980): (a) The mass densities; (b) The temperatures, as functions of Rosseland opacity τ.

Consequently, an adequate method for calculations of electrical conductivity of dense, partially ionized helium plasmas is developed here and all details are published in Srećković et al. (2010). This method represents a generalization of methods developed in Djurić et al. (1991) and Mihajlov et al. (1993), namely modified RPA and SC methods, and gives a possibility to estimate the real contribution of the neutral component to the static electrical conductivity of the considered helium plasmas in wide ranges of the mass densities (ρ) and temperatures (T).

The calculations were performed for the helium plasma in the state of local thermodynamical equilibrium with given ρ and T in regions $1 \cdot 10^4\text{K} \lesssim T \lesssim 1 \cdot 10^5\text{K}$ and $1 \times 10^{-6}\text{g/cm}^3 \lesssim \rho \lesssim 2\text{g/cm}^3$. For the calculations of plasma characteristics of DB white dwarf atmospheres the data from Koester (1980) were used. All results are given in Srećković et al. (2010) and here only the application to DB white dwarf atmospheres will be shown.

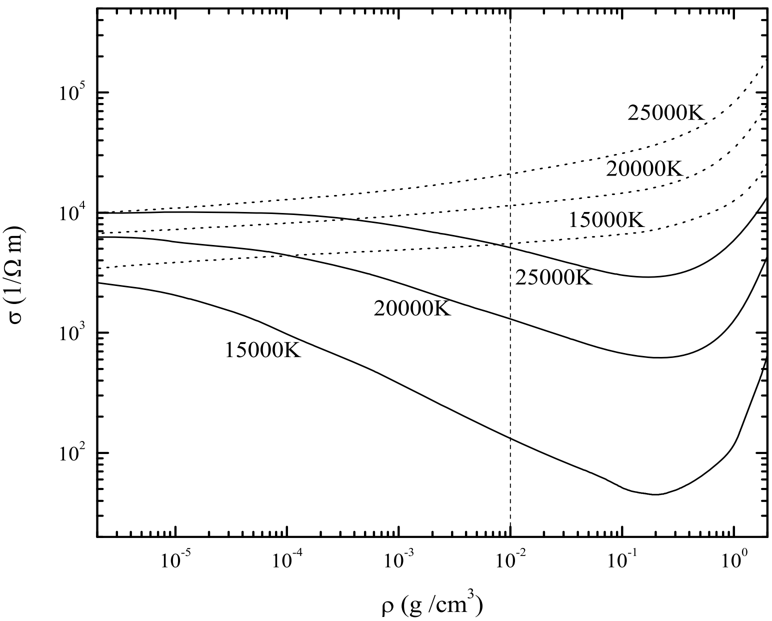

Figure 2. Static electrical conductivity σ of dense He plasmas as a function of mass density ρ (full curves), compared to the Coulomb part of conductivity (dashed curves). The area between the two vertical dashed lines marks the region which is of interest for DB white dwarfs.

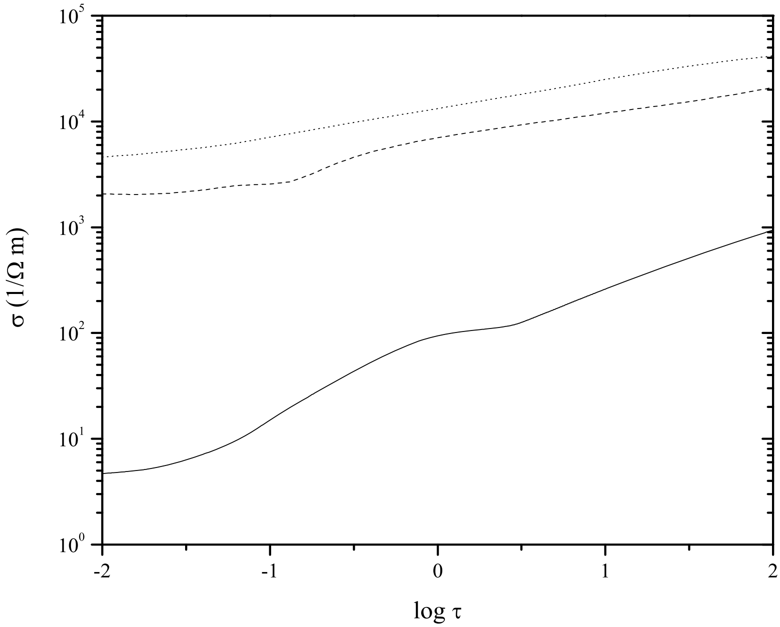

Figure 3. Electrical conductivity σ as a function of the logarithm of Rosseland opacity τ for DB white dwarf atmosphere models with log $g = 8$ and T_{eff}=12000K (full curve), T_{eff}=16000K (dashed curve) and T_{eff}=20000K (dotted curve).

2. RESULTS AND DISCUSSION

In order to apply our results to the study of DB white dwarf atmosphere plasma properties, helium plasmas with electron (N_e) and atom (N_a) densities and temperatures (T), characteristic for atmosphere models presented in the literature (Koester 1980), are considered here. So, the behaviour of ρ and T for models with the logarithm of surface gravity log g =8 and the effective temperature T_{eff} =12000K, 16000K and 20000K is shown in Fig. as a function of Rosseland opacity τ. As one can see, these atmospheres contain layers of dense helium plasma. In order to cover reliably the considered plasma parameter range, we tested our method for the calculation of the plasma electrical conductivity within a wider range of mass density $1 \times 10^{-6}\text{g/cm}^3 \lesssim \rho \lesssim 2\text{g/cm}^3$ and temperature $10000K \lesssim T \lesssim 30000K$.

The influence of neutral atoms on the electrical conductivity of helium plasma is shown in Fig. . In this figure the electrical conductivities for T = 15000, 20000 and 25000K are given as functions of mass density ρ. The range between the two vertical dashed lines corresponds to the conditions in the considered DB white dwarf atmospheres. Two groups of curves are presented in this figure: a) the dashed ones, obtained neglecting the influence of atoms, i.e. with $\nu_{ea} = 0$; b) the full line curves calculated including the influence of atoms. First, one should note that the behaviour of these two groups of curves is qualitatively different: the first one increases constantly with increasing ρ, while the other group of curves decreases, reaches a minimum, and then starts to increase with increasing ρ. One could explain such behaviour of the electrical conductivity by the pressure ionization. This figure also clearly shows when the considered plasma can be treated as "fully ionized".

The developed method was applied to the calculation of plasma electrical conductivity for the models of DB white dwarf atmospheres presented in Fig. . The results of the calculations are shown in Fig. . Let us note a regular behaviour of the static electrical conductivity which one should expect regarding the characteristics of DB white dwarf atmospheres.

The method developed and published in Srećković et al. (2010) 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, this 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 dynamic (high frequency) electrical conductivity.

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