Electrical Conductivity of Plasma in DB White Dwarf Atmospheres

Vladimir A. Srećković*, Ljubinko M. Ignjatović*, Anatolij A. Mihajlov* and Milan S. Dimitrijević†

*Institute of Physics, P. O. Box 57, 11001 Belgrade. Serbia
†Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia

Abstract. We present the calculation of the static electrical conductivity of non-ideal, dense, partially ionized helium plasma 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 . The calculations of electrical conductivity of plasma for the considered range of plasma parameters are of interest for DB white dwarf atmospheres with effective temperatures 10 000 K < T_{eff} < 30 000K.

Keywords: stars: kinematics and dynamics;white dwarfs
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INTRODUCTION

The values of 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.

Interest for data on electrical conductivity in white dwarf atmospheres may be stimulated by the search for extra-solar planets. Some authors 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. They emphasize that this heating may be detected within the optical wavelength range as H_α emission. For deeper investigation and modeling of such electrical currents, the data on electrical conductivity in white dwarf atmospheres will be useful.

THEORY

Here, we calculated the static electrical conductivity of non-ideal, dense, partially ionized helium plasma within a wide range of temperatures and densities, of interest for the DB white dwarf atmospheres with effective temperatures between 10 000 K and 30 000 K. The static electrical conductivity of plasma was calculated by using the modified random phase approximation (RPA) and semiclassical method, specially adapted for the case of dense, partially ionized plasma, by next expression,

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

where m and e are the mass and the 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 (see [1, 2]). The electron-atom collision frequency ν_{ea}, in equation for σ_0, is given by the expression $\nu_{ea} = N_a \upsilon Q^{tr}_{ea}$ where N_a is the He($1s^2$) atom density, $\upsilon(E)=(2E/m)^{1/2}$- relative electron-atom velocity, and Q^{tr}_{ea} momentum transfer cross section calculated by standard method, following the previous papers [3] and [4], using the model potential U(r)

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

The model potential U(r) is defined by equation 2 and table 2 and momentum transfer cross section Q^{tr}_{ea} is presented in figure 1.

TABLE 1. The values for the temperature and density of the model atmosphere from [5].

	T_{eff}= 12 000 K		T_{eff}= 20 000 K		T_{eff}= 30 000 K	
log τ	T(K)	ρ (g/cm^3)	T(K)	ρ (g/cm^3)	T(K)	ρ (g/cm^3)
-2	8474	6.95E-04	14701	7.95E-06	18626	7.54E-07
-1.6	8977	1.05E-03	15195	1.39E-05	19405	1.35E-06
-1.2	9896	1.44E-03	15902	2.20E-05	20930	2.12E-06
-1	10554	1.58E-03	16508	2.60E-05	22158	2.52E-06
-0.75	11229	1.72E-03	18015	2.86E-05	24172	3.04E-06
-0.5	11832	1.85E-03	19625	2.97E-05	26630	3.71E-06
-0.25	12402	1.98E-03	20903	3.10E-05	29439	4.79E-06
-0.125	12685	2.05E-03	21607	3.16E-05	30978	5.58E-06
0	12969	2.11E-03	22106	3.26E-05	32613	6.58E-06
0.2	13429	2.21E-03	23117	3.42E-05	35473	8.66E-06
0.4	13900	2.32E-03	24078	3.64E-05	38600	1.13E-05
0.6	14304	2.45E-03	25052	3.92E-05	42303	1.41E-05
0.8	14807	2.58E-03	26119	4.28E-05	46636	1.65E-05
1	15412	2.70E-03	27302	4.75E-05	51600	1.80E-05
1.25	16095	2.89E-03	28898	5.51E-05	57703	1.94E-05
1.5	16821	3.10E-03	30809	6.60E-05	63607	2.14E-05
1.75	17505	3.37E-03	33409	8.05E-05	69000	2.44E-05
2	18302	3.65E-03	36894	1.01E-04	74039	2.83E-05

TABLE 2. 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

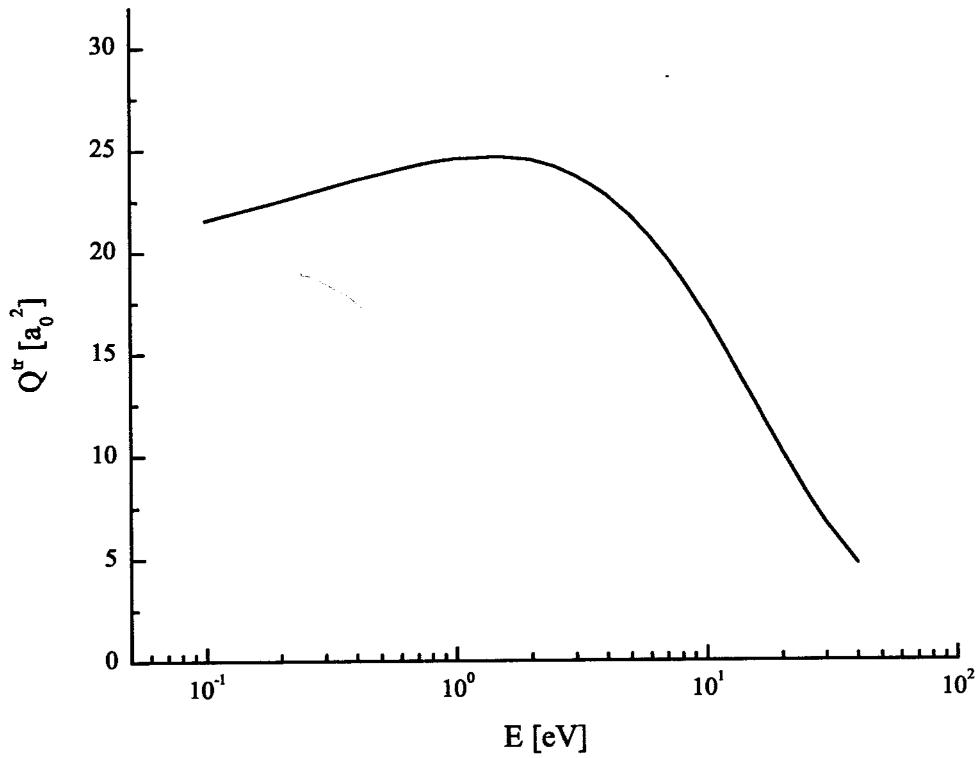

FIGURE 1. Momentum transfer cross section Q_{tr} as a function of energy E.

RESULTS

The developed method was applied for calculation of plasma electrical conductivity for the models of DB white dwarf atmospheres presented in [5]. The results of the calculations are shown in Fig. 2. We found a regular behavior of the static electrical conductivity as we expected.

The model developed in this paper represents a useful tool for research into white dwarfs with different atmospheric compositions (DA, DC etc.).

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, high frequency electrical conductivity, reflectivity.

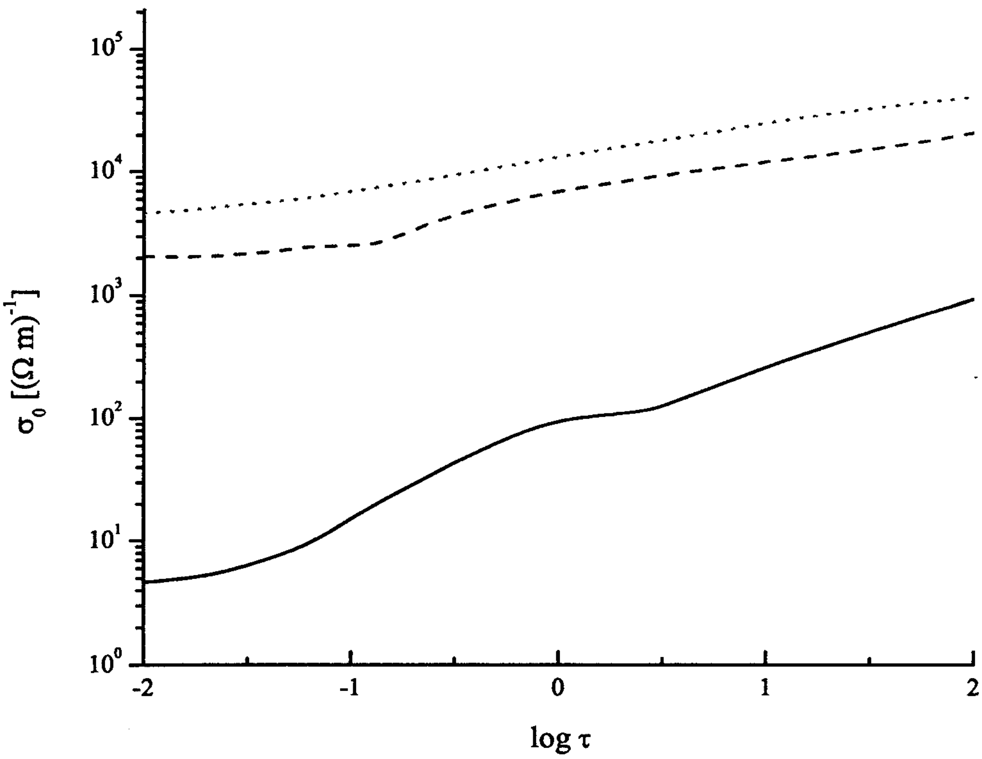

FIGURE 2. DB white dwarf atmosphere static electrical conductivity σ_0 as a function of the logarithm of Rosseland opacity τ for atmosphere models with log g=8 and T_{eff}=12 000K (full curve), T_{eff}=20 000K (dashed curve) and T_{eff}=30 000K (dotted curve).

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