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HF electric properties of the astrophysical plasmas

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The HF characteristics of astrophysical plasmas was determined on the basis of numerically calculated values for the dense plasma conductivity in an external HF electric field. The examined range of plasma frequencies covers the IR, visible and UV regions and considers electronic number density and temperature important for different stellar models. The results presented here are important for the investigation of atmosphere plasmas of astrophysical objects, for example, white dwarfs with different atmospheric compositions (DA, DC etc.), and for the investigation of some other stars (M-type red dwarfs, Sun etc.) as well as for laboratory plasma research.

Keywords: Atomic processes, plasmas, stars: stellar atmospheres

1 Introduction

The HF characteristics such as the electrical conductivity of plasmas of some stellar atmospheres, have recently attracted the attention of the authors. Namely, 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 (see e.g. Zhang et al. (2009), Potter & Tout (2009) and Rodriguez-Gil et al. (2009)) are 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. Also, the transport processes occurring in the cores of some stars have been considered in the literature (see e.g. Baiko & Yakovlev (1995)). Moreover, the electrical properties were particularly investigated for solar plasma, since it is of interest for the consideration of various processes in the observed atmospheric layers, for example, 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).

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2 Theory

In this work we consider a highly ionized strongly coupled astrophysical plasma in a homogenous and monochromatic external electric field $\vec{E}(t) = \vec{E}_0 \exp\{-i\omega t\}$. According to Srećković et al. (2010a) and Sakan et al. (2007), the dynamic electric conductivity of a strongly coupled plasma $\sigma(\omega) = \sigma_{Re}(\omega) + i\sigma_{Im}(\omega)$ is presented by the expressions

$$\sigma(\omega) = \frac{4e^2}{3m}\int_0^\infty \tau_\omega(E)\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{1}$$

$$\sigma_{Re}(\omega) = \frac{4e^2}{3m}\int_0^\infty \frac{\tau(E)}{1+(\omega\tau(E))^2}\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{2}$$

$$\sigma_{Im}(\omega) = \frac{4e^2}{3m}\int_0^\infty \frac{\omega\tau^2(E)}{1+(\omega\tau(E))^2}\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{3}$$

where $\rho(E)$ is the density of electron states in the energy space and $w(E)$ is the Fermi–Dirac distribution function, $\tau_\omega(E)$ is the relaxation time given by

$$\tau_\omega(E) = \frac{\tau(E)}{1 - i\omega\tau(E)}. \tag{4}$$

In Eq. (4) the quantity $\tau(E)$ is the "static" relaxation time. The method of determination of $\tau_\omega(E)$ and $\tau(E)$ is described in detail in Adamyan et al. (2006); Tkachenko et al. (2006); Srećković et al. (2010a,b).

Other HF plasma characteristics can be expressed in terms of the quantities $\sigma(\omega)$. Thus according to Eqs. (1)–(4) the plasma dielectric permeability is defined by

$$\varepsilon(\omega) = 1 + i\frac{4\pi}{\omega}\sigma(\omega) = \varepsilon_{Re}(\omega) + i\varepsilon_{Im}(\omega), \tag{5}$$

where $\varepsilon_{Re}(\omega)$ and $\varepsilon_{Im}(\omega)$ are given as

$$\varepsilon_{Re}(\omega) = 1 - \frac{4\pi}{\omega}\sigma_{Im}(\omega), \quad \varepsilon_{Im}(\omega) = \frac{4\pi}{\omega}\sigma_{Re}(\omega). \tag{6}$$

The coefficients of refraction, $n(\omega)$, and reflection, $R(\omega)$, are determined as

$$n(\omega) = \sqrt{\varepsilon(\omega)} = n_{Re}(\omega) + in_{Im}(\omega), \tag{7}$$

$$R(\omega) = \left|\frac{n(\omega)-1}{n(\omega)+1}\right|^2, \tag{8}$$

where, bearing in mind that

$$|\varepsilon(\omega)| = \sqrt{\varepsilon_{Re}^2(\omega) + \varepsilon_{Im}^2(\omega)}, \tag{9}$$

the real and imaginary parts of refractivity, $n_{Re}(\omega)$ and $n_{Im}(\omega)$, are given by

$$n_{Re}(\omega) = \sqrt{\frac{1}{2}(|\varepsilon(\omega)| + \varepsilon_{Re}(\omega))}, \quad n_{Im}(\omega) = \sqrt{\frac{1}{2}(|\varepsilon(\omega)| - \varepsilon_{Re}(\omega))}. \tag{10}$$

From here, the equation for the plasma reflectivity could be expressed as

$$R(\omega) = \left\{ \frac{1 + |\varepsilon(\omega)| - \sqrt{2}\sqrt{|\varepsilon(\omega)| + \varepsilon_{Re}(\omega)}}{1 + |\varepsilon(\omega)| + \sqrt{2}\sqrt{|\varepsilon(\omega)| + \varepsilon_{Re}(\omega)}} \right\}^{1/2}. \quad (11)$$

The other parameter of interest is the penetration depth of electromagnetic radiation into plasma, $\Delta(\omega)$. This quantity is just the skin-layer width determined as the inverse imaginary part of the electromagnetic field wave number $\Delta(\omega) = \frac{c}{\omega}\frac{1}{n_{Im}(\omega)}$, where c is the speed of light.

3 Results and discussion

Here we continue our previous investigations of plasma static electrical conductivity which are of interest for DB white dwarf atmospheres (see Srećković et al. (2010b,c, 2012)). So, in accordance with the aim of this work, we calculated HF plasma characteristics for wide plasma conditions in order to apply our results to the atmospheres of different stellar types with highly ionized strongly coupled astrophysical plasma.

Figures 1 and 2 illustrate the behavior of the HF conductivity for various plasma conditions (wide range of plasma temperature at high densities) which gives the possibility to calculate other transport properties like $R(\omega)$, n_{Re}, n_{Im} and etc. using Eqs. (5)–(11). One can see that Figs 1 (upper panel) and 2 (upper panel) demonstrate the regular behavior of the quantity $\sigma_{Re}(\omega)$, i.e. the convergence to the corresponding values of $\sigma_0(n_e, T)$ when $\omega \to 0$, and the existence of the interval of variation of ω where $\sigma_{Re}(\omega)$ is practically constant. Similarly, Figs 1 (lower panel) and 2 (lower panel) demonstrate a regular behavior of $\sigma_{Im}(\omega)$, i.e. the convergence to zero when $\omega \to 0$, and the presence of a maximum in the interval $0 < \omega < 0.5\omega_p$. Here, we give attention to the analysis of reflectivity data because this quantity is very important in high energy density plasmas (R measurements as an important diagnostic tool provide information about the density profile). Figure 3 shows the plasma reflectivity as a function of ω/ω_p for $Ne = 5 \cdot 10^{23}$ cm^{-3} and wide region of temperatures 20000 K $< T <$ 1000000 K.

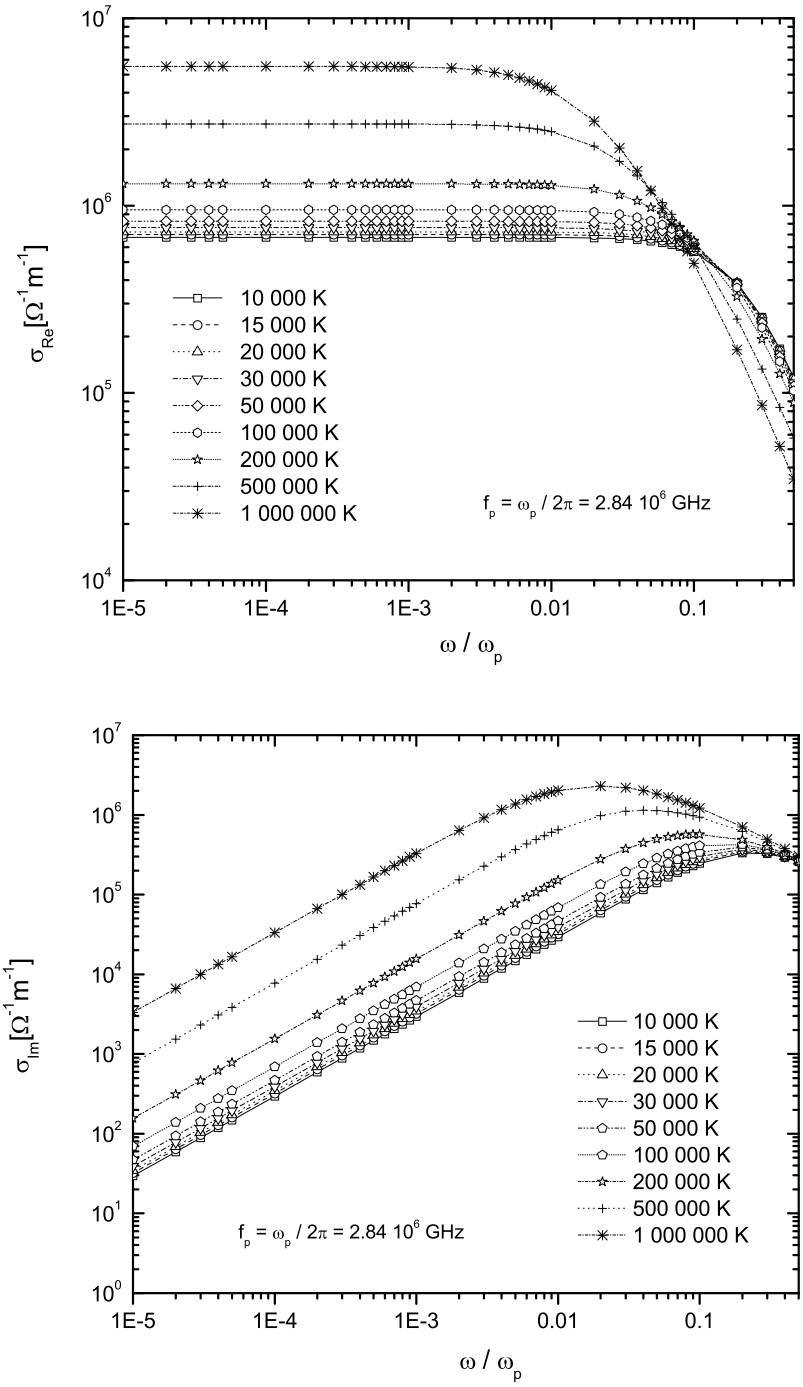


Figure 1 Upper panel: The calculated values of the real part of dynamic conductivity $\sigma_{Re}(\omega)$ for electron density $Ne = 1 \cdot 10^{23}$ cm^{-3} and 20000 K $< T <$ 100000 K. Lower panel: Same as the upper panel but for the imaginary part $\sigma_{Im}(\omega)$.

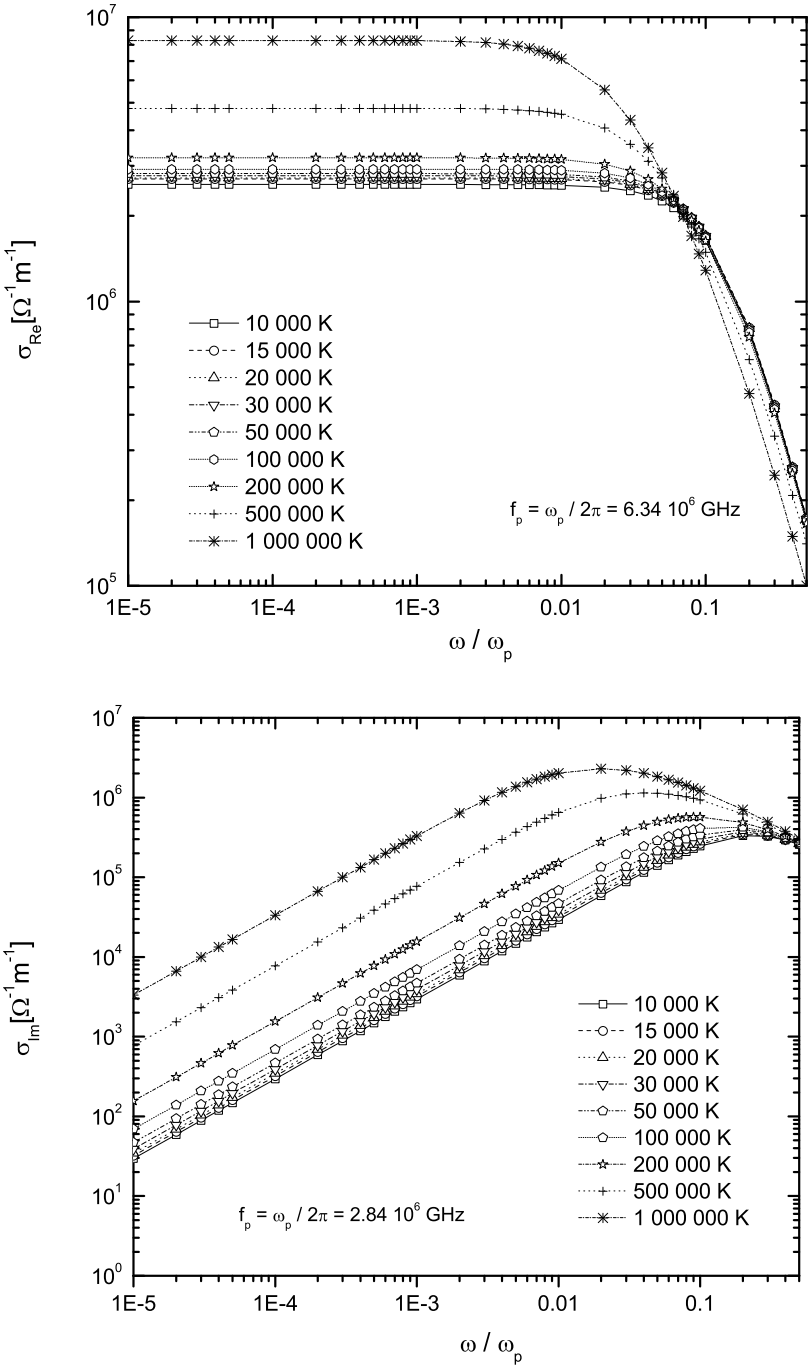


Figure 2 Upper panel: The calculated values of the real part of dynamic conductivity $\sigma_{Re}(\omega)$ for electron density $Ne = 5 \cdot 10^{23}$ cm^{-3} and temperature range 20000 K $< T <$ 100000 K. Lower panel: Same as the upper panel but for the imaginary part $\sigma_{Im}(\omega)$.

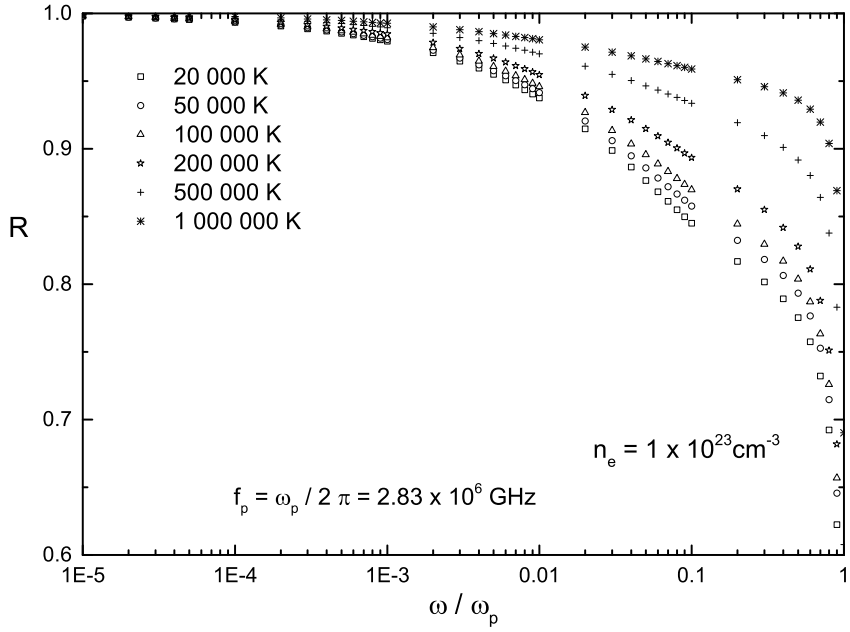


Figure 3 The calculated data for plasma reflectivity at electron density $Ne = 10^{23}$ cm^{-3} and temperature range 20000 K $\leq T \leq$ 1000000 K.

4 Conclusions

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

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References

Adamyan V. M., Grubor D., Mihajlov A. A., Sakan N. M, Srećković V. A., & Tkachenko I. M.: 2006, J. Phys. A, 39, 4401–4405

Baiko D. A. & Yakovlev D. G.: 1995, Astron. Lett., 21, 702

Kopecký M.: 1970, Bul. Astron. Inst. Czechoslovakia, 21, 231

Potter A. T. & Tout C. A.: 2009, MNRAS, arXiv:0911.3657v1 [astro-ph.SR] 18 Nov 2009

Rodriguez-Gil P., Martinez-Pais I. G., & Rodriguez J. C.: 2009, MNRAS, 395, 973
Sakan N. M., Srećković V. A., Adamyan V. M., Tkachenko I. M., & Mihajlov A. A.: 2007, Publications de l'Observatoire Astronomique de Beograd, 82, 171
Srećković V. A., Adamyan V. M., Ignjatović Lj. M., & Mihajlov A. A.: 2010a, Phys. Lett. A, 374, 754–760
Srećković V. A, Ignjatović Lj. M., Mihajlov A. A., & Dimitrijević M. S.: 2010b, MNRAS, 406, 590–596
Srećković V. A., Ignjatović Lj. M., Mihajlov A. A., & Dimitrijević M. S.: 2010c American Institute of Physics Conference Series, 1273, 432–435
Srećković V. A., Ignjatović Lj. M., Mihajlov A. A., & Dimitrijević M. S.: 2012, PASRB, 11, 331
Tkachenko I. M., Adamyan V. M., Mihajlov A. A., Sakan N. M., Šulić D. M., & Srećković V. A.: 2006, J. Phys. A, 39, 4693–4697
Zhang C. M., Wickramasinghe D. T., & Ferrario L.: 2009, MNRAS, 397, 2208