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THE METHODS FOR DETERMINATION OF HF CHARACTERISTICS OF NONIDEAL PLASMA

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Abstract. In this work the previously developed method of calculation of HF electro-conductivity of non-ideal plasma is applied to the area of higher electron densities, up to 10^{24} cm^{-3} and in the temperature range 30 000 K ≤ T ≤ 200 000 K. The computations are carried out in the frequency range [0, $1 \cdot \omega_p$], ω_p being the plasma frequency. A good agreement with the previously published data is obtained.

1. INTRODUCTION

This work is a continuation of the works [2, 1, 3, 4]. In [1] we presented data for slightly non-ideal plasma HF conductivity, while in [2] we have covered the area of moderately non-ideal plasma, while in [3] and [4] we have reached extreme dense concentrations in a range of $1 \cdot 10^{21}$ cm^{-3} ≤ Ne ≤ $1 \cdot 10^{23}$ cm^{-3} and for 30 000K ≤ T ≤ 200 000K. Here we present and compare the data for extremely dense non-ideal fully ionized hydrogen plasmas with thermodynamic conditions data presented in [5]. There are two values that was reproducible from their data $\Gamma = 0.5$ $r_s = 4$, and $\Gamma = 0.5$ $r_s = 1$ which yields $N_e = 2.517 \cdot 10^{22}$ cm^{-3}, T = 15 7882 K and $N_e = 1.611 \cdot 10^{24}$ cm^{-3} T = 63 153 K respectively. Here $\Gamma = \beta e^2/a$, where β is inverse temperature in energy units and $a = r_s$ is the mean interionic distance (electronic Wigner-Seitz radius).

In this work a completely ionized hydrogen plasma is considered in a homogenous and monochromatic HF external electric field

$$\vec{E}(t) = \vec{E}_0 \exp\{-i\omega t\}$$

The dynamic electric conductivity σ(ω) is given by a complex function of the field frequency:

$$\sigma(\omega) = \sigma_{\mathrm{Re}}(\omega) + i \cdot \sigma_{\mathrm{Im}}(\omega)\,, \tag{1}$$

and, according to [1, 2], σ(ω) is taken in the integrated Drude-like form:

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

where ρ(E) is the density of electronic states in the energy space and w(E) is a Fermi-Dirac distribution function τ(E) is the static electronic relaxation time. The basic feature of our theory [8, 9, 10, 11] is the evaluation of the relaxation time within the following approach: each electron (carrier) moves in a self-consistent field generated by all other free charges in the system. The finite values of the transport coefficients result from electron's scattering on the self-consistent field fluctuations. It is based on the paper [12], which related the Lorenz-model expression for the fully-ionized plasma electrical conductivity to the strict quantum-statistical calculation involving the Green's function formalism with the self-consistent field potential. It was shown that thus obtained static conductivity is in semi-quantitative agreement with available experimental data and also possesses correct limiting forms of Ziman and Spitzer, corresponding to high and low densities, respectively [11].

A detailed comparison with alternative methods of theoretical investigation of the dynamic conductivity, see, e.g., [13] and [14] is presented in this paper.

New methods:

$$\sigma(\omega) = \frac{\omega\dfrac{i\omega_p^2}{4\pi} - \Omega^2\sigma_0}{\omega^2 - \Omega^2 + i\omega\Omega^2\dfrac{4\pi\sigma_0}{\omega_p^2}}\ , \tag{3}$$

$$\Omega^2 = \frac{\omega_p^2}{3n_e V} \sum_j^N \left\langle 2 \sum_\nu f(\varepsilon_\nu) \left|\psi_\nu(R_j)\right|^2 \right\rangle_0 , \tag{4}$$

where,
ε_ν - energy levels
ψ_ν - corresponding eigenfunction in one-electron states ν
$f(\varepsilon)$ - Fermi distribution function.

1. First method

$$\Omega^2 = \frac{\omega_p^2}{3}\left(1 + \frac{2m^2e^2}{\pi^2\hbar^4 n_e}\int_0^\infty \frac{1}{\exp\beta(\varepsilon-\mu)+1}\arctan\left(\frac{2}{\kappa}\sqrt{\frac{2m\varepsilon}{\hbar^2}}\right)d\varepsilon\right) , \tag{5}$$

$$\frac{1}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}}\int_0^\infty \frac{1}{\exp\beta(\varepsilon-\mu)+1}\sqrt{\varepsilon}\,d\varepsilon = n_e , \tag{6}$$

2. Second method

$$\Omega^2 = \frac{\omega_p^2}{3}\left\{1 + \frac{\beta e^2}{\lambda_T(1+\lambda_T/\lambda_D)}\right\} , \tag{7}$$

where,
$\lambda_T = \hbar/2\sqrt{\beta/m}$ - electronic thermal wavelength
$\lambda_D^{-2} = 4\pi e^2\beta\sum_{j=0}^{s} Z_j^2 n_j$ - the Debye radius

2. RESULTS

Comparison with the other data: On the basis numerical calculations presented earlier in [3, 4], both σ_{Re} and σ_{Im} are computed, but for the previously mentioned thermodynamic conditions. The results are displayed in the figures 1-4. The figures represent the data from several separate sources [5, 6, 7] as compared to our data. A good agreement with existing data [5, 6, 7] in a wide range of dimensionless frequency ω/ω_p.

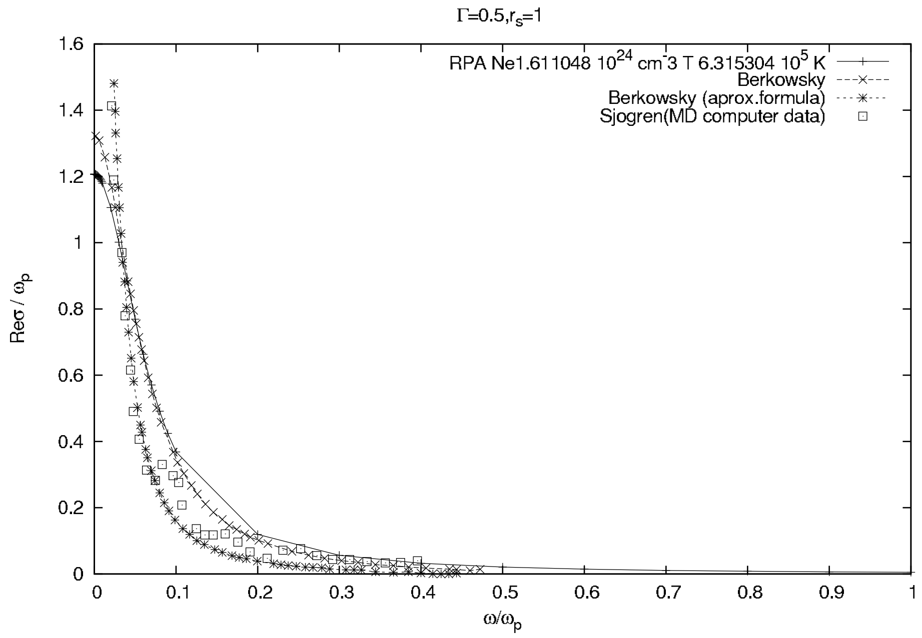

Fig. 1 The real part of HF electrical conductivity of fully ionized Hydrogen plasma for $\Gamma = 0.5$ $r_s = 1$, compared with other authors [5], [6] and [7].

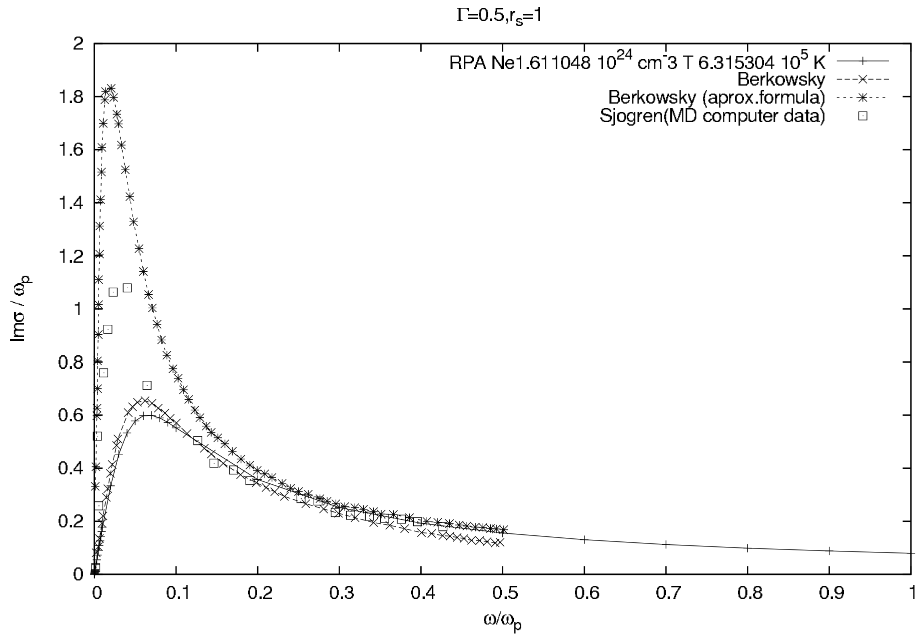

Fig. 2 The imaginary part of electro conductivity, same as Fig. 1.

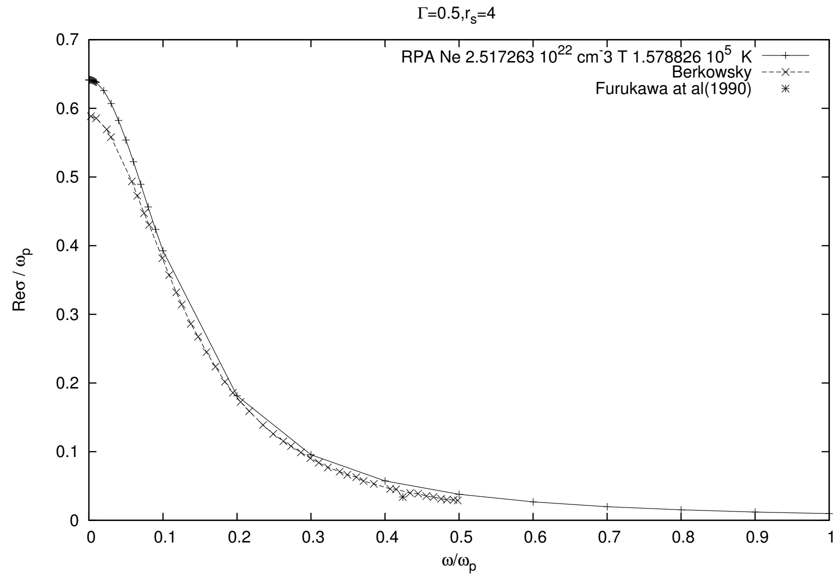

Fig. 3 The real part of HF electrical conductivity of fully ionized H plasma for Γ = 0.5 $r_s = 4$, compared with other authors [5] and [7].

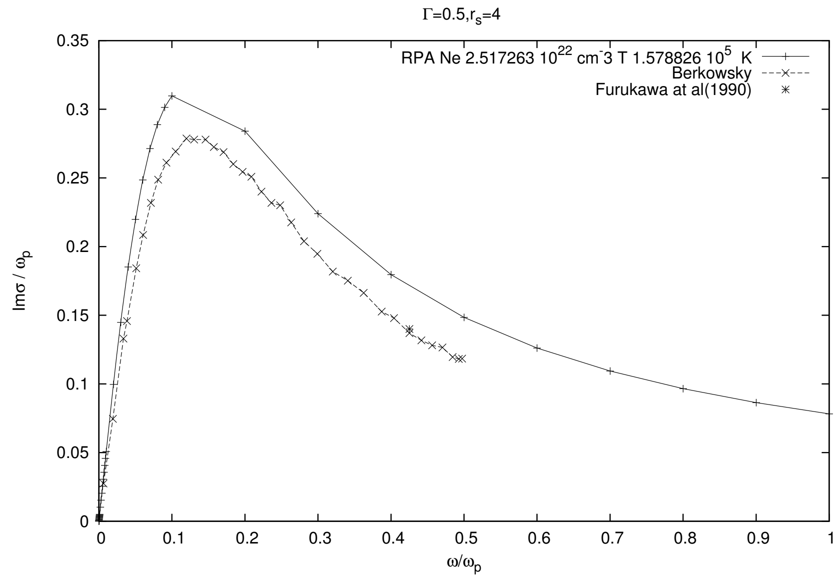

Fig. 4. The real part of HF electrical conductivity of fully ionized H plasma for Γ = 0.5 $r_s = 4$, compared with other authors [5] and [7].

Comparison of the methods: Results of numerical calculations using equations (5), (6), (7) presented earlier in this paper are displayed in the figures 5 – 13.

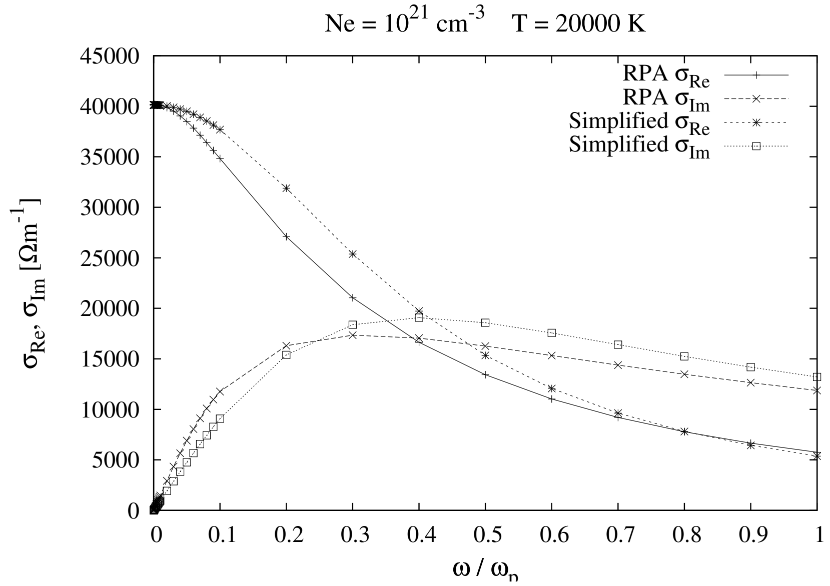

Fig. 5. The comparison of the simplified calculation method and the basic modified RPA method for the fully ionized hydrogen like plasma with the electron density 10^{21}cm^{-3}, and tempereture 20000K.

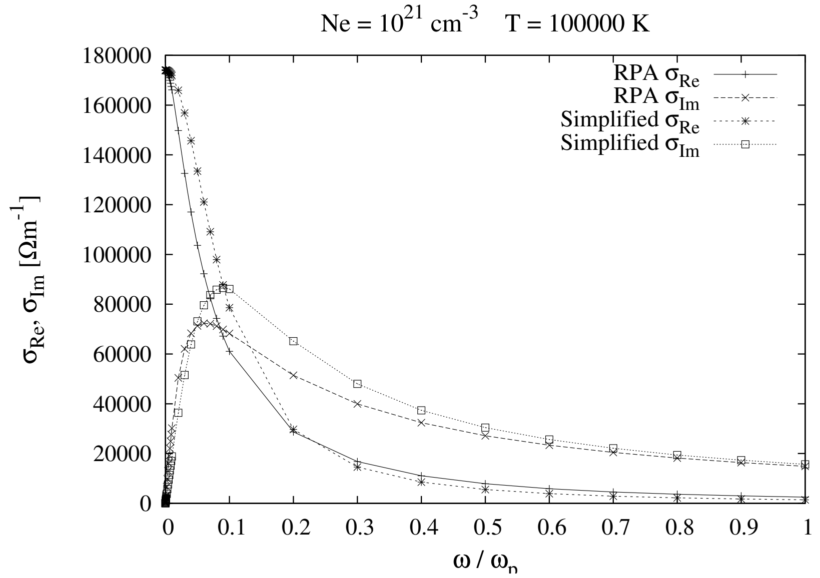

Fig. 6. Same as Fig. 5 but for Ne = 10^{21}cm^{-3} and T = 100000K.

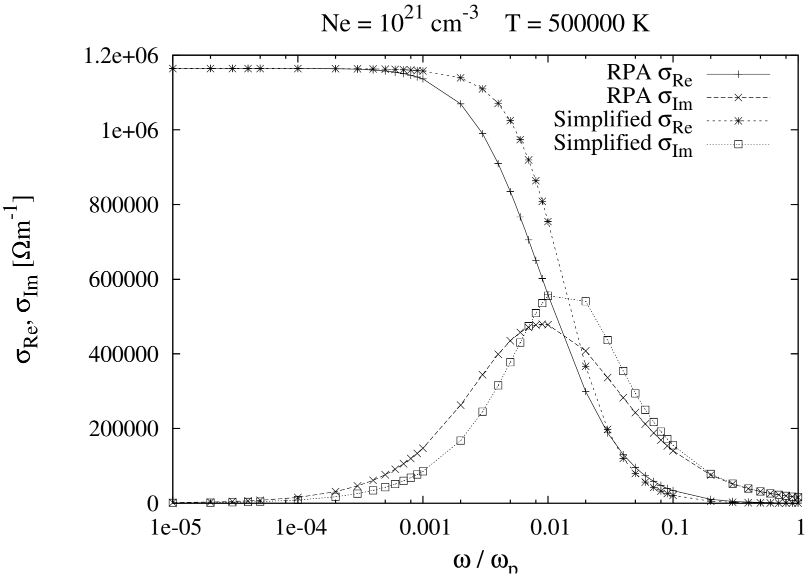

Fig. 7. Same as Fig. 5 but for Ne = 10^{21}cm^{-3} and T = 500000K.

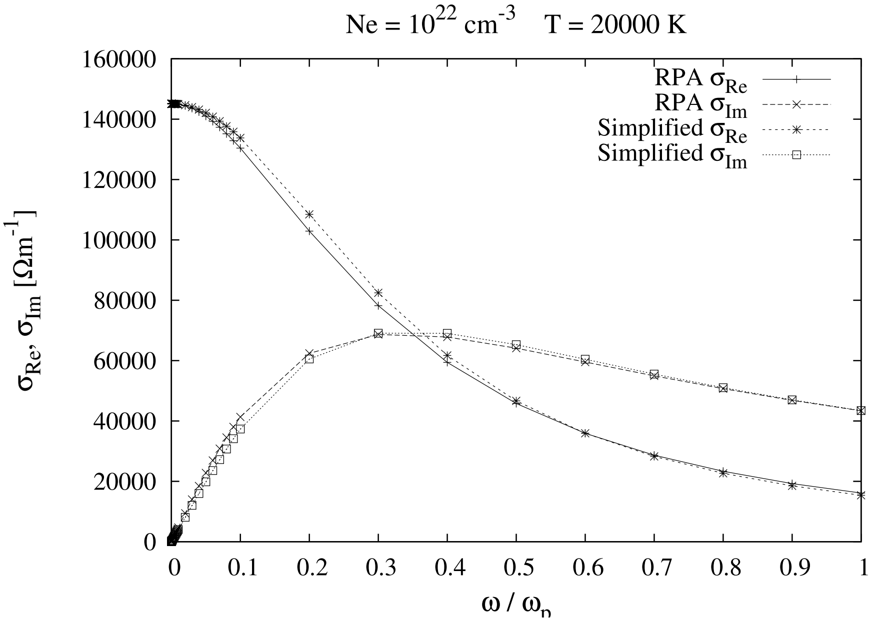

Fig. 8. Same as Fig. 5 but for Ne = 10^{22}cm^{-3} and T = 20000K.

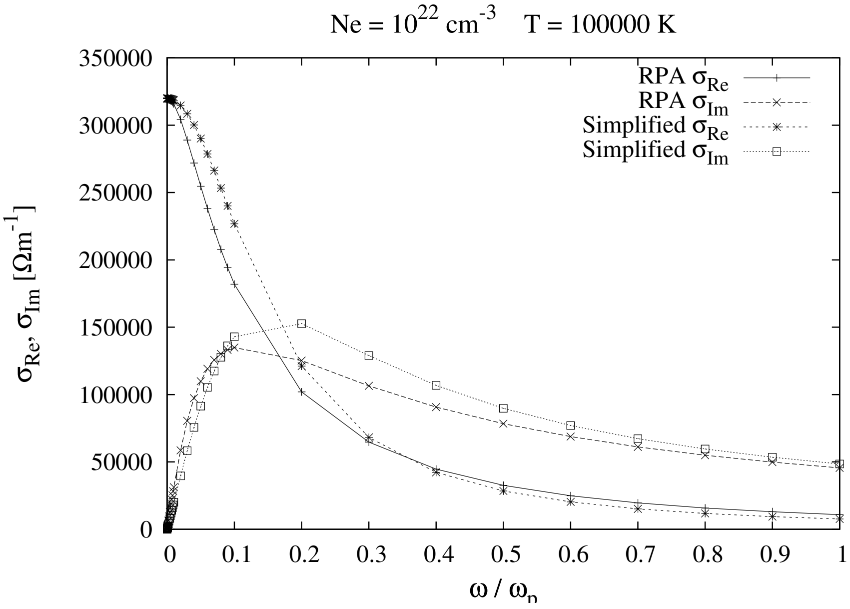

Fig. 9. Same as Fig. 5 but for Ne = 10^{22}cm^{-3} and T = 100000K.

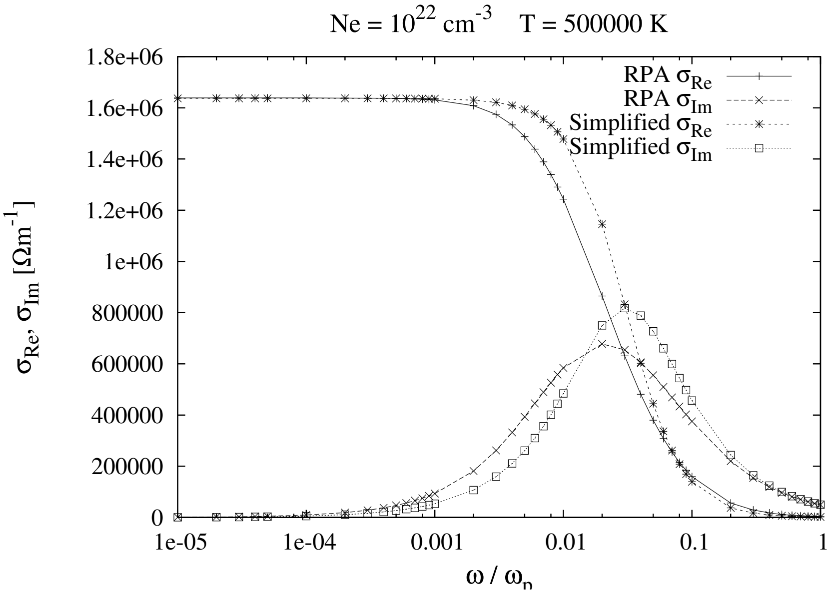

Fig. 10. Same as Fig. 5 but for Ne = 10^{22}cm^{-3} and T = 500000K

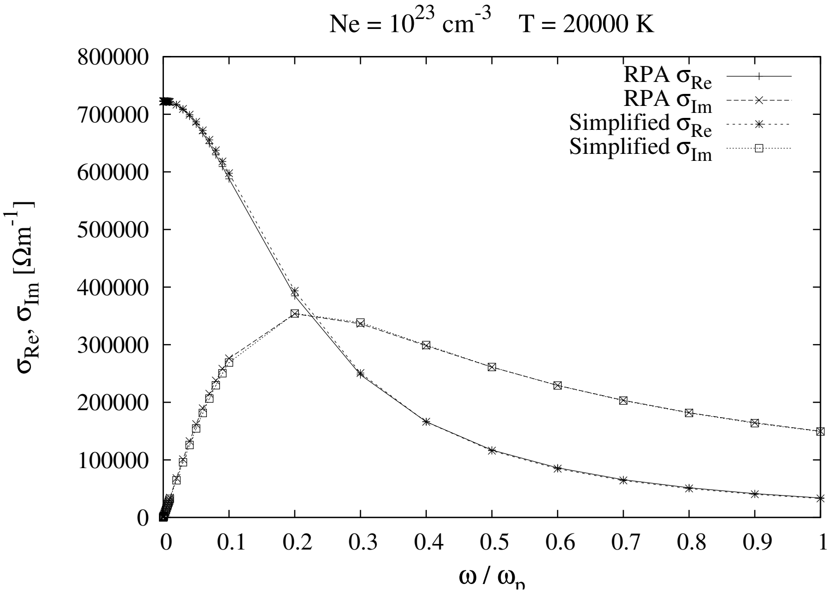

Fig. 11. Same as Fig. 5 but for Ne = 10^{23}cm^{-3} and T = 20000K

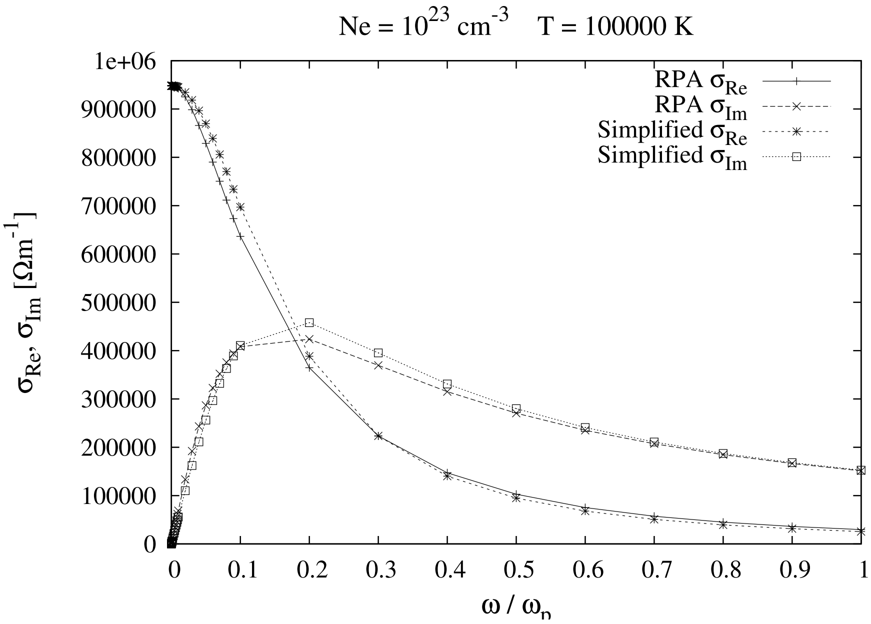

Fig. 12. Same as Fig. 5 but for Ne = 10^{23}cm^{-3} and T = 100000K.

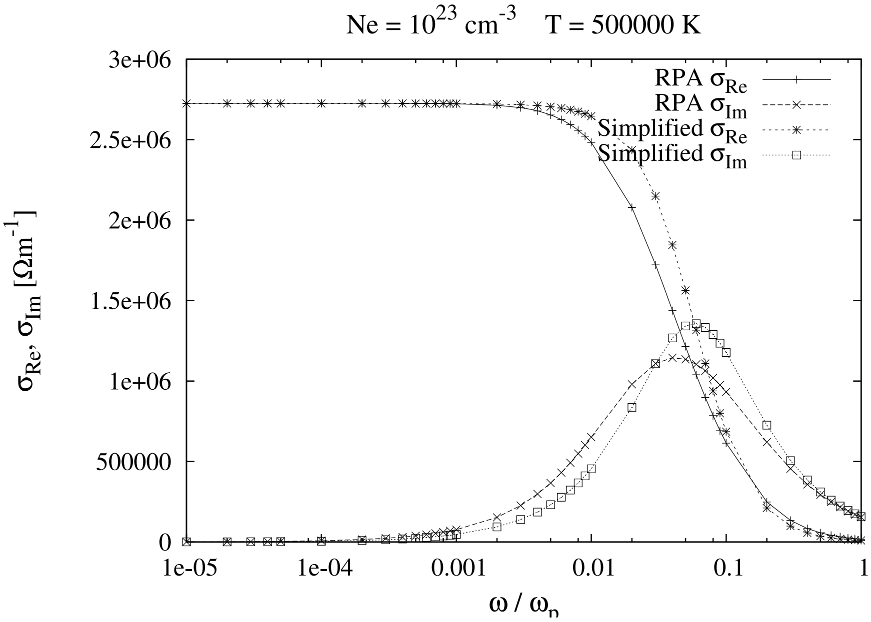

Fig. 13. Same as Fig. 5 but for Ne = $10^{23}cm^{-3}$ and T = 500000K.

With the help of the presented results the other, easily measurable, dynamical characteristics of dense plasma could be obtained [2, 3, 4].

3. CONCLUSIONS

Method of calculations has been proven, and simplified using formulas (5), (6), (7) . Method works well in a much broader area then expected. Work is in progress on inclusion of neutrals, and preliminary calculations with multifold ionized states. Heading towards the area of more dense plasma where a good experimental data exists.

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