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The Modified RPA Conductivity of Dense Two-components Strongly Ionized Plasma

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Abstract. We present modified RPA method of determining the static electrical conductivity of plasma which is applicable in the general case of the dense two-component strongly ionized plasma. Here are given the calculated values of the static electrical conductivity of double and triple ionized plasma. In several cases these results are compared with the Spitzer electro-conductivity.

THEORY

The electro-conductivity of a dense fully ionized plasma was investigated in several previous works [1, 2, 3, 4, 5, 6]. Although older method gave us very good agreement with the experimental results for the single-fold fully ionized plasma, the need for a more precise method for calculation of manifold ionized plasma was needed. In this paper we present a novel approach of calculation of a relaxation time.

As it was mentioned in the previous papers for the calculation of the RPA conductivity

$$\sigma_0 = \frac{4e^2}{3m}\int_0^\infty \tau(E)\cdot\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{1}$$

it is necessary to have the relaxation time $\tau(E)$, here the $\rho(E)$ is the density of a electron states in the energy space and $w(E)$ is a Fermi-Dirac distribution function, e, m are the charge and the mass of the electron. The relaxation time $\tau(E)$ is calculated here with a modified formula

$$\tau^{-1}(E) = \frac{4\pi me^4}{\beta(2mE)^{3/2}}\int_0^{(8me)^{1/2}/\hbar}\frac{dq}{q}\sum_{a,\nu}\frac{\chi^2(a)\prod_{a,\nu}(q)}{\varepsilon_\nu^3(q)} \tag{2}$$

where a numbers electrons and different ion components of a plasma, ν is a Matsubara frequency, $\chi(a) = Z_a^2$ is a form factor of Z-fold ionized atom. The $\prod_{a,\nu}(q)$ is a polarization operator and $\varepsilon_\nu(q)$ is a dielectric function and they are calculated as before [3, 4]. At this point it is necessary to mention that the older and the new formula did not differ for a single-fold ionized plasma (i.e. for $Z = 1$), but the difference becomes more significant for the higher ionization numbers.

TABLE 1. Static electrical conductivity σ_0 in RPA approximation, for $Z = 2$, in units $(\Omega m)^{-1}$.

T $[10^3 K]$	N_e $[cm^{-3}]$ 10^{18}	10^{19}	10^{20}	10^{21}	10^{22}
25	$1.608 \cdot 10^4$	$2.200 \cdot 10^4$	$3.447 \cdot 10^4$	$7.293 \cdot 10^4$	$3.038 \cdot 10^5$
50	$3.943 \cdot 10^4$	$5.102 \cdot 10^4$	$7.280 \cdot 10^4$	$1.249 \cdot 10^5$	$3.321 \cdot 10^5$
100	$9.865 \cdot 10^4$	$1.219 \cdot 10^5$	$1.638 \cdot 10^5$	$2.477 \cdot 10^5$	$4.838 \cdot 10^5$
200	$2.363 \cdot 10^5$	$3.033 \cdot 10^5$	$3.843 \cdot 10^5$	$5.360 \cdot 10^5$	$8.766 \cdot 10^5$
300	$3.997 \cdot 10^5$	$5.182 \cdot 10^5$	$6.408 \cdot 10^5$	$8.649 \cdot 10^5$	$1.319 \cdot 10^6$
400	$5.910 \cdot 10^5$	$7.484 \cdot 10^5$	$9.290 \cdot 10^5$	$1.226 \cdot 10^6$	$1.797 \cdot 10^6$
500	$8.084 \cdot 10^5$	$9.897 \cdot 10^5$	$1.247 \cdot 10^6$	$1.613 \cdot 10^6$	$2.305 \cdot 10^6$

TABLE 2. Static electrical conductivity σ_0 in RPA approximation, for $Z = 3$, in units $(\Omega m)^{-1}$.

T $[10^3 K]$	N_e $[cm^{-3}]$ 10^{18}	10^{19}	10^{20}	10^{21}	10^{22}
25	$1.861 \cdot 10^4$	$2.571 \cdot 10^4$	$4.122 \cdot 10^4$	$9.375 \cdot 10^4$	$4.743 \cdot 10^5$
50	$4.525 \cdot 10^4$	$5.920 \cdot 10^4$	$8.565 \cdot 10^4$	$1.520 \cdot 10^5$	$4.570 \cdot 10^5$
100	$1.136 \cdot 10^5$	$1.408 \cdot 10^5$	$1.909 \cdot 10^5$	$2.942 \cdot 10^5$	$6.072 \cdot 10^5$
200	$2.742 \cdot 10^5$	$3.475 \cdot 10^5$	$4.453 \cdot 10^5$	$6.282 \cdot 10^5$	$1.056 \cdot 10^6$
300	$4.598 \cdot 10^5$	$5.963 \cdot 10^5$	$7.404 \cdot 10^5$	$1.008 \cdot 10^6$	$1.570 \cdot 10^6$
400	$6.748 \cdot 10^5$	$8.663 \cdot 10^5$	$1.069 \cdot 10^6$	$1.425 \cdot 10^6$	$2.123 \cdot 10^6$
500	$9.183 \cdot 10^5$	$1.149 \cdot 10^6$	$1.431 \cdot 10^6$	$1.872 \cdot 10^6$	$2.711 \cdot 10^6$

RESULTS

The RPA method of calculations gave us a possibility of modelling a strongly many-fold ionized plasma in a wide range of electronic temperatures and densities. In the Tables 1 and 2 are presented the results for the static plasma conductivity for the two-fold and three-fold strongly ionized plasma for $10^{18} cm^{-3} \leq N_e \leq 10^{22} cm^{-3}$ and $25 \cdot 10^3 K \leq T \leq 500 \cdot 10^3 K$.

It could be noted that the behavior of a plasma conductivity is similar like in case of a single-fold ionized plasma. The conductivity grows higher with enlargement of N_e and T. Also it is noticeable that the higher ionization led to a higher plasma conductivity.

In the figure 1 the results of a comparison of RPA and Spitzer conductivity for $N_e = 10^{18} cm^{-3}$ and $1 \cdot 10^4 K \leq T \leq 5 \cdot 10^4 K$ and $Z = 1,2,3$ are presented. It should be mentioned that the ratio for the old style calculated values for the RPA relaxation time and the new ones for the $Z = 1$ match because the new and old method do not differ for the $Z = 1$ (the curves marked with the square and cross). Also it is easily noticeable that for the larger Z the new calculated values have better agreement with Spitzer values. In figures 2 the values of σ^{RPA} from the tables 1 and 2 are given in graphical representation.

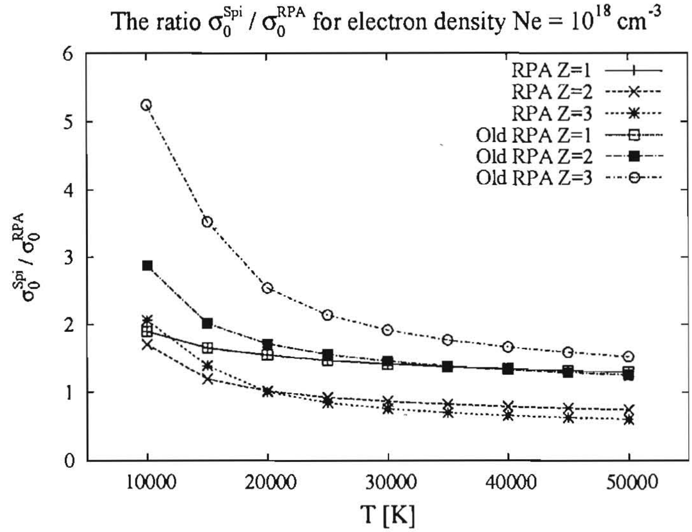

FIGURE 1. The ratio of the Spitzer statical electro conductivity σ_0^{Spi} and the new an old RPA conductivity σ_0^{RPA} as a function of electron temperature for $Ne = 1 \cdot 10^{18} cm^{-3}$.

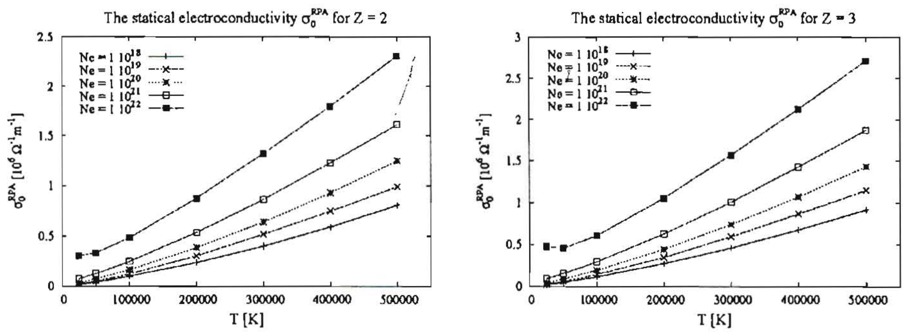

FIGURE 2. The RPA conductivity σ_0^{RPA} as a function of the electron temperature for various Ne and for $Z = 2$ and $Z = 3$.

CONCLUSION

It has been shown in several previous works [1, 7, 8] that this method is good for the modeling of a free plasma as well as plasma in external electrical and magnetic fields. The good agreement of the previous works with the experimental and theoretical results for the single-fold ionized moderately non-ideal and non-ideal plasma known at that time led us in further development and research of a modified RPA theory. Now the modified RPA method presents a strong tool for modeling of single as well as many-fold ionized dense plasma. It could be concluded that the modification of a calculation of relaxation time $\tau(E)$ gave us a good base for a further research in a field of a many-fold ionized, non-ideal and moderately non-ideal plasma.

Results presented here gave us good agreement with the Spitzer formula for $Z > 1$, in the area of applicability of Spitzer formula, and the agreement is better than with the previous method of calculation of relaxation time $\tau(E)$. It is expected that the agreement with the experimental results in the area of more dense plasma, where Spitzer formula is no longer valid, is better with the new approach of calculation of $\tau(E)$. The modification of the formula for the $\tau(E)$ gave us results much better in the region of the higher Z, i.e. for the strongly ionized plasma.

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