X-ray line emission by a superdense plasma

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In connection with development of inertial systems for plasma heating (Proceedings of the Sixth International Conference on Plasma Physics and Controlled Nuclear Research, Berchtesgaden, 6–13 October 1976; Proceedings of International Conference on the Technology of Inertially Confining Systems, Dubna, 19–23 July 1976), a new method is proposed for the diagnostics of a hot plasma with electron density $N_e \gtrsim 10^{22}$ cm^{-3}, by using the relative intensities of the x-ray lines of multiply charged ions.

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A number of methods for determining the electron density in the interval $N_e \sim 10^{20}$–10^{23} cm^{-3}, by using the relative intensities of the x-ray spectral lines of multiply charged ions, have been recently proposed and partially tested.[3–12] However, the

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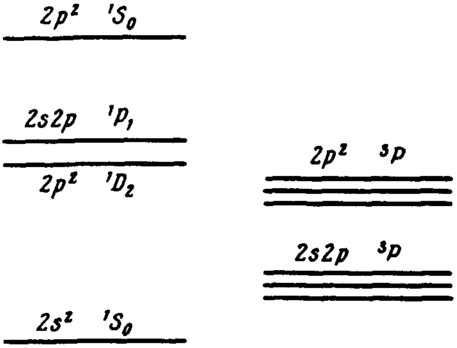

FIG. 1. Scheme of doubly excited levels of He-like ion.

se of these methods for the diagnostics of a plasma with $N_e \gtrsim 10^{23}$ cm^{-3} requires that ıe plasma contain ions with the rather large ionization potential, $I_i \gtrsim 3.5$ keV, i.e., the ıethod is feasible only at sufficiently high electron temperature of the plasma.

In the present paper we propose a spectroscopic diagnostics method, which ıakes it possible to measure the electron density in the region $N_e \sim 10^{22}$–10^{25} cm^{-3} by sing the lines of ions that have much lower ionization potentials ($I_i \sim 0.74$–2.4 keV), ıd consequently exist at much lower temperatures.

Obviously, for the diagnostics of a compressed plasma we can use only lines that art from levels for which the deviation from a Boltzmann population is preserved at trahigh densities. We consider in this connection the change in the relative intensis of the dielectronic satellites of the resonance line of an H-like ion on going from a nuous to a dense plasma. The emission of such lines takes place upon radiative decay the doubly excited states of an He-like ion, i.e., in relaxation transitions of the type $2l' \rightarrow 1s2l''$ (the level scheme is shown in Fig. 1). In the case of a strongly rarefied asma (for example, the solar corona), the population of the levels located outside e continuous spectrum is proportional to the product of the statistical weight g of the vel by the factor $F = \Gamma/(A+\Gamma)$,[3] where A and Γ are the probabilities of the radiative ıd autoionization decay of the level. As the plasma density increases to values N_e $N_1 = A/C$ (where C is the rate of the collisional transitions without change of multiicity) a Boltzmann equilibrium is established within the singlet and triplet level stems.[6] The level population remains as before proportional to the factor F. Howev- A and Γ must now be taken to be the decay probabilities averaged respectively over triplet and singlet states, and consequently the values of the factor F will be the me for all the triplet and, accordingly, all the singlet levels. Finally, in a plasma of ry high density $N_e \gtrsim N_2 = A/C_{TS}$ (where C_{TS} is the rate of collisional intercombinon transitions), all the levels will be characterized by one and the same factor F hich will now contain probabilities averaged over all the levels), and the populans of all the states become simply proportional to their statistical weights, which in t corresponds to a Boltzmann distribution. Since the rate of the collisional intermbination transitions is much smaller than the rate of the transitions without ınge of spin ($C_{TS} \ll C$), it follows that $N_1 \ll N_2$.

Thus, the dependence of the intensity ratio of any pair of lines, one of which starts

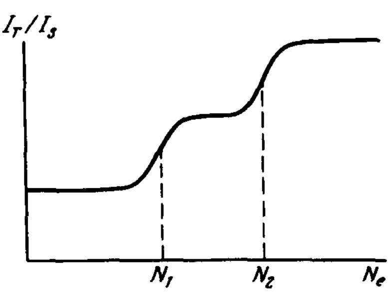

FIG. 2. Dependence of the intensity ratio I_T/I_S of the triplet line and singlet line on the electron density of the plasma.

from the triplet level and the other from the singlet level, on the electron density, takes on the following character (Fig. 2): There are three regions in which the intensity ratio is practically constant and corresponds to the three cases indicated above. These are separated by two transition regions $N_e \sim N_1$ and $N_e \sim N_2$, in which the relative intensities are functions of the electron density of the plasma and can be used to determine this density. The first transition region was analyzed in detail in[6]. In the present article we consider the second transition region, which, naturally, is more suitable for the diagnostics of a superdense plasma.

To calculate the relative intensities in the region $N_e \sim N_2$, we solved a system of balance equations, in which account was taken of the autoionization and radiative decay processes, dielectronic capture, ionization, triple recombination, and collisional transitions between doubly excited states. The following formula was obtained for the ratio of the populations of the triplet (N_T) and singlet (N_S) levels:

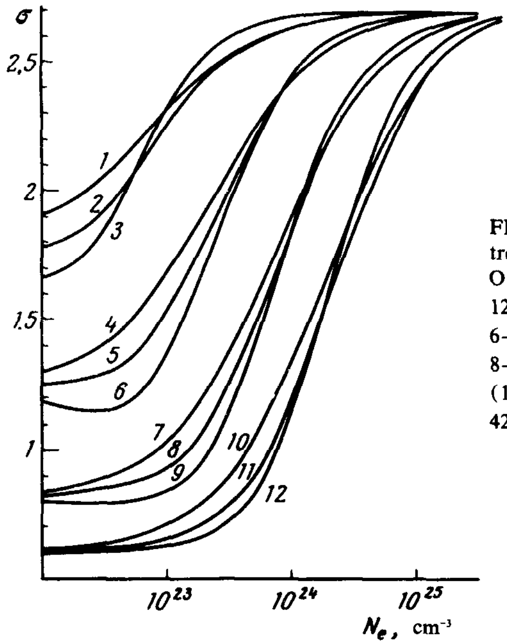

FIG. 3. Plots of $\sigma(N_e)$ at different values of the electron temperature of the plasma for the following ions: O VII (1—kT_e=41 eV, 2—kT_e=81 eV, 3—kT_e= 121 eV); Ne IX (4—kT_e=67 eV, 5—kT_e=134 eV, 6—kT_e=201 eV); Mg XI (7—kT_e=100 eV, 8—kT_e=200 eV, 9—kT_e=300 eV); Si XIII (10—kT_e=140 eV, 11—kT_e=280 eV, 12—kT_e= 420 eV).

$$N_T/N_S = (B_1 + B_2N_e + B_3N_e^2 + B_4N_e^3)/(1 + B_5N_e + B_6N_e^2 + B_7N_e^3), \qquad (1)$$

where the constants B_i are expressed in terms of the probabilities of the elementary atomic processes.

Figure 3 shows plots against N_e, constructed with the aid of formula (1), of the intensity ratio $\sigma = I_T/I_S$ for the ions O VII, Ne IX, Mg XI and Si XIII. Here I_T is the sum of the intensities of several closely lying triplet lines, while I_S is the intensity of the strongest singlet line (values that lend themselves most readily in our opinion to experimental determination), namely:

$$I_S = I\,(2p^2\,{}^1D_2 \to 1s\,2p\,{}^1P_1); \quad I_T = I(2p^2\,{}^3P_1 \to$$
$$\to 1s\,2p\,{}^3P_0) + \sum_{J=0}^{2} [I\,(2p^2\,{}^3P_J \to 1s\,2p\,{}^3P_1) + I\,(2s\,2p\,{}^3P_J \to 1s2s\,{}^3S_1)]$$
$$+ \sum_{J=1}^{2} I\,(2p^2\,{}^3P_J \to 1s2p\,{}^3P_2).$$

As seen from Fig. 3, the $\sigma(N_e)$ plots make it possible, using the ions O VII to Si VIII, to measure the density in the region $N_e \sim 10^{22}$–10^{25} cm^{-3}. We note that the drop in the intensity ratio decreases with decreasing ion change. This circumstance hinders diagnostics based on lines of elements lighter than oxygen, i.e., the investigation of a plasma with an even lower temperature (see Fig. 3).

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