Letters to the Editor

POPULATIONS IN THE OPTICALLY THICK HELIUM PLASMA[1])

ПОПУЛЯЦИИ В ОПТИЧЕСКИ ТОЛСТОЙ ГЕЛИЕВОЙ ПЛАЗМЕ

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The influence of plasma thickness on global population coefficients in the radiation-scattering model of helium plasma is discussed. In our model the ground and metastable states are treated as non-stationary.

We have constructed a radiation-scattering model of helium plasma, which enables us to study some of its properties numerically. This paper is devoted to the study of the influence of photon absorption (described by the escape factors) on the population densities of the corresponding quantum levels.

In our model we use the following energy level scheme: 1^1S, 2^1S, 2^1P, 3^1S, 3^1P, 3^1D, 4^1, 5^1 (the last two states include all states with a different azimutal quantum number) and quasicontinuum. The triplet states are not yet included at present. In what follows the multiplicity index is not included for the state specification.

The processes we take into account are: 1) excitation and deexcitation due to electron collision, 2) electron ionization and the corresponding three-body recombination, 3) emission and absorption of the photons, 4) photoionization and radiative recombination.

The equations of the model we begin with have the form:

$$\frac{dn_i}{dt} = \Sigma T_{ij} n_j + U_i ,$$

where n_i are population densities and T_{ij} and U_i are terms which depend on the processes included.

For higher energy states (i.e. all states with the exception of the $1S$ ground and the $2S$ metastable states) we assume a fast relaxation to stationary values. This leads to neglecting the time derivatives for $i \geqslant 3$. As the remaining algebraical equations are linear in n_i, we obtain for stationary values the following formula

$$\varrho_i = R0_i + R1_i \varrho_{1S} + R2_i \varrho_{2S} ,$$

where $\varrho_i = n_i / n_{i\text{-Saha}}$ are the equilibrium normalized populations, and $R0_i$, $R1_i$, $R2_i$ are the so-called global population coefficients. These coefficients are dependent on the electron density n_e and the electron temperature T_e and, of course, on escape factors, which describe the plasma thickness.

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The escape factors enter in the processes 3) and 4). The processes of emissin and absorption of photons are jointly described as effective emission in the form $\lambda_{ij}A_{ij}$, where A_{ij} are the Einstein coefficients and λ_{ij} are the corresponding escape factors. Thin plasma, it is plasma with no absorption, corresponds to the case, when all λ's are equal to one. Similarly the processes under 4) are described as effective recombination in the form $\lambda_{ci} \cdot F_i(T_e)$, where $F_i(T_e)$ is the photorecombination rate (depending on the electron temperature T_e) and λ_{ci} are the continuum escape factors.

Numerical simulations were carried out for thin plasma and for 4 variants of thick plasma. For choice of escape factors we take into account the fact that in laboratory plasma absorption occurs typically only in the so-called resonant transition — it is the transition from the ground state. We assumed non-one escape factors only for that resonant absorption, other transitions are treated as thin. The non-one factors are given in the Table 1.

Table 1

Variant	$2^1P \rightarrow 1^1S$	$3^1P \rightarrow 1^1S$	$4^1 \rightarrow 1^1S$	$5^1 \rightarrow 1^1S$
Absolutely thick	0	0	0	0
10 torr	0	4 E−2	5 E−12	2 E−6
1 torr	3 E−12	1.5 E−3	7 E−2	3 E−1
Drawin	1 E−4	1 E−3	1 E−2	1 E−1

The 1 and 10 Torr variants are calculated from the approximate formula [1]:

$$\lambda = \exp(-n_{1s} l \langle \sigma \rangle)$$

for l = typical dimension = 0.1 m plasma. $\langle \sigma \rangle$ is the averaged absorption cross-section. The label Drawin corresponds to Drawin C variant of [2].

The results of calculations can be described using what we call the thick to thin ratio for global population coefficients, which is the ratio of the global population coefficient for thick plasma to the global population coefficient for thin plasma.

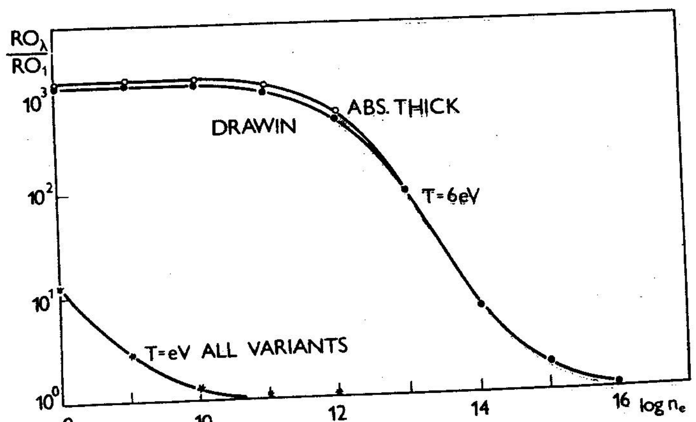

Fig. 1. Global population coefficient: thick to thin ratio for 2^1P level.

We have found that plasma thickness influence is very great for the $2P$ state and is nearly the same on all thick to thin ratios (i.e. for coefficients $R0_{2P}$, $R1_{2P}$ and $R2_{2P}$). These ratios have a value of about 10^3 for lower electron densities up to 10^{11} cm^{-3} and then quickly approach the value one for 10^{16} cm^{-3}. Such a dependence is observed in 2 to 10 eV electron temperature region. For lower temperature the influence is lower.

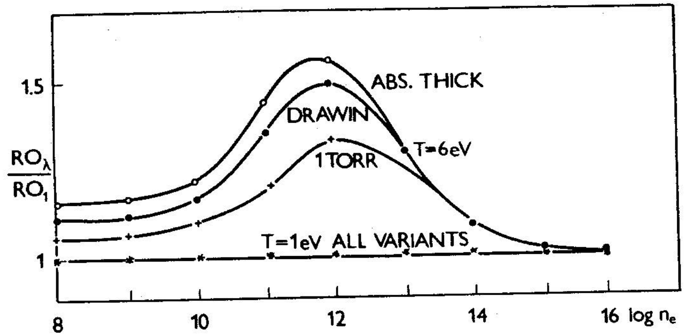

Fig. 2. Global population coefficient: thick to thin ratio for 4^1P level.

For higher energy states the influence is lower, the thick to thin ratio is of the order 1, being the greatest in the middle electron density region of about 10^{11} to 10^{14} cm^{-3}.

These results are illustrated for the 2^1P- and 4^1-states and the $R0_\lambda/R0_{\lambda=1}$ thick to thin ratio. All results are only weakly dependent on the escape factor variant: evidently the $1S \rightarrow 2P$ absorption is dominant. Also the temperature dependence in the 2 to 10 eV region is weak. (For that reason only typical curves are drawn in the figures.)

REFERENCES

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