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INVERSION OF POPULATION IN AN EXPANDING H_2 PLASMA

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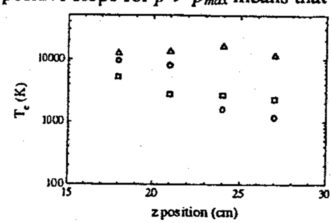
The inversion of atomic hydrogen level population of an expanding nonequulibrium dense plasma has already been demonstrated experimentally by emission spectroscopy [1,2]. An atomic collisional-radiative model has been attempted to explain the experimental data [2,3]. This paper shows an experimental determination of the atomic hydrogen excited levels population in a magnetized expanding cascaded arc plasma. n_e and T_e are measured by Langmuir double probe diagnostics and the classical Langmuir probe theory is used to interpreted the probe characteristic. An explanation to the presented situation in which a large discrepancy is found between the outcome of the model and the measured population densities is given based on the presence of rovibrationally excited molecules.

Fig.1 show n_e and T_e as function of the axial distance to the exit of the cascaded arc as measured by the Langmuir double probe diagnostics. n_e is much larger than in the absence of a magnetic field [4]. The accuracy in T_e is estimated up to 50% and in n_e about 25%. It should be noted that in the measured n_e and T_e ranges the plasma is still recombining in nature and that the excitation and the ionization from the ground state can be neglected. Fig.2 show the absolute population densities n_p/g_p and the b_p factor on the plasma beam axis as a function of the ionization potential I_p of the level p. An population density inversion appears for the levels $3< p <7$. In general the inversion is more pronounced downstream in the plasma jet and the maximum of n_p/g_p occurs for the higher quantum numbers. In the b_p plot, a maximum value occurs for the level p_{max} at which the inversion is found in Boltzman plot. Furthermore, the b_p values for smaller I_p values decrease directed to 1, as expected for levels close to the continuum for which the population is ruled by electron collisions [5]. Another aspect of the b_p plot is the fact that the b_p values for high p are much larger than 1, indicating that a large population source is present. The negative slope of b_p vs. I_p for levels with $p < p_{max}$ means that these levels are recombining since for these levels the optical decay at the given n_e and T_e is dominant over the collisional excitation. Alternatively, the positive slope for $p > p_{max}$ means that these excited levels are ionizing.



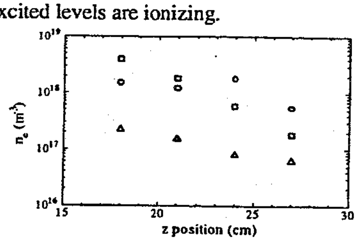


Figure 1 T_e and n_e of a cascaded arc expansion hydrogen plasma
plasma conditions: $H_2 = 0.5$ slm, $I_{arc} = 50$ A, $p = 0.05$ mb, z = 24 cm
□: B = 40 mT, O: B = 24 mT, Δ: B = 8 mT

For an explanation, a mechanism which can lead to the observed large population and should at least populate levels up to p_{max} is required. The purely atomic processes of which the three particle recombination ($e+e+H^+ \rightarrow e+H^*$) is the main population mechanism can not explain the large overpopulation since e.g. for $p = 4$ the calculated density is a order of 4 lower than the measured density at the present condition. Therefore the molecular processes should be included.

The mechanism [4] based on the charge exchange with rovibrationally excited $H_2^{v,J}$ molecules which could be presented in the recirculating plasma flow is also unlikely because it requires large amount of very high rovibrational excited H_2 molecules to reach the population level between 5 and 7. In our experiment, the background pressure is only a few pascal which is an order lower than that in the case in Ref. [4] and the reionization could be occurred in our case due to the application of a magnetic filed.

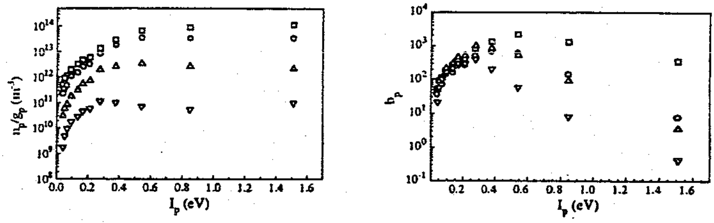


Figure 2 Boltzaman plot and b_p plot of a cascaded arc expansion hydrogen plasma
plasma conditions: $H_2 = 0.5$ slm, $I_{arc} = 50$ A, $p = 0.05$ mb, $B = 40$ mT
□: $z = 18$ cm, $T_e = 5150$ K, $n_e = 3.9\cdot10^{18}$ m^{-3}, O: $z = 21$ cm, $T_e = 2710$ K, $n_e = 1.8\cdot10^{18}$ m^{-3}
Δ: $z = 24$ cm, $T_e = 2610$ K, $n_e = 5.8\cdot10^{17}$ m^{-3}, ∇: $z = 27$ cm, $T_e = 2250$ K, $n_e = 1.8\cdot10^{17}$ m^{-3}

An alternative mechanism is the mutual recombination of H^+ and H^- which is formed by dissociative attachment, but only this is also difficult to explain the large population at $p \geq 4$ since recombination rate for $p \geq 4$ is negligible small. A more probable mechanism is the mutual recombination of H^- and H_2^+ which could be either formed by charge exchange in the expansion [4] or generated in the arc), i.e.

$$H_2^{v,J} + H^+ \rightarrow H_2^+ + H \tag{1}$$

$$H_2^+ + H^- \rightarrow H_2^{v,J} + H_{p\geq2} \tag{2}$$

this mechanism can explain the population of highly excited states since the ionization energy of H_2^+ is about 15.6 eV. Furthermore, it generates rovibrationally excited molecules, which means that there is no need for high vibrational temperatures (or equivalent rotational temperatures). A simplified calculation based on the assumptions of comparative rate of formation of H^- and H^+ and the time limiting step is still the charge exchange and the electron attachment reaction and the molecular states of $v \geq 4$ or equivalent rotational states leads to $n(H^-) \approx n(H_2^+) = 6\cdot10^{17}$ m^{-3}. This means that if the assumptions made are true, the potential of the expanding magnetized hydrogen plasma as a negative hydrogen source is large. Note that there is still competition from dissociative and mutual recombination. Another interesting aspect is that if the proposed mechanisms Eqs.(1)-(2) are correct, this would enable an optical detection technique of the negative ions: by performing laser photodetachment the light emission originating from the excited levels in the range $3 \leq p \leq 6$ should disappear.

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