Population inversion in a magnetized hydrogen plasma expansion due to a molecular mutual neutralization process

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When an expanding hydrogen plasma jet, produced from a cascaded arc source, is weakly magnetized, the emission of the expanding plasma jet is dominated by the red H_α emission in the first centimeters from the exit of the source, but changes to blue at larger distances from the exit due to higher Balmer lines ($n > 4$). Moreover, higher electronic states ($n > 4$) of H atoms become stronger populated than the lower states [1]. The reaction pathway proposed for the formation of these highly excited hydrogen atoms is via mutual recombination of positive (H_2^+) and negative ions (H^-). The latter are formed by dissociative attachment of electrons with ro-vibrationally excited hydrogen molecules.
The emission of the magnetized hydrogen plasma jet is dominated by red H_α light in the beginning of the jet. Since electron energies in the jet are too low (1 eV and less) to excite atomic hydrogen to the state $n = 3$, a possible formation route is via mutual recombination of atomic ions: $H^+ + H^- \rightarrow H + H(n = 2, 3)$. After 20 to 30 cm a transition occurs from a red to a blue emission. This is due to a population inversion between higher excited atomic states of $n = 4$, 5 and 6 in respect to $n = 3$ [1]. The reaction proposed to be responsible for this overpopulation is the mutual ion-ion recombination reaction: $H_2^+ + H^- \rightarrow H_2 + H(n \geq 2)$, in which highly excited hydrogen atoms can be formed.

We have recorded by means of emission spectroscopy the densities per statistical weight of the atomic hydrogen levels $n = 3$ to 6 as a function of the axial position z, i. e., the distance from the exit of the source. For the $H(n = 2)$-state absorption spectroscopy with a tunable diode laser has been employed. The first 22 centimeters of the jet is dominated by H_α light. After that, H_β to H_δ light becomes dominant and the corresponding weighted densities n/g become higher than the one for $n = 3$. By means of Abel inversion the line-of-sight atomic density measurements are converted to spatially-resolved atomic densities. These results show that around the red-to-blue transition the higher excited state densities show a minimum on the expansion axis. Tentatively this is explained by the in-flow of ro-vibrationally excited hydrogen molecules into the plasma jet from the background gas surrounding the jet. These excited molecules produce H^- ions, and form a hollow profile. Since the positive ions and the electrons are mostly confined in the center of the plasma, a maximum production of excited atoms, through the mutual ion-ion recombination process, occurs.

[1] J.J.A. van den Dungen, O. Gabriel, H.S.M.M. Elhamali, D.C. Schram, R. Engeln, IEEE Transactions on Plasma Science **36**, 1028 (2008)