Topic number: 1. Atomic and molecular processes in plasmas

# Population inversion in a magnetized hydrogen plasma expansion as a consequence of the molecular mutual neutralization process

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## 1 Introduction

In this abstract we report on the production of excited H atoms in a magnetically confined hydrogen expansion produced by a cascaded arc. It is known that ro-vibrationally excited $H_2^{rv}$ molecules are produced via wall association. These $H_2^{rv}$ molecules flow into the plasma locally producing $H^-$ ions via the dissociative attachment process [1]. The $H^-$ ions recombine with $H_2^+$ to form hydrogen atoms in highly excited states causing population inversion. We will finish with a discussion on the importance of molecular processes by using a collisional radiative model.

## 2 Experimental Results

The spatially resolved densities of $n$=3-6, obtained from the Abel inverted Optical Emission Spectroscopy (OES) and $n$=2 from Tunable diode laser absorption spectroscopy (TDLAS) are shown in figure 1a.

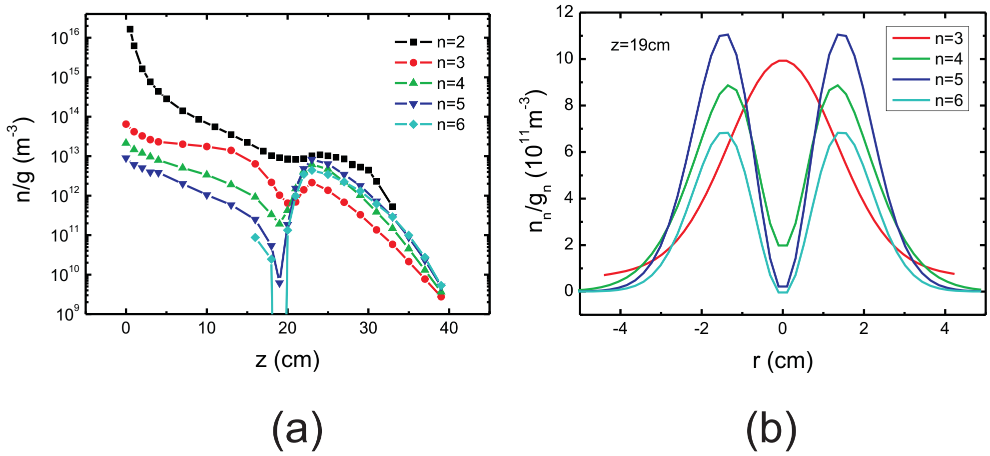


Fig. 1: a) The measured excited state densities. The reduced density of $n$=2 is measured with TDLAS and $n \geq 3$ is measured with OES. b) At the red-blue transition, at z=19cm, a hollow profile is found for $n$=4, 5 and 6. This clearly shows the creation of highly excited states from the outside.

An interesting feature is an observed hollow profile in the red-blue transition, see figure 1b. This red-blue transition occurs at an axial distance from the cascaded arc $z$=18-22 cm. The hollow profile in the red-blue transition is more pronounced for the higher excited states $n$=5 and $n$=6 while for $n$=3 no hollow profile is observed. From this we observe that the maximum population inversion is observed towards the edge of the plasma, at *r*=1.2 cm, while in the center, at *r*=0 cm, no population inversion is observed.

The dominant population processes for *n*=2 and *n*=3 in the red part of the plasma expansion are mainly mutual neutralization of $H^+ + H^- \rightarrow H(n \leq 4) + H(n{=}1)$ and dissociative recombination $H_2^{+,rv} + e \rightarrow H(n \leq 3) + H(n{=}1)$. The branching for the mutual neutralization reaction $H^+ + H^-$ is mainly to *n*=3 whereas it is negligible to *n*=2 and *n*=4 [2]. The hollow profile obtained in the red-blue transition, at *z*=18-22 cm, suggests that there is an inward flow of $H_2^{rv}$ from the vessel wall producing $H^-$ ions. Since the positive ions and electrons are mostly confined in the center of the plasma and the ro-vibrationally excited molecules are more dense away from the center axis of the plasma an optimum of the dissociative attachment process occurs. Hence, the negative ions form a hollow profile and react with the positive ions via the molecular mutual neutralization to form highly excited states.

It is widely accepted that three-body recombination is responsible for the population inversion in a magnetized hydrogen plasma. The importance of three-body recombination is modeled in an atomic CRM from which an ASDF is constructed. In figure 2, the CR-model results are compared with the experimental data retrieved by OES. The ASDF at *z*=33 cm shows that the

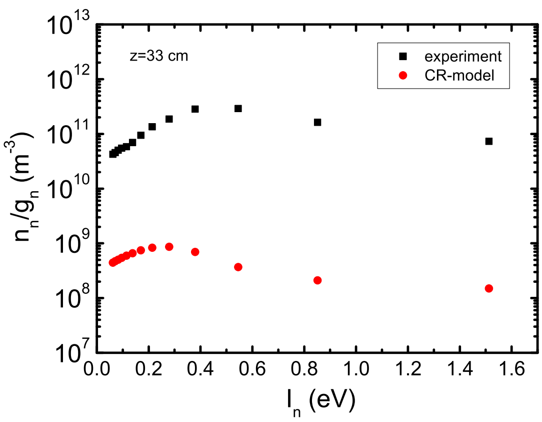


Fig. 2: Comparing the atomic CR-model with the data retrieved from OES at *z*=33 cm. The densities with the model are two orders of magnitude lower than the OES measurements and also the maximum population is at a higher quantum number *n*=7 instead of *n*=5.

CR-model predicts the densities to be two orders of magnitude lower than measured. The reason that three-body recombination cannot explain the high densities of the excited states is because the electron densities in the plasma are too low. Therefore, molecular processes must play an important role in the formation of excited states.

## 3 References


[1] Gabriel O G, Schram D C and Engeln R A H 2008 *Phys. Rev. E: Stat. Phys. Plasmas Fluids Relat. Interdisciplin. Top.* **78**, 016407

[2] Eerden M J J, van de Sanden M C M, Otorbaev D K and Schram D C 1995 *Phys. Rev. A* **51**, 3362 - 3365