LASER DIAGNOSTICS OF H^- FORMATION IN A MAGNETIC MULTICUSP ION SOURCE

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Abstract

The populations of ground electronic state atomic hydrogen and ground electronic state, vibrationally-rotationally excited hydrogen molecules in an negative hydrogen ion source discharge have been measured using vacuum ultraviolet (VUV) laser absorption spectroscopy. Vibrational states up to v=8 and rotational levels as high as J=15 have been measured. The measurements have been made under a range of discharge conditions. The complete vibrational population distribution for v=1-8, J=1 has been obtained. The vibrational distribution appears to be thermalized and does not exhibit a "plateau" at the higher vibrational levels, in contrast to most models of this system. In contrast, the high rotational states are populated suprathermally. These determinations indicate that rotationally excited molecules may play an important role in the production of H^- in these sources.

I. INTRODUCTION

The development of intense sources of high energy neutral beams is of critical importance to the magnetic fusion community [1]. Central to this development are efficient sources of multi-ampere beams of H^- (D^-). Several types of sources have been proposed to produce these ions. One of these is the so-called magnetic-multicusp volume production ion source. This source has been under development in many laboratories around the world. Yet, in spite of this importance, a precise understanding of the mechanism of H^- production in these sources is lacking. This paper describes experiments to measure the absolute density, temperature, and internal energy distribution of the hydrogen atoms and molecules in this type of source. These species, in particular vibrationally excited molecules, are thought to play critical roles in the production of H^-. These measurements are obtained using vacuum ultraviolet laser absorption spectroscopy. This technique is capable of making non-perturbative measurements of these species directly in the the plasma. Coupled with measurements of the charged particles, these measurements may allow a better understanding of the H^- formation kinetics to be developed.

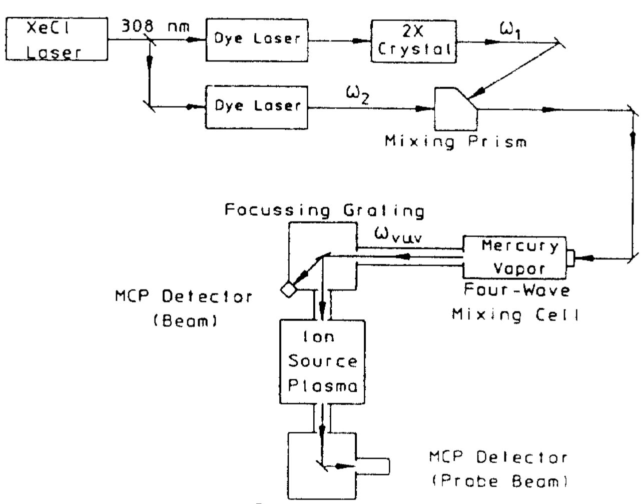

Fig. 1: Schematic diagram of VUV laser absorption spectroscopy system.

II. EXPERIMENTAL APPARATUS

The VUV laser absorption system has been previously described in detail [2]. A schematic of the system is shown in Figure 1. Using the technique of four-wave sum mixing (FWSM) in mercury vapor, narrow bandwidth pulses of coherent VUV are produced. With FWSM the energies of three photons (waves) of energies ω_1, ω_1, and ω_2 are combined to produce a fourth photon with energy ω_{vuv}. VUV with wavelengths from 97 nm to 128 nm has been produced in pulses approximately 20 ns long. These wavelengths encompass both the atomic Lyman series and the (B-X) and (C-X) molecular absorption bands.

The VUV is directed through the ion source where it is detected using microchannel plates. Absorption spectra are obtained by tuning the VUV wavelength through a molecular or atomic transition. The intensity of the transmitted VUV is measured as a function of the wavelength, producing the absorption lineshape. The area under the absorption lineshape is proportional to the density of the absorbing species, while the width of the lineshape is proportional to its translation temperature.

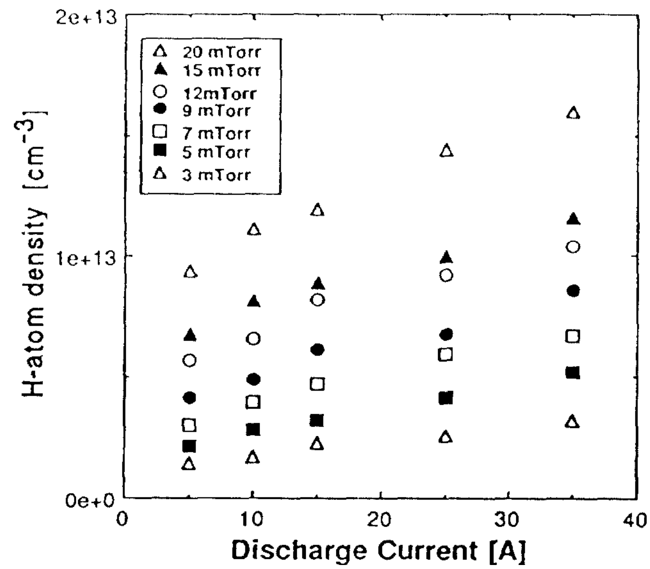

Fig. 2 Atom density as a function of discharge current for several pressures. Discharge voltage is 120 V.

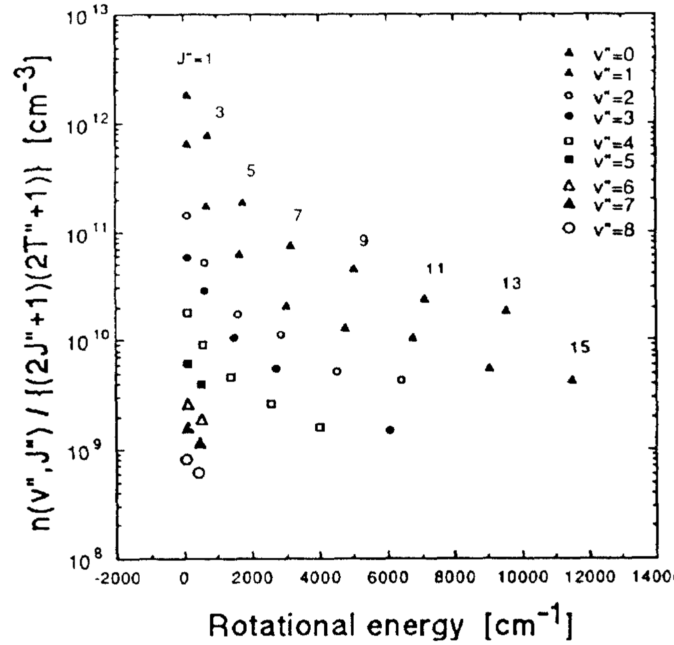

Fig. 3 The measured rotation-vibration populations of hydrogen. Discharge conditions are 25A, 120 V, and 8 mTorr.

The ion source studied is the Lawrence Berkeley Laboratory 25 cm diameter volume source. A magnetic multicusp ion source, it is cylindrical and has rows of magnets to provide a confining magnetic field for the charged particles of the plasma. The cathodes are tungsten filaments. Discharge was obtained with 25 A discharge current and 120 V discharge voltage. Typical hydrogen pressure is 8 mTorr.

III. RESULTS AND DISCUSSION

The results of typical measurements of H-atom are shown in Figure 2. Here, the atom density was measured as a function of discharge current for several hydrogen pressures. The discharge voltage was a constant 120 V for all data shown. As can be seen, the atom density rises monotonically with increasing current, although with only a small slope. The degree of dissociation of the hydrogen is small, less than 3% of the filling pressure at even the highest current. The translational temperature of the atoms is also observed to increase with discharge current. The absorption lineshapes are well characterized by a single temperature, ranging from 0.06 to 0.17 eV at 5 A and 35 A of discharge current, respectively.

The absolute population in many vibrational-rotational states of molecular hydrogen is also measured. Figure 3 displays the results obtained for many of these states. The population in each vibrational level is subdivided among the different rotational states (labeled by J in the figure.) In this type of representation, a thermalized rotational population distribution would be characterized by a straight line. As can be seen, although the population of the lower J states (J=1-4) fall on a line, the higher J state populations do not. The linear portion of the population is described by a rotational temperature of 500K. The high J states are suprathermally populated and cannot be assigned a temperature. The excess population in these states may have important implications for the production of H^-.

If the rotational distribution is the same for all vibrational levels, the correct shape of the vibrational state population distribution will be obtained even if only the populations in the v=n, J=1 states are plotted against vibrational energy. This analysis has been performed and the results are shown in Figure 4. As can be seen, the population distribution is linear and is described by a vibrational temperature of 4900 K. However, a more accurate vibrational population distribution for the hydrogen molecules would be obtained by summing the population in all J states for each vibrational level. As was shown in Figure 3, high J levels can have a significant population. Based on the trends exhibited by the states that were measured, estimates of the population were made for J states all the way out to the dissociation limit. Summing these and plotting the resulting populations yielded a distribution which, although different than the original, could still be well fit by a temperature near 6000 K. This indicates that the high rotational levels can contribute substantial populations to vibrational levels thought to be important in forming H^-.

The effect of increasing the discharge power of the source on rotational-vibrational populations is shown in Figure 5. Here the populations in v=4, J=1 and 7 are shown as a function of discharge current. As can be seen, the population in J=1 peaks at only 12 A and decreases slightly as the current is increased. On the other hand, the population in J=7 increases over the range of currents used. This increase in the

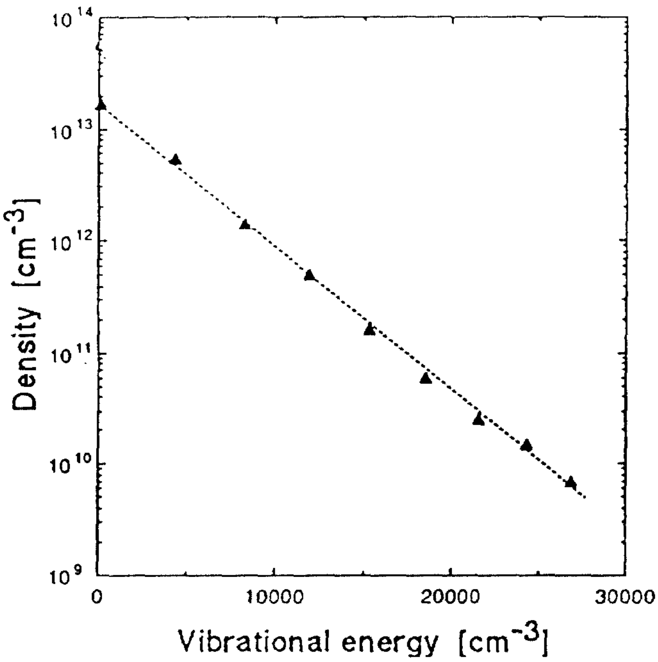

Fig. 4 Vibrational population distribution using J=1 states.

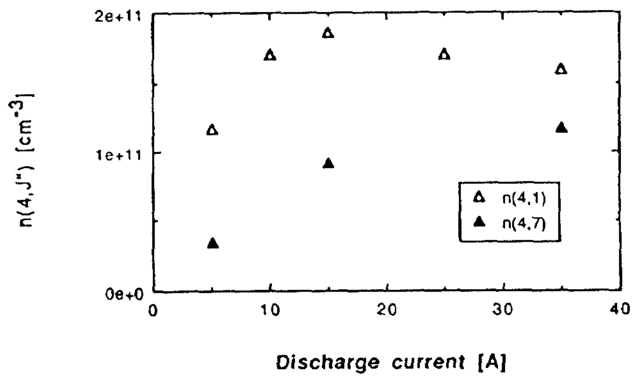

Fig. 5 Variation of rotational population with discharge current. States shown are J=1 and J=7 of v=4. Note the enhancement of J=7 with increasing current.

population of the higher J states with increases in discharge current is also seen in other vibrational levels.

The increase of high J state populations with discharge current has important implications for H^- formation. Calculations [3] indicate that both vibrational and rotational excitation will give enhanced H^- production. Therefore, increasing the population in v=4, J=7 relative to J=1 will increase the total rate of H^- production With sufficient population in the high rotational levels of even moderate vibrational levels($4 \leq v \leq 7$), large populations in the high vibrational levels (v>7) would not be necessary. In particular, a "plateau" in the vibrational distribution, a feature common to many models [4], might not be necessary.

Because the density of molecules in these high J states has not been measured, it is not known how much they contribute to H^- production. However, it is known that for this source increases in discharge current in this parameter range lead to enhanced H^- emission current [5]. Since increasing the discharge current also enhances the population in states which are more efficient in producing H^-, i.e. high J states, the increasein the emission current with discharge current may be due in part to populations in high rotational levels rather in high vibrational levels.

SUMMARY

VUV laser absorption spectroscopy has been used to measure the density and temperature of hydrogen atoms and molecules in an H^- ion source discharge. The translational temperature of the atoms ranges from 0.06 to 0.17 eV, depending on the discharge conditions. The density of the atoms increases mildly with discharge current, but remains below 3% of the molecular density. The molecules exhibit a large degree of vibrational and rotational excitation. The rotational distribution is not thermalized, with the high J states being overpopulated. The vibrational distribution appears to be thermalized, but the temperature of the distribution depends on the assumptions made about the population in the highest J states.

The population in the high J states is of crucial importance in understanding the H^- formation mechanism. The scaling of the H^- current and the high J state populations suggest that these states play a significant role in negative ion formation. Experiments are now underway to measure these states and elucidate their role in H^- production.

ACKNOWLEDGEMENTS

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