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H atom density measurement using a combination of optical emission spectroscopy and Langmuir probes diagnostics.

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As an alternative to laser induced fluorescence (TALIF) for H atom density measurement, a method called “refine actinometry” using a combination of optical emission spectroscopy and Langmuir probe measurements is evaluated. This evaluation has been performed both experimentally and theoretically. Experiments have provided variations of H atom density with respect to experimental working conditions and a 1D code has given H densities for the same conditions.

Classical actinometry measurements are based on radiative de-excitation of the H(n=3) state down to the H(n=2) state at 656.5 nm (H_α) or H(n=4) state down to the H(n=2) state at 486.1 nm (H_β). This diagnostic requires the direct excitation of ground-state hydrogen atom H(n=1) by electron impact and the use of a reference gas (Ar). Hence, when all actinometry hypotheses [1] are fulfilled, emission line intensity ratio is said to be proportional to the atomic hydrogen concentration [H] in the plasma as illustrated by relation 1.

$$[H] \propto \frac{I(H_\beta^*)}{I(Ar^*)}[Ar] \qquad (1)$$

This simple and low-cost method has been validated by several methods such as TALIF [2] in higher pressure working conditions. Whereas this method uses the natural H_α or H_β emission line, its use is limited to the nearby discharge where the line intensities are strong and where dissociative excitation is weak. If the plasma produces a large amount of hot electrons dissociative excitation increases. Hence, hypotheses of relation (1) are no longer valid and “refine actinometry”, as we called it, must be set. For that purpose, we intend to use not only the relation (1) but the complete equation (2) where the following terms are used: transition wavelengths λ_X, transition probabilities A^x, radiative lifetimes τ^{X^*}, quenching coefficients $q^{Y^*}{}_X$, apparatus response $C(\lambda_X)$ at the wavelengths λ_X. These coefficients will be measured or even calculated using Langmuir probe (LP) measurements, calibration light and available published results.

$$[H] = \underbrace{\frac{I(H^*)\cdot A^{Ar}\cdot\tau^{Ar}\cdot\lambda_H\cdot C(\lambda_{Ar})\cdot k_{Ar}^{exc}}{I(Ar^*)\cdot A^{H}\cdot\tau^{H}\cdot\lambda_{Ar}\cdot C(\lambda_H)\cdot k_H^{exc}}\cdot[Ar]}_{\text{"classical" actinometry with explicit k "constant"}}\cdot\underbrace{\left(\frac{\tau_{H^*}^{-1}-[H_2]\cdot q_{H_2}^{H^*}-[Ar]\cdot q_{Ar}^{H^*}}{\tau_{Ar^*}^{-1}-[H_2]\cdot q_{H_2}^{Ar^*}-[Ar]\cdot q_{Ar}^{Ar^*}}\right)}_{\text{quenching processes}}\underbrace{-\frac{k_H^{dis}}{k_H^{exc}}\cdot[H_2]}_{\text{dissociative excitation}} \qquad (2)$$

Hence, if all coefficients are properly calculated using the measured Electron Energy Distribution Function (EEDF), via LP, TALIF method which requires high-power pulsed tunable laser (Nd-Yag and a Dye laser) to excite atoms from the ground state H(n=1) to an upper level H(n=3) to produce fluorescence at 656.5 nm could be avoided.

EEDF is provided by LP measurements near plasma sources where the magnetic could be high (650 G). Ions (Ar^+) are too massive to be magnetized (their Larmor radius is too large): a constant increase of the ion density is observed if we get closer to the source. For electrons, their density seems to

decrease for the same locations. This artefact is no longer observed if a correction suggested by Arslanbekov *et al.* [3] is employed. Hence, even if our probe measurements are in magnetic field area, corrections could provide reliable results being used for excitation coefficients calculations.

The gas temperature is needed to estimate the density of the actinometer [Ar] for relations (1, 2). For that purpose, we used the (2-2)Q branch of H_2 Fulcher-α band system (622.4-628 nm). It appears that whatever the pressure is (between 1 and 12 mtorr) the gas temperature remains 400 K.

If the following parameters are obtained by LP or OES measurements: EEDF, Tg, and the spectrometer calibrated via a tungsten lamp, *eq.* 2 can be used to estimate the absolute atom density.

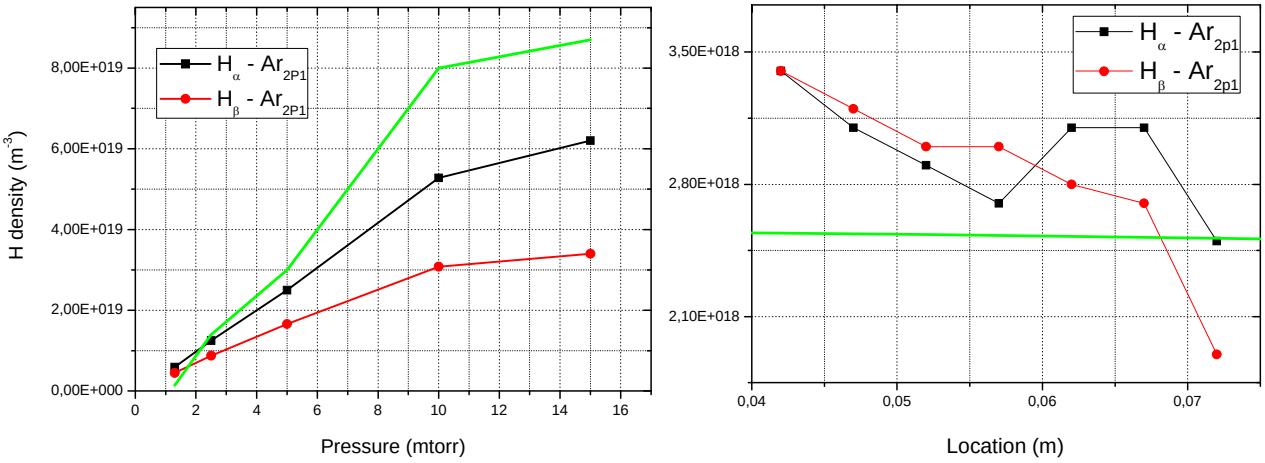

Fig. 1 a) Variations of H atom density with respect to the pressure of H_2. Measurements have been performed in a network of the 7 plasma sources. b) Variations of H atom density with respect to the radial location with respect to the source axis (in the mid plan of the magnet).
In a) and b), the green lines refer to the values obtained with the 1D code of LSPM – Villetaneuse.

Variations of H atom density with respect to the pressure of H_2 in the plasma are presented in Fig.1a). Measurements have been performed in the network of 7 plasma sources. For that purpose, as LP measurements are localized and refer to a small plasma area around the probe tip, we have used a lens to obtain localized emission measurements of emission lines. We compare in this figure our results to those obtained with a 1D code issued by LSPM – Villetaneuse. We found a good agreement between the numerical results and the density of H obtained by using the ratio H_α/Ar_{2p1}.

For radial location (Fig. 1b), agreement between experimental and theoretical values is good. The density is lower than values presented in Fig. 1a) because for these measurements (Fig. 1b) only a single plasma source is used instead of 7 in the case of Fig. 1a. In that case, Abel's inversion has been used to get localized values of emission lines to use in combination with LP localized values.

References:

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