



Debye shielding measurements in a multipolar plasma with a Starkquenching of a metastable atomic hydrogen beam technique

Laurence Chérigier-Kovacic, A Lejeune, F Doveil

► To cite this version:

Laurence Chérigier-Kovacic, A Lejeune, F Doveil. Debye shielding measurements in a multipolar plasma with a Starkquenching of a metastable atomic hydrogen beam technique. 31st International Conference on Phenomena in Ionized Gases, Jul 2013, Grenade, Spain. hal-03533618

HAL Id: hal-03533618

<https://hal.science/hal-03533618>

Submitted on 19 Jan 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Debye shielding measurements in a multipolar plasma with a Stark-quenching of a metastable atomic hydrogen beam technique

L. Chérigier-Kovacic¹, A. Lejeune², F. Doveil¹

¹ Aix-Marseille-Université, CNRS, PIIM UMR7345, F-13397 Marseille cedex 20, France

² CAMECA SAS, 29 Quai des Grésillons, 92622 Gennevilliers Cedex, France

Electric fields play a key role in plasmas: they originate in a balance between what can be externally controlled and the collective behaviour of particles. The aim of this paper is to describe a new technique to measure electric fields. This diagnostic is based on the emission of the Lyman-alpha radiation induced by the Stark quenching of 2s metastable level of hydrogen or hydrogenic species. The intensity of the radiation is proportional to the square of the electric field absolute value, which makes this technique very sensitive and allows to measure fields as low as 1 V/cm. We show measurements of a constant electric field generated in vacuum or in a plasma between two polarized plates.

1. Introduction

The Debye sheath in a plasma is the region of transition between the plasma bulk and a conductor immersed in the plasma. It originates in the difference of mobility between ions and electrons: the potential taken by the conductor is much lower than the plasma potential. The sheath can extend over a few Debye lengths. Usual methods to measure subsequent electric fields in cold plasmas are Langmuir probes[1], but these are perturbative by their conductive nature and there can be issues in interpreting their data. Laser spectroscopy has already proven its efficiency in this domain[2, 3]. Here we present a new original method based on the measurement of the Lyman-alpha radiation intensity resulting from the 2s_{1/2} Stark induced quenching in metastable hydrogen or hydrogenic species.

The apparatus and method have been described in a previous publication[4], we will just briefly recall the most important features. When a metastable H(2s) atomic hydrogen beam interacts with an external electric field, the Lyman-alpha radiation ($\lambda = 121.6$ nm) is emitted. This is due to the Stark mixing of the 2s_{1/2} and 2p_{1/2} levels separated by the Lamb-shift[5]. It is well known that the intensity of the radiation is proportional to the square of the electric field amplitude, giving a method to directly measure the local electric field[6]. The theory is based on a perturbation calculation on the n=2 levels of the hydrogen atom fine structure and details can be found in ref. [7].

In this paper, we first experimentally show the quadratic dependance of the intensity of the Lyman-alpha radiation with the field module, as well as the limits of the diagnostic. Then we apply the diagnostic to measurements of the Debye shielding of the potential in a plasma.

2. Material and method

A scheme of the experiment is displayed in Fig. 1. The ion beam is produced in a thermoionic source of hydrogen plasma (#1 in fig. 1). The walls of this vessel are biased to 500V with respect to the rest of the device to set the beam energy, which contains three species (H⁺, H₂⁺, H₃⁺).

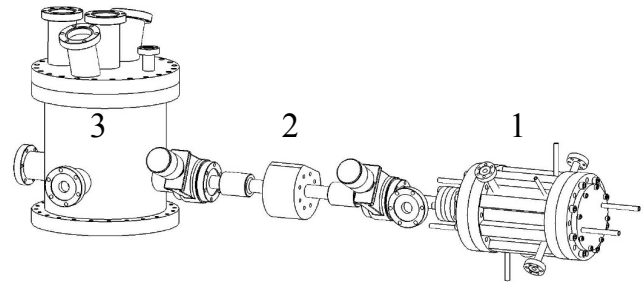


FIG. 1: Experimental apparatus

Metastable hydrogen atoms are produced along the path of the beam between the source and the measurement vessel (#3 in fig. 1), either by collisions of H₂⁺ with the residual gas or by a resonant charge exchange process between H⁺ ions and cesium in the vessel isolated by two valves (see #2 in fig. 1). A specific mass spectrometer in the

measurement vessel allows us to measure the three species ratio in the beam[8]. The best source discharge conditions can then be set depending on the way of production of the metastable. For example, when not using the charge exchange process in cesium, the H_2^+ ions have to be the dominant species in the beam. This is the case in the following.

The beam is sent into the measurement vessel between a movable assembly of two plates. The lower plate can be polarized while the upper plate is grounded. This system is designed in order to create a field as homogeneous as possible between the plates. The interaction length along the beam path is kept as short as possible in order not to lose signal before the diagnosed volume, as the detection optics is not yet movable. However the field extends a little outside of the diagnosed volume. When the beam is passing through the electric field produced between the plates, the Lyman-alpha radiation resulting from the Stark mixing of $2s_{1/2}$ and $2p_{1/2}$ is recorded at a right angle from the beam path by a VUV photomultiplier (not shown on fig. 1).

A lock-in amplifier technique is used to increase signal to noise ratio and to eliminate spontaneous emission at the same wavelength from the short lifetime level $2p_{1/2}$. The space resolution is set by the beam diameter and the size of the photocathode. The diagnosed volume is about 1 cm^3 in the experiments described below, which can be readily improved by inserting a diaphragm along the beam path.

3. Experimental results

3.1 Measurements in vacuum

The intensity of the Lyman-alpha radiation is recorded as a function of the voltage between 0 and -600 V applied to the biased plate. Results are displayed in fig. 2.

We clearly observe the expected quadratic dependance of the signal with the potential (or the field modulus, considering the distance of 5 cm between the plates) as long as the field is not too high. The finite density and time transit of the beam in the detection volume induces a saturation of the signal, followed by a decrease. As the absolute value of the potential increases, the interaction with the metastable atoms before they enter in the detection volume becomes stronger. This is why the signal is decreasing. The solid line is a fit of the data by a

function modelling this behaviour. The only adjustable parameters are the amplitude of the fitting function and the length of interaction between the field and the metastable before they enter the detection volume.

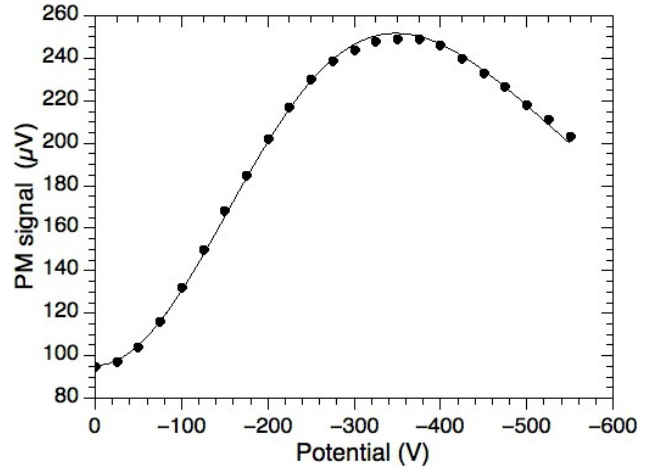


FIG. 2: Full dots = measurement of the Lyman-alpha signal as a function of the potential applied to the plate; solid line = fit by a model with two parameters: amplitude and interaction length between $H(2s)$ and the field before the detection volume.

3.2 Measurements in a plasma

Fig. 3 displays measurement of the electric field between a grounded plate and a polarized plate in vacuum (open symbols) or in a DC argon plasma (full symbols). Plasma discharge parameters are in this case:

- Argon pressure $P_3 = 5 \cdot 10^{-5}$ mbar
- Discharge potential $V_3 = -60$ V
- Discharge current $I_3 = 240$ mA

The intensity of the Lyman-alpha radiation is recorded as a function of the position between the plates (electrodes) by moving the plates assembly itself up or down, zero being the centre of the system. The lock-in detection is performed with the reference signal being the modulation of the beam at 10 Hz. The potential applied to the electrode at $x=2.5$ cm is 100V, so that the electric field amplitude in vacuum can be estimated to 20 V/cm.

We first measure the background signal I_B without plasma by subtracting the signal without the field from the signal with the field on. Then we turn

the plasma on and evaluate the difference I_p between the case with and without field. The square root of the ratio I_p/I_B gives the relative value of the field screened by the plasma.

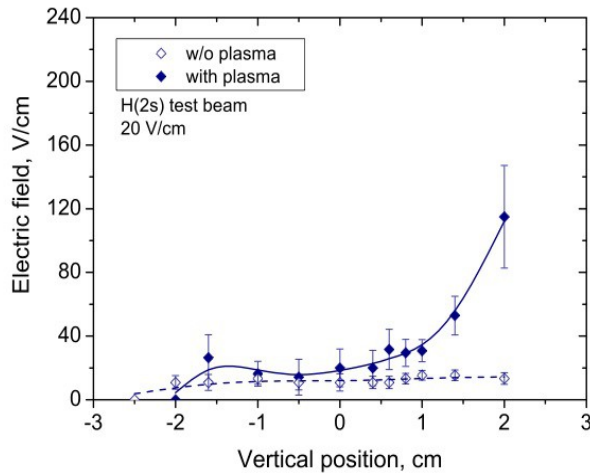


FIG. 3: Electric field measured between a grounded plate ($x=-2.5\text{cm}$) and a polarized plate ($x=2.5\text{cm}$) in vacuum (open symbols) and in a plasma (full symbols).

Fig. 3 shows a constant field across the inter-electrode region in the case without plasma (open symbols). It clearly exhibits the sheath as the electric field increases near the polarized plate when the plasma is on (full symbols). The signal in the close vicinity of both electrodes is less than expected because of the interception of the beam and of the line of view of the detection optic by the plate. In the plasma “bulk”, the value of the field is expected to be null. We do not observe this here, probably because of the incompletely neutralized beam space charge and the noise induced by collisions.

4. Conclusion

We demonstrate the ability of a new technique to measure a constant electric field in vacuum and in a plasma. This technique is based on the Lyman-alpha radiation induced by Stark quenching of the 2s level in hydrogen. We show, in accordance with the theory, a quadratic dependance of the radiation intensity with respect to the field module. By measuring the 2s quenching signal, in vacuum and in a plasma, with and without an externally imposed electric field between a grounded and a biased electrode, we derive the electric field profile. The

Debye shielding of the field by the plasma is clearly featured.

In a previous publication[6], we also show that there is a strong enhancement of the signal when the field is oscillating at the Lamb-shift frequency. Beside vacuum and plasmas, this technique can also be applied in diluted fluids. Further development is in progress to improve this promising technique.

5. References

- [1] S.V. Ratynskaia, V.I. Demidov, K. Rypdal, *Phys. Plasmas* **9**, (2002) 4135-4143.
- [2] G. Bachet, F. Skiff, F. Doveil, R.A. Stern, *Phys. Plasmas* **8**, (2001) 3535-3544.
- [3] U. Czarnetzki, D. Luggenhölscher, V. A. Kadetov, H. F. Döbele, *Pure Appl. Chem.* **77** (2005) 345–358.
- [4] F. Doveil, A. Lejeune, L. Chérigier-Kovacic invited paper GI3.1, 54th Annual Meeting of the APS Division of Plasma Physics, *APS Bulletin*, **57** (2012) 12.
- [5] W.E. Lamb Jr., R.C. Retherford, *Phys. Rev.* **79**, (1950) 549-572.
- [6] A. Lejeune, L. Chérigier-Kovacic, F. Doveil, *Appl. Phys. Lett.* **99**, (2011) 181502.
- [7] A. Lejeune, PhD thesis, Université de Provence (2010).
- [8] A. Lejeune, L. Chérigier-Kovacic, F. Doveil, *ECA 32I*, 35th EPS Conference on Controlled Fusion and Plasma Physics, Hersonissos (2008) 189-192.