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FEATURES OF THE HeI 492.2 nm LINE PROFILE REGISTERED AT DIAGNOSTICS OF DC AND STREAMER DISCHARGES

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Abstract. Formation of the registered profile of the HeI 492.2 nm line during diagnostics of cathode drop of DC normal glow discharge in atmospheric pressure helium depending on the parameters of the optical system and sharp gradients of the electric field strength are shown. Obtained results are used for interpretation of experiment results in streamer discharges.

1. INTRODUCTION

Recently, Stark polarization spectroscopy of the helium line HeI 492.2 nm has been widely used to study helium plasma jets at atmospheric pressure, excited by pulsed and alternating currents [see Sretenović et al. 2014, 2019; Mirzaee et al. 2021]. However, the published experimental results do not reproduce the large amplification of the electric field predicted by simulations [see Norberg et al. 2015; Babaeva et al. 2019]. The main reason for this, apparently, is the insufficient temporal resolution, enhanced by the possible instability of the discharge ignition time, as well as an inadequate interpretation of the formation of the recorded profile of the HeI 492.2 nm line. In this work, we will consider how the recorded profile of the HeI 492.2 nm line is formed depending on the parameters of the optical system and sharp gradients of the electric field strength in pulsed and direct current discharges.

2. MODEL EXPERIMENT

A DC normal glow discharge at atmospheric pressure in helium was ignited in a sealed chamber between a flat copper cathode and a weakly rounded tungsten anode [see Arkhipenko et al. 2000]. Using an optical system consisting of two achromatic objectives with focal lengths of 110 and 210 mm, a 2-fold magnified discharge image was focused in the plane of the entrance slit of a MDD-500x2 (Solar) high-resolution scanning monochromator. With two diffraction gratings of 1800 lines/mm, the inverse linear dispersion is 0.52 nm/mm, and the instrumental profile has a Gaussian shape with a full half-width of about 0.02 nm. A film polarizer was installed between the objectives. To reduce the aperture of the optical system, a slit with a width of 2–3 mm was used. The emission spectrum was recorded using a U2C-14T3 CCD array and a personal computer.

Experimental parameters: discharge current 0.4 mA, helium flow 1 l/min, discharge gap 10 mm, the aperture of the optical system in the axial direction about 0.025, the entrance slit of the monochromator 40 μm (spatial resolution about 20 μm). The profile of the HeI 492.2 nm line, registered at the distance about 20 μm from cathode surface, is shown in Figure 1*a* (circles). The position of the Stark π-components with instrumental profile for a constant field of strength E_0 = 27 kV/cm, in accordance with the data of [see Foster 1927], are shown here too.

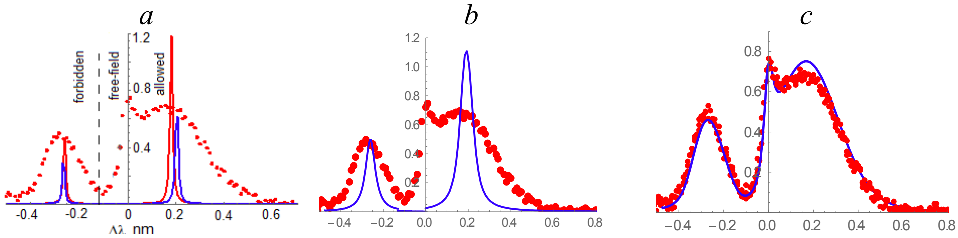

Figure 1: Experimental (circles) and calculated profiles of the HeI 492.2 nm line at E_0 = 27 kV/cm: no broadening (*a*), nonelectrical (*b*) and electrical (*c*) broadenings

In order to approximate the experimental profile of the HeI 492.2 nm line, it is necessary to take into account the broadening of the Stark components, which is caused by external factors of an electrical and non-electrical nature when acting on an emitting atom. Estimates show that the main non-electrical reasons for the broadening of the spectral line components in the region of the cathode drop in the potential of a normal glow discharge in helium at atmospheric pressure under the conditions of this experiment can be van-der-Waals (with a half-width of ~ 0.05 nm), Doppler (~ 0.01 nm) and instrumental (~ 0.02 nm) broadening. The largest half-width w_L = 0.05 nm of them is given by the van-der-Waals broadening, which has a Lorentz's profile. The broadening of the Stark components caused by electric fields can be caused by fluctuations of the discharge current and charged particles, as well as a large gradient of the cathode potential drop within the spatial resolution of the optical system.

In Figure 1*b*-*c* (solid curves) show how the calculated profile of the HeI 492.2 nm line will change when taking into account nonelectrical (*b*) and electrical (*c*) broadening mechanisms. In case of nonelectrical mechanisms (Figure 1*b*), simulation was performed at E_0 = 27 kV/cm and van der Waals broadening with a half-width of 0.05 nm. A difference is observed with the experimental profile both in the widths of the allowed and forbidden components and in their intensity. The same situation will be observed with the predominance of Doppler or instrumental broadening, as well as for the resulting profile when convolving three profiles determined by these three broadening mechanisms.

In case in Figure 1*c*, we taken into simulation the parameters: constant electric field E_0 = 27 kV/cm; fluctuating electric field with value of E_G = 15 kV/cm, caused by the random generation of anode spots; broadening of the Stark components, similar to the broadening of the unshifted component w_L = 0.05 nm. As you can see, calculated profile of the helium line is in satisfactory agreement with the experimental one. Thus, only three parameters are needed for the simulation. The broadening of the Stark components w_L can be characterized by the half-width of the unshifted component to the left of its center.

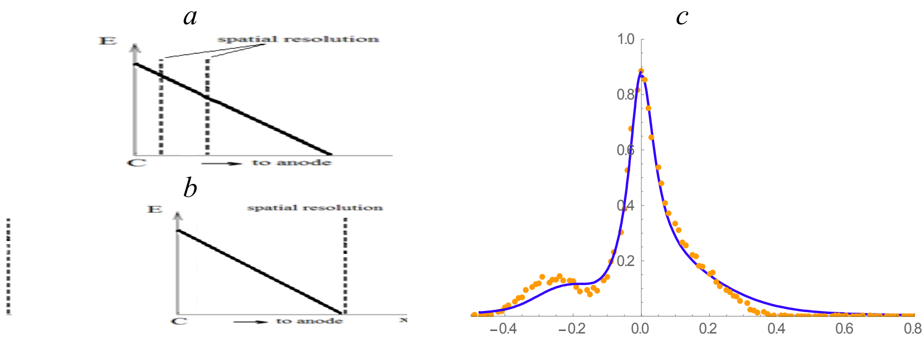

Figure 2: Influence of the spatial resolution on the recorded profiles of the helium line.

The recorded profile of the HeI 492.2 nm line near the cathode surface depends on the spatial resolution (Figure 2). Figure 2*a* schematically shows the position of the image of the entrance slit (vertical dashed lines) and the distribution of the electric field strength for case of Figure 1*c*. Let us increase the entrance slit of the monochromator to 150 μm so that the entire region of the cathode potential drop falls into the monochromator (Figure 2*b*). It can be seen that the recorded profile of the line has changed significantly (Figure 2*c*, circles). The broadening of the Stark components is determined in this case by an instrumental profile with a half-width of ~ 0.09 nm. The calculated profile of the helium line, obtained by summing the Stark profiles for intensities from 0 to the maximum value, satisfactorily corresponds to the experimental one (Figure 1*c*). When recording line profiles near the cathode surface, the choice of aperture is very important as well.

3. EXPERIMENTS IN THE STREAMER DISCHARGES

Let us interpret the profile of the HeI 492.2 nm line in the case of rapidly changing fields, namely, in the case of a slower streamer (9×10^3 m/s and 4×10^4 m/s) [see Sretenović et al. 2014] and a fast streamer (2.5×10^5 m/s) [see Mirzaee et al. 2021]. In the first case, the streamer or a part of it with the maximum field is in the field of view (Figure 3*a*). The registered profile is shown in Figure 4*b* (circles). The profile was approximated by analogy with Figure 2*c*. Calculation parameters: E_{max} = 19 kV/cm, half-width 0.07 nm, relative intensity of the unshifted component is about 0.15. In blue in Figure 3*b* shows the forbidden and allowed components, red - unshifted, black line - total profile. Here, the dashed lines show the profiles from [see Sretenović et al. 2014]. Although in terms of wavelengths these profiles correspond to our approximation, they are symmetric, and their half-width is more than 0.12 nm, and its justification in [see Sretenović et al. 2014] is not given. The field strength in terms of the distance between the maxima is only about 11 kV/cm.

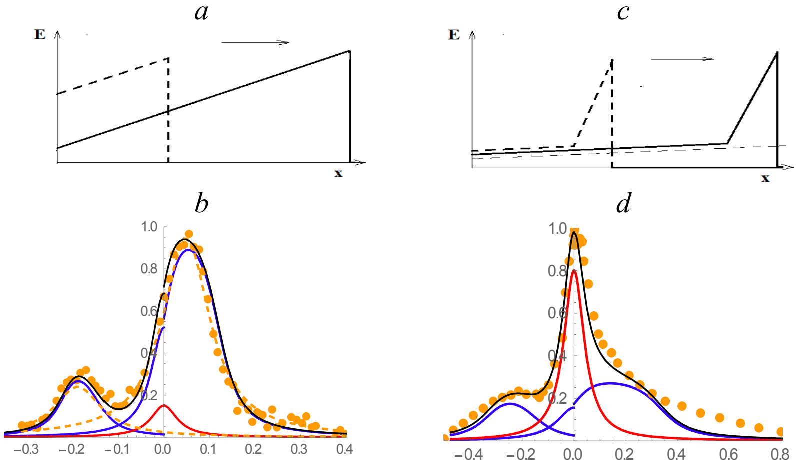

Figure 3: Line profiles of HeI 492.2 nm for slow and fast streamers.

In the case of a fast streamer [see Mirzaee et al. 2021], the distance equal to the spatial resolution, the streamer spreads about 0.2 ns. However, the registration time in this case was 4 ns. In Figure 4*c* shows schematically how a streamer appears, passes, and disappears from the field of view. During the registration time, only a small part of the radiation will fall on the region with high field strength. The registered profile of the HeI 492.2 nm line [see Mirzaee et al. 2021]] is shown in Figure 3*d* (circles). Calculation parameters: E_{max} = 40 kV/cm, half-width 0.08 nm, relative intensity of the unshifted component about 0.75. The calculated profile is represented by a solid black curve. It is seen that the approximated profile satisfactorily corresponds to the experimental one from the side of the forbidden component. From the side of the allowed component, there is less compliance.

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