Optical investigations of turbulent electrostatic oscillations produced when a plasma stream interacts with a partially-ionized gas

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We determined the turbulent electric fields produced when an ion stream interacts with a plasma, by measuring the intensities of the forbidden lines of neutral helium and the Stark broadening of the hydrogen-atom lines.

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Previously described experiments[1,2] on the charge exchange of a plasma stream in a gas target have shown that the stream ions are anomalously scattered in the target. The dependence of the effect on the charge state of the stream and its threshold character indicated a buildup of unstable oscillations in the interaction of a plasma jet with an ionized target.

This paper is devoted to the determination of the electric fields of the oscillations responsible for the scattering of the stream ion, by measuring the intensity of the forbidden lines of neutral helium[3] and the Stark broadening of the lines of the hydrogen atom.[4] The parameters of the plasmoid and of the target at the point of observation were the following: plasmoid density $n_b \approx 2.5 \times 10^{14}$ cm^{-3}, its velocity $v \approx 7 \times 10^7$ cm/sec, duration of the interaction process ~ 1 μsec, density of helium target $n_0 \approx 4 \times 10^{14}$ cm^{-3}, and density of hydrogen target $n_0 \approx 1.2 \times 10^{14}$ cm^{-3}. The spectral analysis of the radiation from the interaction region was with the aid of a photoelectrically-recording VMS-1 monochromator placed almost perpendicular to the stream direction.

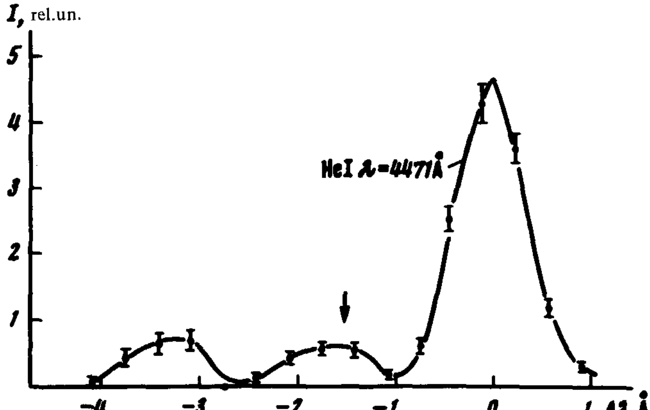

FIG. 1. Profile of neutral-helium line of 4471 Å wavelength.

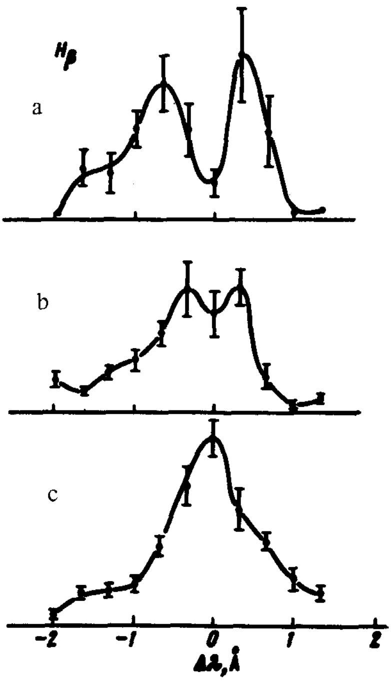

FIG. 2. Profiles of the hydrogen atom H_β line at different instants of time: a and b—successive instants of active interaction of the ion stream with the plasma; c—instant of time after the passage of the plasmoid.

Figure 1 shows a section of the emission spectrum near the HeI line of wavelength 4471 Å. The resolved line ($\Delta\lambda = 0$) is clearly seen together with two radiation flashes at shorter wavelengths; the position of one of the flashes practically coincides with the calculated position of the forbidden line marked by the arrow. In addition to the forbidden line, a "remote" satellite also appeared in the spectrum, and its distance to the forbidden line corresponded to the oscillation frequency $\omega \approx 1.4 \times 10^{12}$ sec^{-1}. We note this frequency is close to the plasma electron frequency ω_{pe}. The absence of a "close" satellite from the spectrum may be due to the fact that under the conditions of our experiment its position coincides with the allowed line and seems to lead to its anomalous broadening. The appreciable width of the allowed line ($\Delta\lambda_{0.5} = 0.8$ Å) cannot be attributed to Doppler broadening since the half-width of the 6678 Å HeI line, obtained under the same conditions, is half as large.

The fact that the spectrum contains, besides the forbidden line due to quasi-stationary, seemingly ion-sound oscillations, also one of the forbidden-line satellites is evidence that interaction of the plasmoid with an ionized helium target leads also to excitation of electron Langmuir oscillations.

By calculating the ratio of the integral intensities of the forbidden line and its satellites to the integral intensity of the allowed line we can calculate the electric fields of the ion-sound and electron Langmuir pulsations.[3] Under the conditions of our experiment they were found to equal ≈ 12 and 27 kV/cm, respectively.

The interaction of the plasma stream with a hydrogen target was investigated by using the Stark broadening of the hydrogen lines H_β and H_α. Figures 2 and 3

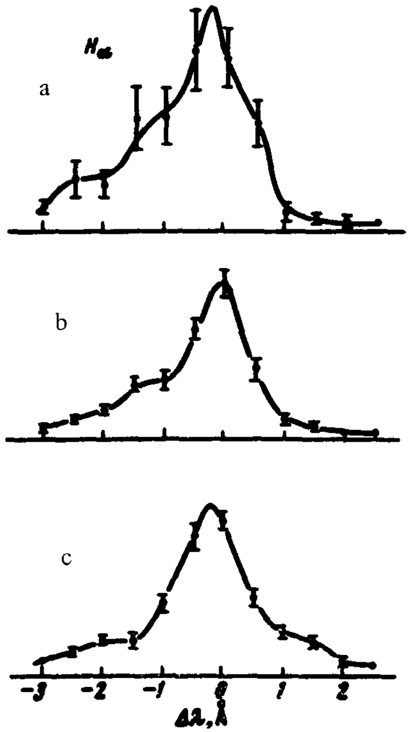

FIG. 3. Profiles of H_α line at the same instants of time.

show the profiles of the hydrogen spectral lines H_β and H_α for different instants of time. It is seen how the H_β line is split in the fields of the quasistationary instants during the time of flight of the plasmoid through the ionized target (Figs. 2a and 2b), the electric field of these oscillations being equal to ≈ 14 kV/cm.[4] The H_α line was also broadened during this stage of interaction, but its half-width turned out to be smaller than that of H_β (Figs. 3a and 3b). If it is assumed that the broadening of the H_α line is due to the development of Langmuir electron oscillations in the plasma, as is confirmed by the existence of a satellite of a forbidden line of neutral helium, then we can estimate from the results of[4] the electric fields of these high-frequency oscillations, namely $E \approx 25$ kV/cm. We note also the evident asymmetry of the H_β and H_α lines (Figs. 2a, 2b, 3a, 3b) during the active stage of the process, probably as a result of the drift character of the excited oscillations.

After the plasmoid has passed through, the Doppler broadening mechanism begins to predominate, since the half-width of the line H_α becomes larger than that of H_β (Figs. 3a, 3c). The temperature of the atoms of the expanding target then reaches a value $T \approx 5$ eV.

Additional probe measurements have shown that constant (during a time on the order of the duration of the process) electric fields cannot be responsible for the observed splitting of the H_β line and for the appearance of the forbidden helium line, since their value does not exceed 0.1 kV/cm.

The aggregate of the results leads to the conclusion that intense ion-sound oscillations with frequencies $\omega \lesssim \omega_{pi}$ build up in the plasma-stream charge-exchange zone and are responsible for the scattering of the plasmoid ions; electron Langmuir oscillations, whose role seems to reduce to that of heating the plasma electrons, are also excited.

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