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EXPERIMENTAL STUDY OF STARK BROADENING OF NEUTRAL HELIUM LINE 5876 Å IN A PLASMA

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Abstract: A study has been made of the broadening of the line 5876 Å of neutral helium in the shock wave plasma in helium-hydrogen gas mixture. The electron density of the plasma was found from the broadening of H_β line, while the temperature was determined from the relative intensities of neutral helium lines. Temperatures were in the range 3700 — 4900 °K, and electron densities varied from 2.4 to $3.5 \cdot 10^{16}$ cm^{-3}. The Fabry-Perot-axicon technique was used to determine the profile of He I 5876 Å line. The broadening of this line was found to increase linearly with the electron concentration and is compared within 5 % with the theory.

1. Introduction

Analysis of Stark broadened spectral lines is one of the standard methods for detemination of plasma electron concentration. The method is broadly used in the case of hydrogen and deuterium plasmas, because of the well elaborated and sufficiently exact theory. In the theory by Griem et al.[1, 2, 3] for hydrogen and singly ionized helium lines, the error was estimated to be 10 — 20 % mainly due to various approximations. Detailed comparisons between theory and experiment[4] have shown that the calculations for the hydrogen line H_β may be reliable within $\pm$ 3.5 % in the range of electron densities $2 - 8 \cdot 10^{16}$ cm^{-3}. The hydrogen H_β line could be therefore used with confidence for the determination of electron density in most laboratory plasmas. It is always possible to add small amount of hydrogen to any plasma without changing considerably its properties. However, one is faced sometimes with the difficulties concerning the possibility of merging a broad H_β line with the lines of other plasma components. Therefore there is a considerable interest in the lines of other gases such as helium, with less pronounced Stark broadening effect.

The theory of Stark broadening of neutral helium lines by Griem et al.[3] is exact to about 20 % due to various approximations used in the computation. To improve the theory it is necessary to study the line profiles experimentally and analyze the role of electron concentration in the broadening process.

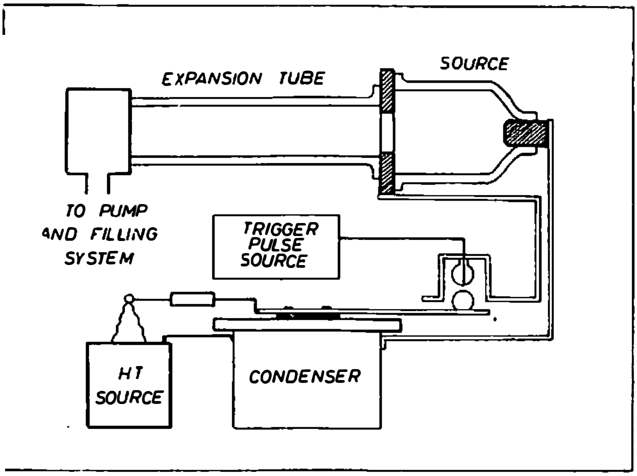

Fig. 1 — Experimental arrangement of the plasma source and associated electric circuit.

Experiments performed in this laboratory were concerned with the dependence of the broadening of neutral helium line 5876 Å on electron concentration in the range $2 - 4 \cdot 10^{16}$ cm^{-3}. The electron density was measured from H_β profile, adding a certain amount of hydrogen into a helium plasma.

2. *Apparatus*

Plasma source. The helium plasma was produced by the shock wave in a source of Josephson type[5] given schematically in Fig. 1. A condenser battery of 3.75 μF charged up to 9.5 kV, was discharged via a triggered spark gap. The discharge between the ring and cylindrical electrode in the source is pinched, causing the shock wave to propagate along the expansion tube. The plasma was checked for homogenity using STL image converter camera in the framing mode. Velocity of the shock wave was measured by the same camera in the streak mode. The tube was filled with a mixture of helium and hydrogen in the ratio 10 : 1, and the pressure was kept constant (0.5 mm Hg). The electric properties of the discharge were tested by a Rogowski coil. It was found that the discharge and the plasma are sufficiently reproducible, better than 10 %.

Fabry-Perot-axicon interferometer. The profile of helium 5876 Å line was scanned using a Fabry-Perot-axicon (FPA) combination and a photomultiplier detector. Reflectivity of Fabry-Perot mirrors was 72% at 5876 Å. The free spectral range could be varied between 2.4 and 4.5 Å. In the majority of cases 4.1 Å spectral range was used, capable to cover a full line profile.

The interferogram was scanned by an axicone — an axial glass cone[7, 8] which transforms the angular into axial distribution of light. The FPA inter-

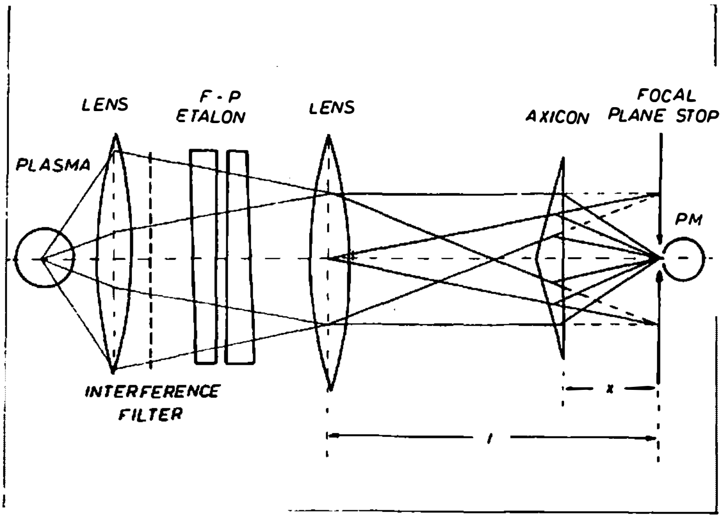

Fig. 2 — Schematic diagram of the Fabry-Perot-axicon interferometer.

ferometer used in this experiment is presented in Fig. 2. The axicon is positioned between a collimator and the image plane of the interferogram. The light belonging to a single resolution interval is concentrated by an axicon into the entrance aperture of a photomultiplier (type RCA 1P28). The line was scanned moving the axicon along the optical axis. The length along the axis which corresponds to one free spectral range of 4.1 Å was 41 mm. Since the light coming from the whole resolution interval is projected onto an entrance aperture, there is no loss of the luminosity. This is the main advantage of the method compared with other methods, especially in the case of low intensity sources and narrow spectral lines.

The H_β line was scanned using the Zeiss SPM 2 monochromator. The same monochromator was used to scan also the He I 5876 Å line, to check the results obtained with FPA interferometer. In the order to determine electron temperature, the relative intensities of He I spectral line (3188 Å, 3889 Å, 4026 Å and 5876 Å) were recorded using the Hilger Medium Quartz spectrograph equipped with the photomultiplier scanning attachment. The transition probabilities were taken from Wiese, Smith and Glennon[10].

3. Results

An example of experimental points and theoretical line profiles of Lorentz type is given in Fig. 3. Experimental points were obtained averaging results of ten successive measurements. The discharge current was monitored simultaneously for each shot. Oscilloscope traces obtained at various wavelengths were analyzed and the values were taken at few time instants after passage of the shock front.

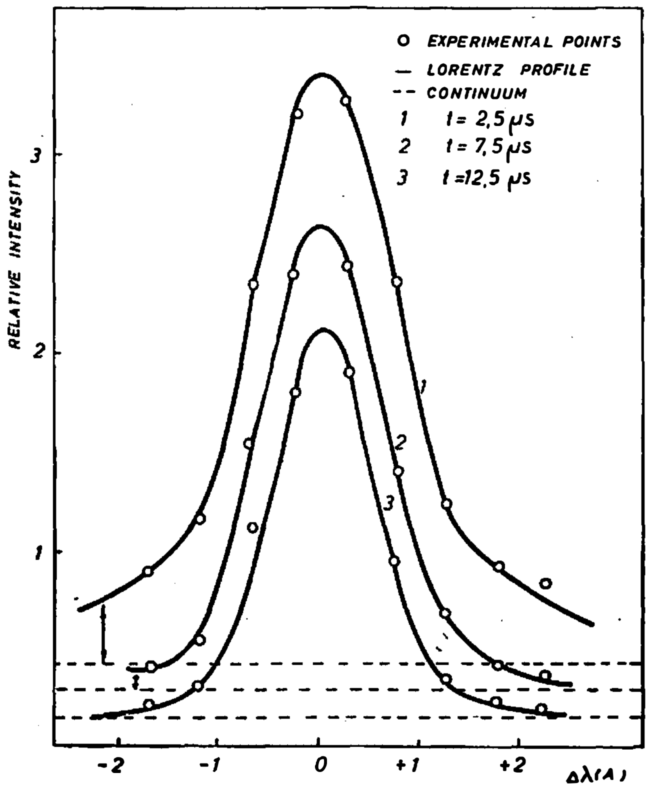

Fig. 3 — Theoretical Lorentz profiles fitted to the experimental values of 5876 Å He I line, taken at three different time instants. No correction was taken for instrumental width.

The experimental profiles are in fact a convolution of an instrumental and Stark profile of the line, since the influence of other broadening processes in the plasma can be neglected in this case. To obtain the Stark profile, the usual deconvolution procedure for two Lorentzian profiles[9] was used. The electron concentration was evaluated from the profile using the theory of Griem[3] and his approximate formula for the total line width,

$$w_{tot} = [1 + 1.75\,a\,(1 - 0.75r)] \cdot w,$$

where w_{tot} is the total width due to both ions and electrons, w is electron impact width, a is a broadening parameter and r is the ratio of the mean distance of the ions and Debye radius. Value of obtained electron concentrations are presented in Fig. 4, together with electron concentrations obtained

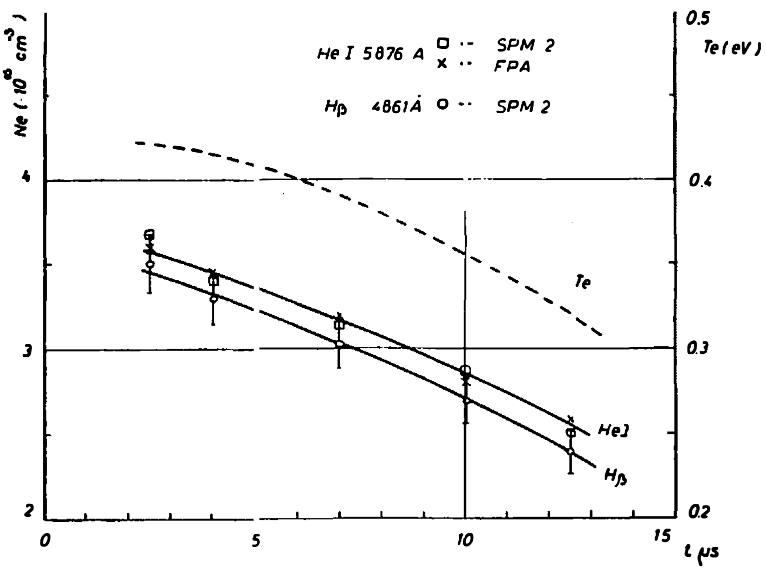

Fig. 4 — Temporal variation of electron density and temperature. Time $t = 0$ corresponds to the passage of the shock front.

from H_β profile and from He I 5876 Å line scanned with the monochromator, which are given for the purpose of comparison. The dashed curve gives the values of the electron temperature evaluated from relative intensities of He I lines.

4. Conclusion

The analysis of results for plasma electron concentrations obtained from the He I 5876 Å line scanned with FPA interferometer leads to the conclusion that within the experimental error they agree with the values obtained from the H_β. Deviation is rather small, slightly exceeding the value of 5 %. It should be pointed out that the values of electron concentration found from He I line are always higher than those obtained from H_β. Probably the effect of ions on the line broadening process is not sufficiently stressed in the theory. The results of these measurements are in agreement with the present theory better than those obtained by Berg et al.[6] where discrepancy was 18 %, although that result was obtained at higher electron density and temperature ($n_e = 1.6 \cdot 10^{17}$ cm^{-3} and $T_e = 4.9 \cdot 10^4$ °K).

The Fabry-Perot-axicon interferometer proved to be very useful for the determination of line profiles. However, the main application of this technique would be at smaller electron densities where other techniques fail.

Acknowledgement

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EKSPERIMENTALNO ISPITIVANJE ŠTARKOVOG ŠIRENJA LINIJE 5876 Å NEUTRALNOG HELIJUMA U PLAZMI

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Sadržaj

U radu je ispitivano širenje linije neutralnog helijuma 5876 Å u plazmi udarnog talasa, u smeši helijuma i vodonika. Koncentracija elektrona u plazmi određena je merenjem širenja H_β linije vodonika a temperatura elektrona plazme dobivena je iz relativnih intenziteta neutralnih linije helijuma.

Izmerene su vrednosti temperature od 3700 — 4900 °K i elektronske gustine od 2,4 — 3,5 · 10^{16} cm^{-3}. Za snimanje profila linije neutralnog helijuma 5876 Å korišćena je kombinacija Fabry-Pèrot interferometra sa aksikonom. Utvrđeno je da širina ispitivane linije raste linearno sa elektronskom koncentracijom i nađeno je slaganje sa teorijom u granicama od 5 %.