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DETERMINATION OF THE TEMPERATURE OF A DENSE PLASMA FROM A SPECTRAL LINE SHIFT

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16. Abstract The method of maximum spectral line shift proposed by Bardocz et al. (1966) was successfully applied in the diagnostics of dense plasmas produced by high-power pulse discharges. It is pointed out that the effect of the shock wave pressure on the spectral line shift has to be taken into account in order to obtain accurate results with this method for high-power discharges. A pressure-dependent function was introduced in the expression given by those authors to provide the necessary correction.

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DETERMINATION OF THE TEMPERATURE OF A DENSE PLASMA FROM A SPECTRAL LINE SHIFT

A.M. Sultanov and V.A. Ageyev

Different methods are known for determining the temperature of plasma, in particular the plasma of a pulse discharge with low power [1, 2]. For instance, the authors of [2] determine the temperature of a plasma jet of a spark discharge acccording to the shift in maximum spectral lines. /26

In the present work it is pointed out that this method can be used during diagnostics of a dense plasma of a high-power pulse discharge. However, then it is necessary to pay attention to the effect of pressure on the shock wave for the shift of the line. Therefore, when using the results [2] in the formula for determining temperature a function which depends on pressure was introduced:

$$T = A \frac{\Delta \nu^{\prime\prime} U_r P^2 (T)}{C^{1/4} (r+1) \left(\frac{g_{r+1}}{g_r}\right)^2}, \qquad (1)$$

where

$$A = \left(\frac{2}{3}\right)^{3/4} \frac{e^{3/4}}{k},$$

$$C = \frac{9}{4} \frac{(2.6)^2 e^4 a_B}{h^2 c^2} \left[\frac{(n^2 - l^2)(l^2 - m^2)(\nu_{l-1} - \nu_l)}{4 l^2 - 1} - \frac{\{n^2 - (l+1)^2\}\{(l+1)^2 - m^2\}(\nu_l - \nu_{l+1})}{4 (l+1)^2 - 1} \right]. \qquad (2)$$

$P = \frac{0.79 P_1}{1.5 + L^2}$ is the pressure on the shock wave [3]; $\Delta\nu$ is the value of the shift of the spectral line; L is the length of the periodic structure; P_1 is atmospheric pressure; h is Planck's constant; c is the speed of light; n is the main quantum number; is the orbital quantum number; m is the magnetic quantum number; ν_{-1}, ν, ν_{e+1} are the values of terms belonging to the main quantum number n and the orbital quantum numbers $l-1$, l, $l+1$; r is the degree of ionization; g_r

*Numbers in the margin indicate pagination in the foreign text.

is the statistical weight; m_e is the mass of the electrons; U_r is the ionization potential.

In a number of published works [4--6] it was pointed out that in a high-power pulse discharge when encountering two supersonic jets or when running against a flat obstacle and with streamline flow past bodies of different shapes shock waves can form which are formed similarly when moving a supersonic flow in gas dynamics and hydrodynamics [7--9].

Here sharp increases in the basic parameters of the incoming flux in particular T, P, ρ are observed on the shock waves. The spectrum of the compacted zone is characterized by continuous radia- /27 tion, asymmetrical expansion and a shift of the line primarily in the long wave field of the spectrum.

In the present work temperature and concentration of charged particles were determined in the plasma for some of the cases of shock wave formation indicated above.

Experimental studies were made with the following regime of discharge contour: the capacity of the battery of the pulse capacitors amounted to 200--400 μf, flashover voltage was 3 kV and inductance was 1 μhenry. The spectra of radiation of the plasma jet was measured on an ISP-28 spectrograph. The system of the discharge chamber is similar to that used in [6].

1. Supersonic plasma flow (SPP [sverkhzvukovyy plazmennyy potok, supersonic plasma flow, SPF]) runs into a solid obstacle. An aluminum plate is used as the obstacle. The time base photographed on a SFR-2M camera indicates that when the SPF encounters an obstable (as was indicated earlier [6]) a compacted region of plasma is formed with a thickness of about 1--2 mm which exists during the entire time of the discharge and is characterized by continuous radiation. The plasma spectrum basically consists of lines of material of electrodes of the discharge chamber and components of the air. As an example, Figure 1 shows the contour of the line of the Cu II

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283.7 nm before the shock (a) and on the shock wave (b). It is clearly obvious that on the shock wave one observes an increase in the intensity of the copper ion line and simultaneously a shift in the maximum of the line occurs toward the long-wave side of the spectrum.

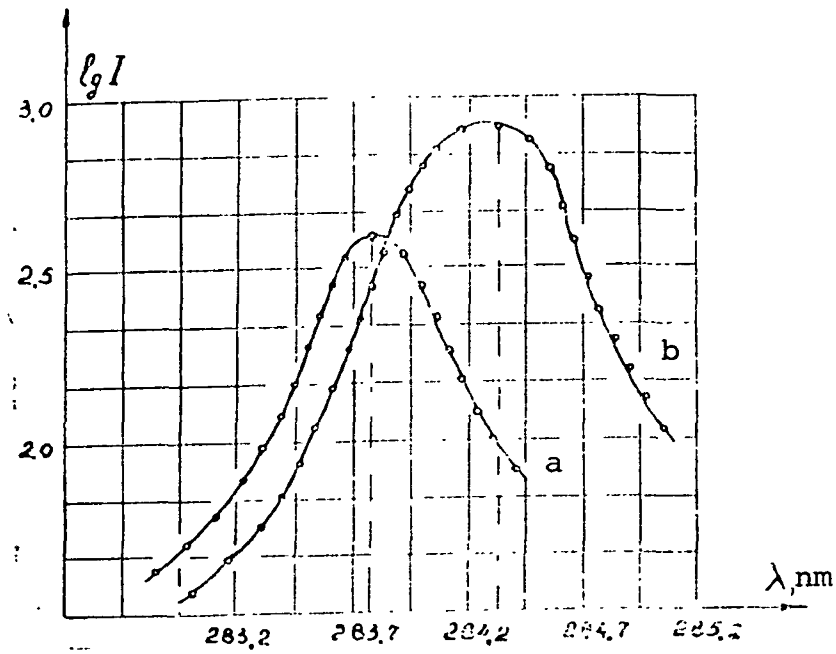

Figure 1. Contours of the spectral lines of CuII 283.7 mn when encountering a solid obstacle:

a. before the shock wave; b. at the shock wave

On the contour of the characteristic lines we measured the half-width and shift of the maximum for different elements; then, temperature (according to formula 1) and concentration of the charged particles on the shock wave were calculated. Results of measurement are presented in the Table (a); here Stark constants which were /28 calculated according to formula 2 are given.

The values of the temperature of plasma determined by other methods [10, 11] are in good agreement ($\pm 5 \div 10\%$) with the results of the present work.

2. When encountering SPF in an interelectrode space also there forms an impact compression region of plasma limited on two sides by

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DETERMINATION OF TEMPERATURE AND CONCENTRATION ACCORDING TO THE SHIFT OF SPECTRAL LINES IN THE IMPACT REGIONS OF THE PLASMA

a Элемент и длина волны, нм	b Переходы между уровнями	c Энергия ионизации, эв	d Полуширина линии, нм	e Смещение линии, нм	f Постоянные Штарка, 10^{-14} $см^4 сек^{-1}$	g Концентрация частиц, 10^{18} $см^{-3}$	h Температура, 10^4 К
1 a При встрече с твердой преградой							
Cu I 379,8	4 p² P° — 8 s² S¹	7,26	0,9	0,1	0,17	3,6	2,5
Al I 394,1	3 p² P — 4 s ² S¹	3,11	0,8	0,35	0,21	3,9	2,2
Cu II 251,1	4 p¹ D — 7 s ¹ D	13,38	1,0	0,15	0,10	3,5	2,8
O II 136,7	3 s⁴ P — 3 p⁴ P	25.83	0.95	0.13	0,22	1,0	2,7
2 б При встрече друг с другом							
Cu II 273,9	4 p³ D — 5 s³ D	13,61	1.12	0,57	0,553	2,8	2,3
Cu II 287,7	4 p¹ P — 5 s³ D	13,12	1,50	0,72	0,515	3,6	2,5
Cu II 276,9	4 p¹ F — 5 s² D³	13,38	1,50	0,80	0,123	1,2	1,3
Cu II 271,5	4 p¹ F — 5 s³ D	13,12	1,10	0,70	0,155	6,5	2,6
Cu II 272,1	4 p¹ D — 5 s³ D	13,61	1,10	0,56	0,511	2,9	2,1
Cu II 271,3	4 p³ D° — 5 s³ D	13,12	1,38	0,60	0,182	3,0	2,6
Cu II 270,0	4 p¹ F — 5 s¹ D	13,67	1,30	0,57	0,112	2,7	2,1
Cu II 254,1	4 p³ D — 5 s³ D	13,38	1,50	0,73	0,115	3,5	2,6
Cu II 259,0	4 p³ F — 5 s³ D	15,61	1,50	0,82	0,523	1,3	4,2
Cu II 250,6	4 p³ F — 5 s³ D	13,12	1,50	0.80	0,168	1,2	1,1

Key:
- a. element and wavelength, nm
- b. transitions between levels
- c. energy of ionization, eV
- d. half-width of the line, nm
- e. shift of the line, nm
- f. Stark constants, $10^{-14} cm^4 s^{-1}$
- g. concentration of particles, $10^{18} cm^{-3}$
- h. temperature, 10[illegible]°K
- 1. a. when encountering the solid obstacle
- 2. b. when encountering each other

[Commas in tabulated material are equivalent to decimal points.]

shock waves. Then the radiation of this region is somewhat more intense than the radiation of the region formed when a supersonic flow encounters a flat obstacle with identical parameters of the discharge contour.

In this variation of the experiment, in distinction from the first case, many lines of the ions of the components of the electrodes

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on the shock wave are recorded in self-reversal (Figure 2, a) at the same time that before the shock wave self-reversal of the lines is not noted (Figure 2, b). The value of the shift of the basic maximum for a number of characteristic lines of ions of copper and the values of the half-width of their contours are presented in Table 1, b.

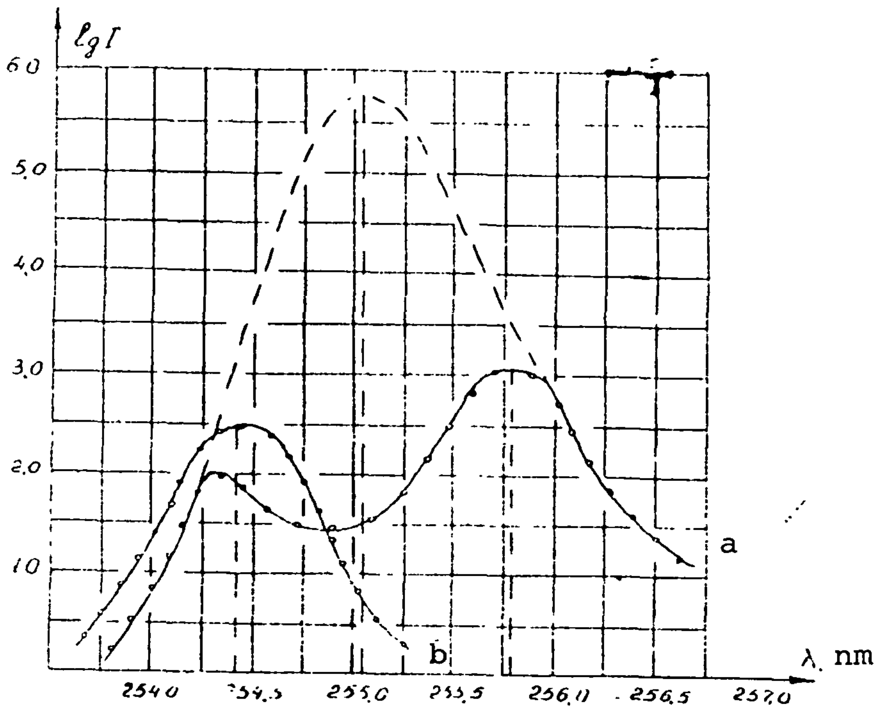

Figure 2. Contours of the spectral line of CuII 254.4 nm when two supersonic plasma flows meet:

a. at the shock wave; b. before the shock wave.

Experimental results presented in the Table make it possible to note that during interaction of two SPF between them the values of the parameters at the shock wave are somewhat higher than when running into a solid barrier; this is strongly apparent in the half-width and shift of the maximum of the spectral lines.

Thus, according to the value of shift of the maximum of the spectral lines on the impact compression fields of the plasma it is possible to determine temperature according to the change in half-width of the contour of the concentrations of charged particles in the plasma. One should note that experimental data presented in this present work confirm the opinion of the authors of [12] as to the fact that the shift of the maximum of spectral lines has a large effect on the value of pressure.

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