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Abstract

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LIMITING BRIGHTNESSES OF THE CHANNEL OF A SPARK DISCHARGE

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A number of works have been devoted to the study of the limiting brightnesses of the channel of a spark discharge ([1–3]); however, only in heavy inert gases has it been possible to observe brightness saturation over a broad spectral region (2300—9000 Å). In light gases, at the rates of current rise that were used, brightness saturation occurred only in the long-wavelength part of the spectrum.

The purpose of the present work was to study the limiting brightnesses of the channel of a spark discharge in argon, nitrogen, air, and helium at extremely high rates of current rise ($U/L \simeq 10^{12}$ A/sec). The discharge was produced in a high-pressure chamber having a window for the exit of light*. The discharge circuit was characterized by the following parameters**: $C = 0.1$—1.0 μF, $L = 4$—8 nH, $U = 2$—10 kV, and the length of the spark gap was $l \simeq 1.5$ mm.

Table 1

Gas	P, atm	Regime	$T_{\text{br.}}$, °K	B, Mb		
Gas	P, atm	U/L, 10^{12} A/sec	C, μF	C, μF	$T_{\text{br.}}$, °K	B, Mb
Helium	31	1.02	0.2	0.2	70 000	37
Nitrogen	3	1.1	0.1	0.1	62 000	32
Argon	3	0.32	0.2	0.2	46 000	22
Air	1	0.85	0.1	0.1	38 000	17

Brightness measurements were carried out from the radiation of the continuous background in the spectral interval 4000—9000 Å and at spectral points corresponding to the maxima of strongly broadened spectral lines: He II 4686 Å, Ar II 4348 Å, Ar II 4806 Å, N III 4097 Å, N II 5045 Å.

Owing to the very high rates of current rise, it was possible to reach limiting brightnesses in all the gases studied. The values of the limiting brightness temperatures of the channel and the corresponding discharge regimes are given in Table 1.

The radiation of the channel was observed both from the end and in a direction perpendicular to the discharge axis. The brightness-temperature values obtained in these two cases coincided with one another.

It was established that changing the capacitance of the discharge circuit does not have a noticeable effect on the brightness of the channel.

It should be noted that the limiting brightnesses of the radiation of the spark discharge measured in the present work in helium, argon, and air differ substantially from the results of the corresponding measurements reported in works ([4,5]). There is reason to suppose that the considerable overestimation of the brightness values in works ([4,5]) is connected with neglect of the spectral distribution of the radiation of the discharge channel.

Figure 1 gives the dependences of the limiting brightness temperatures of the discharge channel on wavelength in saturation regimes. It can be seen from the figure that, in the saturation regime, the radiation of the spark-discharge channel is close to blackbody radiation.

* The design of the chamber was developed by V. R. Muratov.

** In this work we used low-inductance capacitors similar in design to those described in work ([4]).

It has been established that if, after the limiting brightness values have been reached, the discharge regime becomes still more severe, then a certain decrease in brightness is observed; this is apparently connected with absorption of the radiation in the peripheral layers of the discharge channel. As an example, Fig. 2 shows the dependence of the brightness temperature of the channel in helium on the discharge regime.

A very important question is the degree to which impurities affect the brightness of the channel in helium. Owing to the high ionization potential of this gas, the presence of small quantities of impurities of easily ionized gases may lead to a lowering of the temperature of the discharge channel in helium. Experiments

(Figure: Fig. 1 and Fig. 2)

Fig. 1. 1 –helium, 2 –nitrogen, 3 –argon
Fig. 2

carried out with helium of different degrees of purification have shown that even at the maximum content of heavy impurities ($\sim 4\%$) no cooling of the channel is observed in helium.

The investigations carried out confirm the conclusion, drawn in works ([1–3]), that as the atomic weight of a gas decreases, the limiting temperature of the spark-discharge channel increases. Air is an exception: its temperature is lower than in nitrogen and argon. The reason for this has not been clarified. In works ([7–9]) it was established that the temperature of the spark-discharge channel in air is practically independent of the discharge regime (within the known limits of variation of the latter). Therefore it may be assumed that the attainment of limiting brightness values is due to the attainment of opacity of the discharge channel.

If one uses the conclusions of the Kramers–Unsöld theory ([6]) for the absorption coefficient of continuous radiation and the hydrodynamic theory of channel expansion, one can obtain the following relation, connecting the steepness of the current rise in the circuit, U/L, necessary for attaining opacity of the channel, with the basic plasma parameters of the discharge:

$$\left(\frac{U}{L}\right)^{5/3} = c\,\frac{(kT)^{5/2}\nu^3}{\rho_0^{7/6} Z_{\text{eff}}^2\left(e^{h\nu/kT}-1\right)}\,t^{-1/6},$$

where T is the plasma temperature (the plasma is assumed to be isothermal); ν is the frequency of the light oscillations; ρ_0 is the initial gas density; Z_{eff} is the effective ion charge; t is the time measured from the beginning of the discharge (it is assumed that $t < \sqrt{LC}$); c is a constant.

From the above relation the following conclusions may be drawn:

1. The condition of opacity is more easily fulfilled for low frequencies. Thus, as the rate of current rise in the discharge increases, opacity of the channel is first attained in the red region of the spectrum, and then in the blue.
2. For given parameters of the discharge circuit, opacity of the channel is most easily attained in heavy gases. If one also takes into account that the temperature of the channel decreases with increasing atomic weight, this makes clear the strong dependence of the current steepness required for attaining brightness saturation on the atomic weight of the gas.
3. An increase in pressure facilitates the attainment of brightness saturation. It is easy to see that the theoretical regularities are in good agreement with the experimental results.

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Note: Figure translations are in progress. See original paper for figures.