MEASUREMENT OF THE DENSITY OF A PLASMA DECAYING IN A MAGNETIC FIELD BY MEANS OF MICROWAVE RADIO INTERFEROMETERS AND A FABRY-PEROT INTERFEROMETER

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The density of a plasma decaying in a magnetic field was measured in the range from 7×10^{11} to 4×10^{13} cm^{-3} by means of microwave interferometers at wavelengths of 8 and 4 mm. In the range above 4×10^{13} cm^{-3}, the plasma density was measured by the Stark effect on the Balmer lines in hydrogen. The time dependence of the electron density of a plasma decaying in a magnetic field was measured by these techniques.

THE creation of a plasma by preliminary ionization with a known electron density is the necessary condition for setting up most experiments in plasma physics. For this purpose, we have used a plasma that is freely decaying in a magnetic field;[1,2] The initial concentration in this plasma was obtained by a short term direct discharge in the working space. The freely decaying plasma is convenient in that by its nature it is a quiescent, current-free plasma and has a certain (diffusion) density distribution in the volume.

An important parameter of a freely decaying plasma is its time dependent curve of density decay. In a research devoted to the physics of turbulently heated plasma,[1] the decay curve was constructed from the results of measurement of the density by "beaming through" the plasma to microwaves. However, it is clear that this method is not sufficiently convenient and accurate for the stated purpose.

In the present research, which was carried out in conjunction with an investigation of shock waves in a rarefied plasma,[2] the electron densities for the plotting of the decay curve were measured by radio interferometers at wavelengths of 8 and 4 mm. Inasmuch as the density of the decaying plasma falls off monotonically in time, interferometers based on a very simple microwave bridge circuit were used. One beam in such a bridge goes through the plasma under study and an attenuator. The second beam (in the reference channel) passes through an attenuator and a phase shifter. The voltage oscillations at the output of the detector in such a circuit depend on the relation of the phase oscillations taking place in the two channels, and are determined in the final analysis by the change in the plasma density in the measurement channel (for details see[3]).

In the experiment, about ten experimental points of the decay curve were obtained with the help of each interferometer in the corresponding range of electron concentrations n_e. In the overlapping range $5 \times 10^{12} < n_e < 10^{13}$ cm^{-3} the readings of the interferometers agreed with excellent accuracy.

The range of concentrations $n_e \gtrsim 4 \times 10^{13}$ cm^{-3} is ill-suited for microwave measurements because of the great technical difficulties. The density of the decaying plasma here can be measured from the Stark broadening of the Balmer lines of hydrogen. In fact, the half-width of the shape of H_β for $n_e = 4 \times 10^{13}$ cm^{-3} is equal to 0.2 Å, since the Doppler broadening can be neglected in the present case. Actually, the electron temperature of a preionized plasma, obtained in[1,2] by discharge in

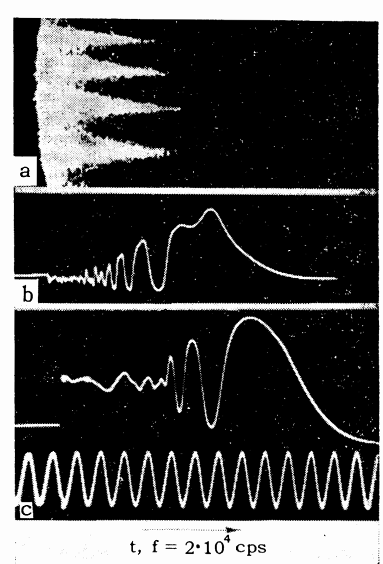

FIG. 1

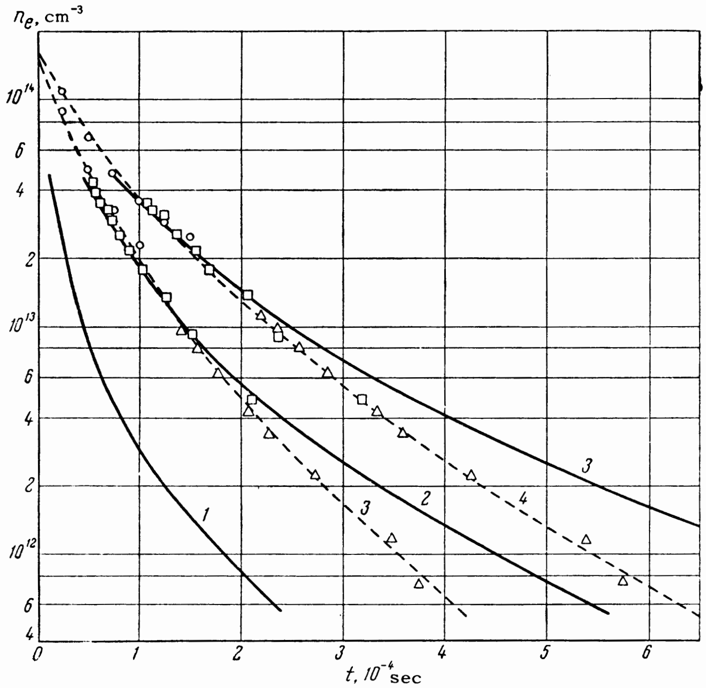

FIG. 2. Decay curves of electron density in a plasma: o – data of the Fabry-Perot interferometer; □ – data of the microwave interferometer for $\lambda = 4$ mm; △ – data of the microwave interferometer for $\lambda = 8$ mm. The curve 1 – H = 100 Oe, 2 – H = 300 Oe, 3 – H = 500 Oe, 4 – H = 1200 Oe. (dashed curves – helium with hydrogen in the ratio 6:4, solid curves – helium).

helium, falls off after 10—20 microseconds to a temperature ~ 0.1 eV, when intense three-particle electron recombination begins. (Cooling of the hydrogen plasma takes place more rapidly; evidence of this is given by the absence of a dark prerecombination gap in the afterglow spectrum.) The decrease in the electron temperature in the present case takes place as the result of collisions with ions and neutral particles. The ions in turn "cool off" through a process of charge exchange with the neutral gas. The neutral gas, owing to energy exchange with the walls, is virtually at room temperature, which also allows us to neglect the Doppler broadening of the H_β line in comparison with the Stark broadening for $n_e \gtrsim 4 \times 10^{13}$ cm^{-3}.

In the experiment, the Stark broadening of the hydrogen lines was measured by means of a Fabry-Perot interferometer connected with an ISP-51 spectrograph with a camera having f = 30 cm. Measurement of the broadening of the spectral lines in time was recorded by a rapid scanning method using an electron-optical converter.[1] 1) An IT-51 interferometer was used with a thickness of the intermediate ring of 1 mm. The dispersion region was 1.2 Å and the limit of resolution 0.05 Å. The limit of resolution, determined by the electron-optical converter, amounted to 0.1 Å under the conditions of our experiments. The entire apparatus broadening, measured from the broadening of lines of helium atoms, was equal to 0.11—0.13 Å.

The results of measurements on the Fabry—Perot etalon are satisfactorily "joined together" with the data of microwave interferometers in the case of a spectroscopic apparatus broadening of 0.1 Å and under the assumption of a homogeneous distribution of plasma density over the diameter of the discharge tube.

The experimental results that were obtained are shown in Figs. 1 and 2. Figures 1b and c give oscillograms of the output voltages of radio interferometers at wavelengths of 4 and 8 mm, respectively, and a photograph of the time development of the H_β line, resolved by the Fabry-Perot interferometer (Fig. 1a); the time scale plotted at the bottom refers both to the oscillograms and to the spectrogram.

Figure 2 shows the decay curves of the electron density in the plasma obtained under different experimental conditions. The solid curves give the decay curves of the plasma density obtained in technically pure helium at an initial pressure of 10^{-2} mm Hg and for different values of the magnetic field shown in the graph. The dashed lines with marked experimental points show the decay curves of the plasma density obtained in a mixture of 6 parts helium and 4 parts hydrogen at a total initial pressure ~ 2×10^{-2} mm Hg. The more rapid decay of the dashed curves is associated with the rapid diffusion of the plasma in this case.

1) An electron optical converter was used in conjunction with a Fabry-Perot etalon in a number of researches.[5,6]

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[1] Zagorodnikov, Smolkin, and Sholin, JETP **45**, 1850 (1964), Soviet Phys. JETP **18**, 1268 (1964).

[2] Zagorodnikov, Rudakov, Smolin, and Sholin, JETP **47**, 1717 (1964), Soviet Phys. JETP **20**, (1965).

[3] V. D. Rusanov, Sovremennye metody issledovaniya plazmy (Modern methods of plasma Investigation) Gosatomizdat, 1962.

[4] Griem, Kolb, and Shen, Phys. Rev. **116**, 4 (1959); Astrophys. J. **135**, 272 (1962).

[5] Malyshev, Razdobarin, and Sokolova, DAN **145**, 768 (1962), Soviet Phys. Doklady **7**, 701 (1963); ZhTF **33**, 191 (1963), Soviet Phys. Tech. Phys. **8**, 137 (1963).

[6] Butslov, Plakov, Shapkin, and Yashin, Optika i spektr. **16**, 329 (1964).

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