The experimentally observed threshold field was compared with the theoretical calculations of Keldysh[2] and of Gold and Bebb[3]. Calculations with formulas for hydrogen-like atoms[2], with allowance for the fact that xenon has 8 external electrons, of which 6 are in the p-state, yields $E_{thr} = 4.5 \times 10^7$ V/cm. If xenon has levels with energy differences (relative to the ground state) close to an integral number of quanta, then this can lower the threshold field by an additional factor 1.5 - 2. A numerical calculation made in [3] yields $E_{thr} = 2.7 \times 10^7$ V/cm. We note that not account was taken in [2] and [3] of the smearing of the upper levels in a strong electric field, which can lead to a decrease in the number of quanta needed for ionization.

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EXCITATION AND THERMALIZATION OF ELECTRON PLASMA WAVES IN A STRONG-CURRENT GAS DISCHARGE

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The theoretical principles underlying the use of two-stream instabilities to heat plasma were developed in papers of Fainberg[1] and Buneman[2]. In Zavoiskii's experiments[3] this heating mechanism is realized by the large vortical electric field on the shock wave in the plasma. Analagous processes should occur in a strong-current gas discharge upon thermalization of plasma waves excited by "runaway" electrons.

In our earlier studies[4,5] we investigated in detail the conditions for the excitation of two-stream instabilities in a current-carrying plasma.

It was shown that at large electric fields the plasma absorbs a considerable part of the energy from the external source. The bulk of the absorbed energy goes into the development of intense electrostatic oscillations. This increases greatly the plasma resistance, the acceleration processes are terminated, and intense microwave and x-ray emission from the discharge is observed. Oscillograms of the corresponding signals are well correlated with one another and fit within the pattern of appearance of two-stream instability and subsequent thermalization of the plasma waves.

The experiments were carried out with a linear strong-current gas discharge in hydrogen, stabilized by a longitudinal magnetic field. The construction of the set-up was described in [4]. The discharge current was of the order of 100 kA, the half-life 4.5 μsec, and the stabilizing magnetic field 1.5 kOe. A highly ionized plasma pinch, limited by a diaphragm of 80 mm diameter, is produced in the discharge during the first half-cycle. The corresponding plasma density varied in the range 10^{15} - 10^{14} cm^{-3}.

The energy of the transverse motion of the electrons was determined both by measuring in various foils the absorption of the x-rays due to deceleration of the electrons in the target[6], and by determining the diamagnetic effect[7].

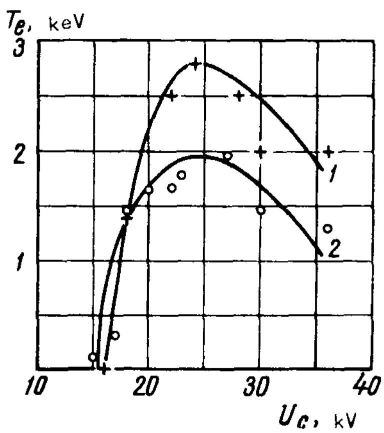

Figure 1.
Dependence of the electron temperature on the capacitor-bank charging voltage: 1 - from an x-ray analysis, 2 - from diamagnetic signals.

Measurement of the absolute intensity of the x-ray emission made it possible to estimate the plasma current to the chamber wall.

These measurements were made in a wide range of electric fields and at varying plasma densities. Figure 1 shows the dependence of the electron temperature on the capacitor-bank charging voltage at a constant plasma density 7×10^{14} cm^{-3}. The temperature was estimated from the x-ray absorption under the assumption that the electrons have a Maxwellian velocity distribution. The electron temperature determined from the x-irradiation agrees well with the value obtained from the diamagnetic signal.

It is also seen from Fig. 1 that there exists an optimal electric field in the plasma, for which the electron heating is the most effective. The decrease in heating efficiency with increasing electric field can be attributed to a decrease in the plasma wave increment with increased current-drift velocity.

Direct measurements of the microwave emission from the plasma, at a frequency

$$\omega \approx \sqrt[3]{\frac{m_e}{M_i}}\,\omega_o$$

(ω_0 = electronic plasma frequency), yield a similar dependence (see Fig. 2). This indicates that the electron heating is a consequence of plasma-wave thermalization.

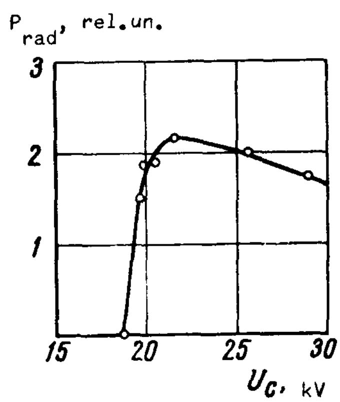

Figure 2
Dependence of the intensity of 8-mm microwave emission from the discharge on the capacitor-bank charging voltage

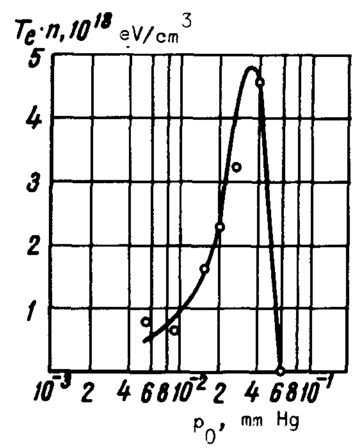

Figure 3
Dependence of the energy of thermal electrons per unit volume on the initial pressure of neutral gas in the discharge at a constant capacitor-bank charging voltage

The decrease in the heating efficiency due to the decrease in the increment should be manifest also when the plasma density is varied and the field maintained constant. This is in good agreement with the experimental results shown in Fig. 3.

The presence of a diamagnetic signal corresponding to the plasma temperature indicates that the discharge is sufficiently well insulated from the walls by the strong magnetic field.

We have thus attained effective heating of electrons by thermalization of plasma waves in a gas discharge. Approximately 20% of the energy fed to the discharge goes directly into heating. At a plasma density 10^{15} cm^{-3} and at optimal discharge parameters, the electron temperature was of the order of 3 keV and was limited by the magnitude of the stabilizing magnetic fields. The plasma was well insulated from the discharge chamber walls, and the rapid cooling of the electrons was determined essentially by the energy flux to the electrodes, due to the absence of a mirror magnetic-field configuration.

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