absorption or amplification of the wave by small material clusters with variable dimensions or shapes. We shall call this "deformation absorption." Let us estimate the magnitude and the contribution of the deformation absorption in the case of plasmoids.

If the frequency of the wave exceeds the plasma frequency ($\omega > \omega_p$) the power lost to deformation is

$$w \simeq N \dot{a} E_0^2 \simeq N a \left(\frac{\omega_p}{\omega}\right)^2 \frac{u}{a} E_0^2 \, ,$$

where N is the plasmoid concentration, a the plasmoid radius, and u the spreading rate. Comparison with dissipation due to collision $w_{col} \simeq N \, (\omega_p/\omega)^2 a^3 (E_0^2/4\pi) \nu_s$ yields the condition under which the deformation absorption exceeds the collision absorption: the collision frequency is

$$\nu_s < \left(\frac{\omega_p}{\omega}\right)^2 \frac{u}{a} \, .$$

In this case the absorption coefficient is

$$\kappa \simeq 4\pi N a \left(\frac{\omega_p}{\omega}\right)^2 \frac{u}{ac} \simeq 4\pi a^2 N \left(\frac{\omega_p}{\omega}\right)^4 \frac{u}{c}$$

for $\omega > \omega_p$ and $\kappa \simeq 4\pi a^2 N u/c$ for dense plasmoids ($\omega_p > \omega$). At large powers $u = u(E_0^2 t)$ and the absorption becomes nonlinear. Rapidly expanding plasma inhomogeneities can be produced, for example, with the aid of lasers, whose flashes transform small particles of matter arrosols, etc into plasma.

Observation of the considered effect is possible in a wide range of conditions, from laboratory to astrophysical.

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ANOMALOUS ABSORPTION OF A POWERFUL ELECTROMAGNETIC WAVE IN A COLLISIONLESS PLASMA

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We have previously performed experiments [1 - 3] on the interaction of a powerful line-early polarized H_{11} wave in a round waveguide with a cylindrical dense plasma beam injected along the radius of the waveguide normally to the direction of the electric field. The plasma was collisionless ($\omega_{Le} \geq \omega \gg \nu_{ei}$, where ω_{Le} is the electron plasma frequency, ω the microwave generator frequency, and ν_{ei} the electron collision frequency). In all the experiments, $\lambda_g \gg a$, where λ_g is the length of the wave in the waveguide and a is the radius of the beam. The maximum electric field intensity E at the waveguide center changed from 100 V/cm to 6 kV/cm. At E > 1 kV/cm, a change was observed in the character of the motion of the plasma beam, and accelerated ions appeared [1, 3], indicating effective transfer of the wave
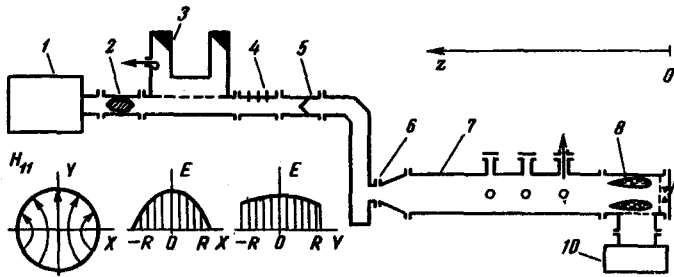
Fig. 1. Experimental setup with H_{11} wave: 1 – microwave generator, 2 – ferrite attenuator regulator, 3 – directional coupler, 4 – matching section, 5 – vacuum microwave window, 6 – exciter for H_{11} wave in round waveguide, 7 – round waveguide with stubs for the introduction of the microwave and of the plasma probes, 8 – absorbing microwave load, 9 – plasma source, 10–vacuum pumping section.

energy to the plasma. A change was also noted in the structure of the microwave field in the waveguide [1, 2]. The nonlinear phenomena in a column of a gas-discharge plasma bounded by a tube, at E from 10 to 150 V/cm, were investigated in [4].

In the present paper we present the results of an investigation of the interaction between a powerful H_{11} wave with a plasma "piston" occupying the entire cross section of the waveguide ($\lambda_g \simeq 2a$). We note that the structure of the field of the H_{11} wave in the central part of the waveguide cross section is close to that of a plane wave in free space. The experiments were performed with a setup (Fig. 1) described in detail in [1 – 3, 5]. We used both a powerful pulsed 10-cm generator (~ 1 MW) and a low-power measuring generator (~ 10 mW). The plasma injection ($T_e = 4$ eV) was by means of a spark source located in the center of the rear flange of the round waveguide, through the free space of a microwave load next to the wall. The density of the plasma "piston" was practically uniform over the radius. The density gradient at the leading front was $10^9 - 10^{10}$ cm^{-4}. The front velocity was $\sim 10^7$ cm/sec. The maximum density of the plasma leaving the microwave load reached 10^{12} cm^{-3} ($\omega_{Le} \gg \omega$). As the plasma "piston" moved along the waveguide axis z, the maximum concentration decreased in proportion to z^{-3}. Depending on the source voltage U_s or, which is the same, on the initial number of particles in the flux, the plasma became transparent to the electromagnetic wave ($\omega_{Le} < \omega$) at a certain value of z.

At a low microwave level (E = 0.1 V/cm), when $v_{Te} \gg v_E$, where $v_{Te} = (3kT/m)^{1/2}$ and $v_E = eE/m\omega$, we obtained practically 100% of reflection of the wave from the dense plasma ($\omega_{Le} < \omega$), in full agreement with the theory (see [6], Sec. 18).

At a high microwave power level, with E increased from 0.2 to 2 kV/cm ($v_{Te} \simeq v_E$), the microwave power reflected from the plasma was registered with the aid of a directional coupler, and the transmitted power was measured with the aid of electric antennas introduced through the wall of the round waveguide (see Fig. 1). The microwave power was applied prior to the instant of plasma injection. Figure 2 shows the oscillograms of the signals from the microwave and plasma probes. The microwave signal amplitude is proportional to the microwave power. It follows from Fig. 2 that the relative level of the reflected microwave power decreases with increasing electric field intensity E in the waveguide. The microwave signal reveals also short-duration "dips" with minimum reflection, having an interval on the order of 1 μsec. The signal from the antenna introduced through the wall of the round waveguide at a distance z = 45 cm from the source, along the direction of the electric field, remained
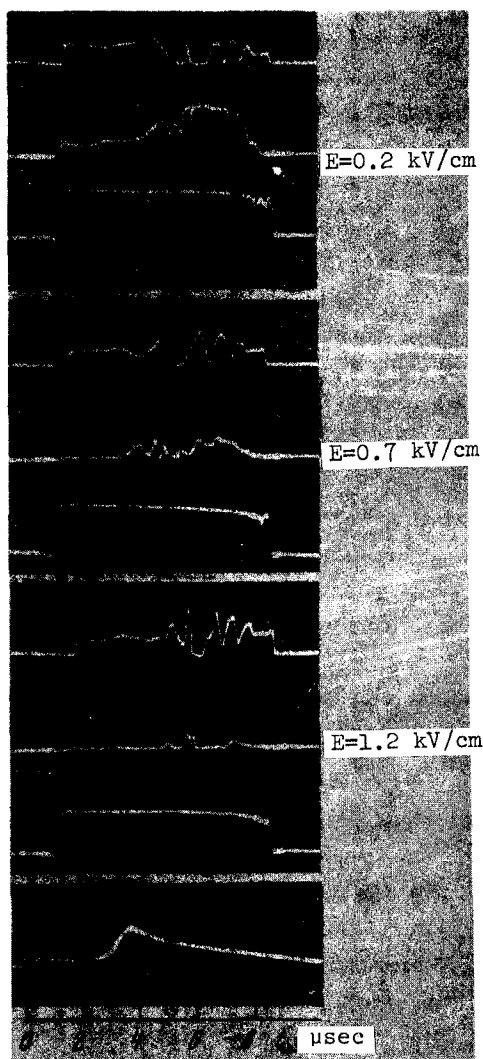
Fig. 2. Oscillograms of microwaves and plasma signals at $U_s = 5$ kV and different E. Top - signal of reflected microwave power (the total-reflection microwave signal is shown for comparison). Below - microwave signal from antenna inserted in round waveguide along E at z = 45 cm. The plasma-probe signal (ion current) in the center of the round waveguide is shown separately.
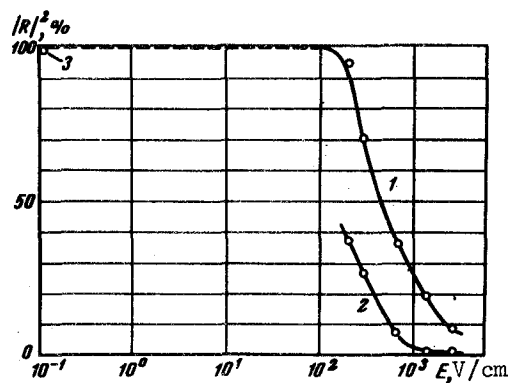

Fig. 3. Reflection coefficient $|R|^2$ vs. E at $U_s = 5$ kV: 1) from maximum values of reflected microwave power; 2) from minimum values (in the "dips"), 3) measurements with low-power microwave generator.

constant at first, so long as the plasma remained within the limits of the microwave load, and then assumed a periodic character, indicating the presence of a certain reflection of the H_{11} wave from the moving plasma "piston" (the nodes and antinodes of the standing wave). This is followed by a relatively long "cutoff" of the H_{11} wave by the plasma "piston" ($\omega_{Le} > \omega$). In this case the plasma screens the antenna against the microwave field. The duration of the "cutoff" decreases both with increasing initial plasma density, i.e., U_s, and with increasing E. Finally, the plasma becomes transparent to the wave and the microwave signal reaches the initial value. We note that in these experiments we did not register the appearance of a microwave signal from an antenna introduced through the wall of the round waveguide normally to the orientation of the electric field of the H_{11} wave. This indicates that the plane of polarization of the H_{11} wave did not rotate, nor was an E_{01} wave, the propagation of which is possible in a waveguide of this diameter, produced.

Figure 3 shows the dependence of the power reflection coefficient of the wave $|R|^2$ on E, both for maximum values of the reflected microwave power (using the ratio of the amplitude of the microwave signal upon plasma injection to the amplitudes of the signal obtained when the rectangular waveguide feeding the microwave power is covered with a metallic shutter) and

for $|R|^2$ in the "dips" (see Fig. 2). We see that $|R|^2$ decreases with increasing E, starting with a "threshold" value $E \simeq 10^2$ V/cm ($v_E \simeq 0.1\ v_{Te}$), and subsequently to $E \simeq 10^3$ V/cm ($v_{Te} \simeq v_E$). Since, in accordance with Fig. 2, the H_{11} wave does not pass beyond the plasma "piston" in this case and is reflected from it only in part (in our case within 3 - 4 µsec), obviously there is appreciable wave absorption in the plasma. The absorption coefficient can be found from the known relation

$$|D|^2 = 1 - |R|^2 - |T|^2,$$

where $|T|^2$ is the transmission coefficient $|T|^2 = 0$). Thus, a strong increase of $|D|^2$ takes place with increasing E in the range of E investigated by us. This phenomenon is apparently connected with the excitation of an instability that leads to plasma heating. The already-noted decrease of the duration of the "cutoff" with increasing E is due to the spreading of the plasma.

The observed anomalously strong electromagnetic-wave absorption in a collisionless plasma (in the absence of an external magnetic field), occurring at electric field intensities higher than 100 V/cm, makes it possible to realize effective transfer of the wave energy to the plasma.

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Figure 2 of the article by I. R. Gekker and O. V. Sizukhin, Vol. 9, No. 7, p. 245, is upside down. Its correct form is shown on the next page.

E = 0.2 kV/cm

E = 0.7 kV/cm

E = 1.2 kV/cm

0   2   4   6   8 t, μsec