EVIDENCE OF ANOMALOUS RESISTANCE IN PLASMAS*

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Several years ago Buneman[1] predicted an anomalous resistance in plasmas having electrons drifting through ions with drift energies greater than $\sim 0.9kT$. The destruction of these drifts by instabilities should occur after some 30 electron plasma periods in hydrogen (longer in other gases since growth rates are proportional to the third root of the mass ratio). Observations to be reported here appear to confirm this effect, in that qualitative agreement with several essential features of the phenomenon was found.

Our investigations were made during the afterglow of an intense plasma (densities near 10^{13} cm^{-3}) created by a pulsed reflex-type discharge (with magnetic field ~200 gauss) similar to the machine described in a paper by Geller and Pigache.[2] The drifts were created by the strong electric fields (~50 V/cm) in the capacitive region of a 200-Mc/sec re-entrant cavity through which the discharge column penetrated (see Fig. 1). At 200 Mc/sec, each half-cycle lasts at least 30 plasma periods (at 10^{12} density), allowing anomalous resistance to develop. Normal resistance is negligible, since collision probability is low in a half-cycle and the intrinsic cavity losses are negligible compared to the expected loss due to anomalous resistance. Skin depth, i.e., field penetration, is 20% of the discharge radius, or $\frac{1}{2}$ cm. (The Debye length is 0.1 mm.)

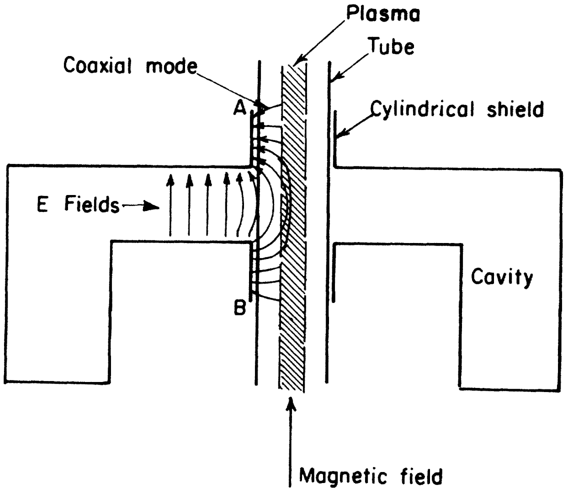

FIG. 1. Re-entrant cavity and fields creating electron drifts in the plasma.

The plasma resistance was inferred from the ratio between incident and reflected power into the cavity, observed on a dual-beam scope while the plasma density decayed. To interpret the scope traces requires a discussion of the effect of the plasma on the cavity for very high densities. Taking the plasma dielectric constant as $\epsilon = \epsilon_0(1 - \omega_p^2/\omega^2)$, and making allowance for the complicated geometry,[3] one computes a curve of loaded cavity frequency, f, vs density, n, like that displayed in Fig. 2. The ionizing pulse creates a density (~10^{13} cm^{-3}) corresponding to points at the right-hand end of the curve.

In the afterglow the density decays exponentially during a tenth of a second, causing the resonant frequency to sweep the range from f_{max} down to f_0. If the signal frequency is between these limits, a resonance is seen in the power reflected from the cavity. By choice of the signal frequency one can therefore pick out different plasma densities.

At low signal power ($P_{\text{inc}} - P_{\text{refl}}$ less than a watt for our cavity) the fields excite drifts which do not exceed the thermal speeds. Instabilities do not occur, resistance is normal, so the cavity Q is high and independent of power. Likewise, at higher powers but low densities ($n < 10^{12}$), there would not be the necessary 30 plasma periods in each half-cycle for instability buildup. Again, the resistance should be normal.

Measurements of resistance were made in hydrogen first at densities near 10^{11} and then at

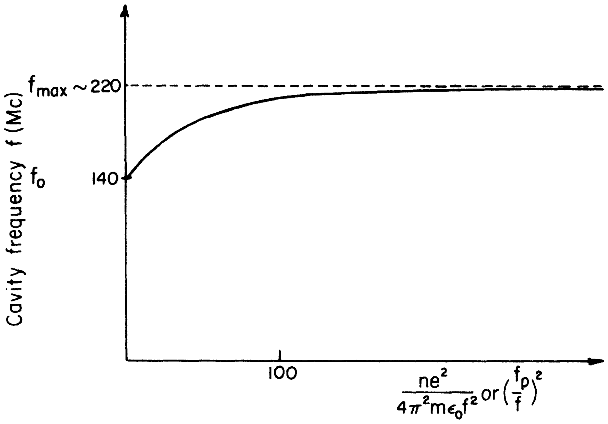

FIG. 2. Cavity resonant frequency vs density (or plasma frequency).

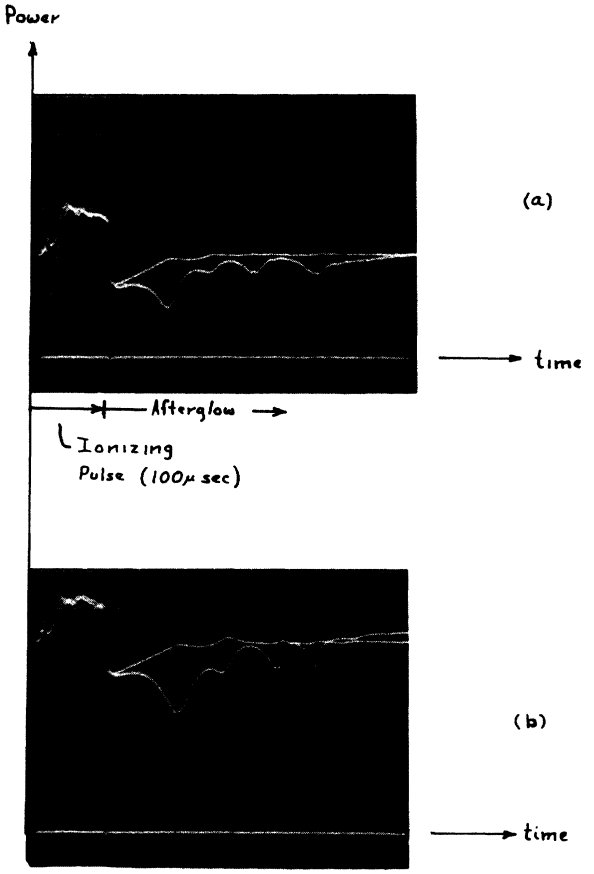

FIG. 3. Incident and reflected power traces in hydrogen at densities between 10^{12} and 10^{13} for (a) low power and (b) high power (just above the threshold for creating instabilities). (The pulse at the left is stray pickup from the pulse generator.)

densities near 10^{13}. In the former case the loss was found not to change as the power was increased (although it was higher than anticipated by a large amount—see below). In the latter case, however, the loss increased by a factor of two as the power was increased 50%, putting its value above the computed threshold (about $\frac{1}{2}$ watt). This is shown in Fig. 3 which gives traces of the incident power (upper trace) and reflected power (lower trace) as a function of time (50 μsec/cm). The reference level (zero power) is the straight line at the bottom of each picture. In (b), the power levels are higher than in (a). The loss is found from the ratio of reflected to incident power at the first resonance in the afterglow (or from the resonance at the extreme left, which occurs because the density is rising). The last three resonances on the right are caused by other phenomena. One can see that at the higher power levels the loss is greater [vertical sensitivities are the same in (a) and (b) with the incident power level in (a) being about 1 watt].

Measurements leading to the traces in Fig. 3 were repeated (at the same density as in Fig. 3) in argon (rather than hydrogen). Since growth rates are slower in argon than in hydrogen, we expected a null result at high power and density. This was the case: Only a very small increase in loss was found for a factor of 2 increase in power. The argon experiment shows quite generally that a mere increase in electron density is not the cause of the anomalous, nonlinear resistance arising in hydrogen.

The background loss seen in the absence of anomalous resistance was, as mentioned, quite high compared to estimates using the ratio between collision frequency and cavity frequency. This may be explained by power leakage out of the cavity in the coaxial mode at "*A*" and "*B*" (Fig. 1). This *Q* change should, however, be independent of power. Resonances of this coaxial line might also explain the other observed resonances which occur at lower densities (later in time). However, the important evidence in support of anomalous resistance is the nonlinear increase in loss with power.

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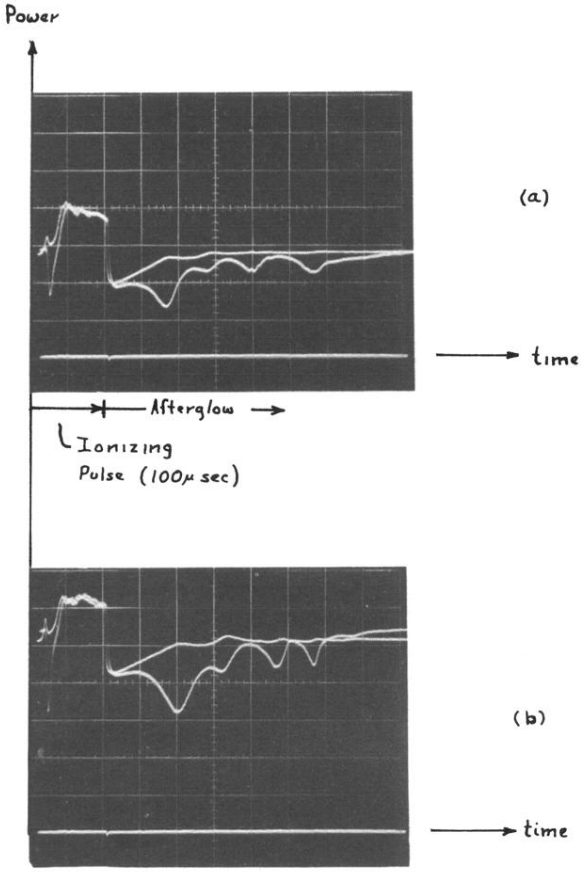
[1] O. Buneman, Phys. Rev. 115, 503 (1959).

[2] R. Geller and D. Pigache, J. Nucl. Energy 4, 229 (1962).

[3] K. Thomassen, Stanford Electronics Laboratories Report 251-2, 1962 (to be published).



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