PHYSICAL REVIEW LETTERS

VOLUME 8 FEBRUARY 15, 1962 NUMBER 4

DEMONSTRATION OF CLASSICAL PLASMA BEHAVIOR IN A TRANSVERSE MAGNETIC FIELD*

D. A. Baker and J. E. Hammel
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico
(Received January 2, 1962)

Experiments on dense, fully ionized gases in strong magnetic fields usually involve a multitude of plasma processes. As a consequence the behavior of such a plasma has rarely been shown to follow simple classical theory. In an experiment performed to examine the properties of a low β $(=2\mu_0 nkT/B^2)$ plasma streaming transverse to a magnetic field, we were able to demonstrate that the motion of the plasma is stopped when its internal electric field is removed. The magnetic field $\vec{B}$ is produced transverse to the symmetry axis of a cylindrical Pyrex vacuum chamber (20-cm diam, 177 cm long) by a pair of rectangular coils. Within the magnetic field region are located a pair of parallel-plate electrodes (15×30 cm separated by 7 cm) which are used to establish an electric field $\vec{E}$ orthogonal to both the chamber symmetry axis and the magnetic field over an axial distance of 30 cm. A coaxial gun,[1] operating on a 0.6 cc-atm pulse of deuterium gas, is located on the symmetry axis 30 cm outside the magnetic field region and injects plasma along the axis into the space between the electrodes. The velocity of injection $\vec{v}_i$ and the fields are oriented so that $\vec{E}$, $\vec{B}$, and $\vec{v}_i$ form an orthogonal right-handed system.

A deuterium plasma of density ~10^{-8} g/cm^3, whose degree of purity is presently unknown, emerges from the parallel-plate electrodes with a velocity $v \sim 5\times10^6$ cm/sec in the $\vec{E}\times\vec{B}$ direction. This plasma continues to stream along the vacuum chamber for the full extent of the transverse magnetic field region (130 cm). The plasma stream is found to be well penetrated by the transverse magnetic field. Magnetic probes indicate a decrease of $\vec{B}$ owing to passage of the plasma such that $\Delta B/B \approx 0.2$ when $B=6.5$ kgauss and when the E-field electrodes are energized with a 15-μf capacitor initially charged to 8.5 kv.

For such a plasma to stream through a transverse magnetic field with velocity $\vec{v}$, an orthogonal electric field $\vec{v}\times\vec{B}$ must be present. The plasma leaving the electrode region can make its own electric field by polarization. Electric probe measurements show that a polarization electric field is indeed present, and moreover, the measured value of E/B is in agreement with the plasma velocity as determined by time of flight with magnetic probes.

A demonstration that the removal of electric field will halt the streaming of the plasma transverse to the B field was accomplished by making use of the fact that electrons are unimpeded by magnetic forces when flowing along B-field lines. This property allows the plasma's electric polarization field to be shorted by electron flow to conductors outside the plasma stream which are connected to it by B lines extending into the plasma.

A region of shorted electric field extending the full diameter of the vacuum chamber was produced 20 cm downstream from the parallel-plate electrodes by means of a conducting sheet formed into a half-cylinder to fit the inner wall of the vacuum chamber and oriented to intersect all the B-field lines for a length of 15 cm. Figure 1(a) is a time-integrated photograph showing that the effect of this conducting sheet is to stop the plasma's forward motion. The plasma penetrates no farther than approximately 2 cm beyond the leading edge of the shorting conductor. Magnetic probe measurements support the photographic observations in detecting no plasma beyond the region of "shorted lines." Time-resolved Kerr-cell photo-

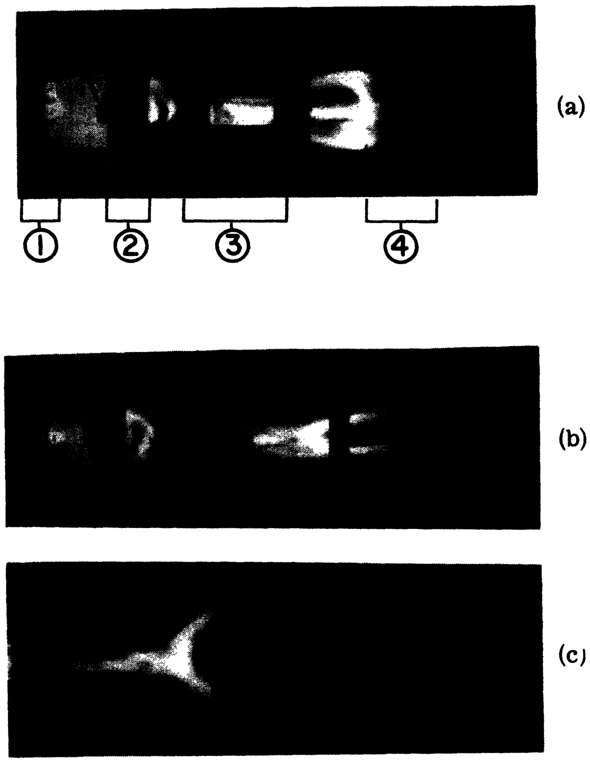

FIG. 1. (a) Time-integrated photograph showing the stopping of a plasma stream by a conducting liner. (1) End of coaxial plasma gun; (2) leading edge of the windings of the B-field coil ($\vec{B}$ out of paper); (3) E-field electrodes ($\vec{E}$ upward); (4) conducting liner (half-cylinder on wall away from the reader). (b) and (c) Over-all and close-up time-integrated photographs showing the exclusion of plasma flow found in the region of zero E-field produced by a conducting sheet of 4-cm height at the far chamber wall.

graphs show that the forward motion of the plasma stops and portions of the plasma drift upward and downward across the magnetic field and are directed backward at the glass wall.

When the electric field is removed from only a portion of the stream, that portion is impeded,

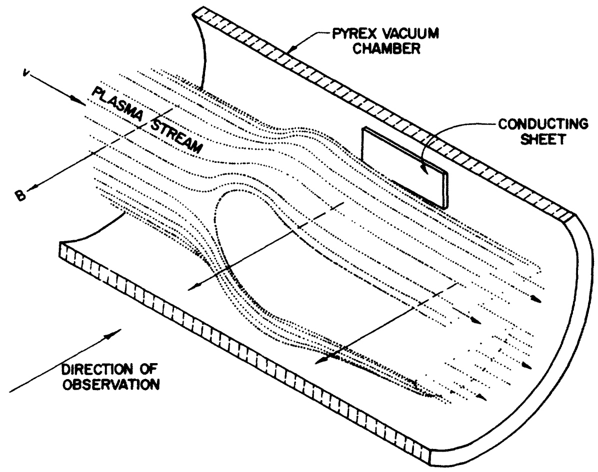

FIG. 2. Schematic diagram of the plasma flow around the forbidden region of zero electric field created by a conducting strip located adjacent to the inside wall of the vacuum chamber.

and the flow continues outside the shorted region. Over-all and close-up photographs of this phenomenon with the conducting sheet 4 cm high and 15 cm long are shown in Figs. 1(b) and 1(c). Kerr-cell photographs indicate that the plasma stagnates in front of the shorted E-field region and portions of it divide and flow around. It should be emphasized that in these experiments the conducting sheets were immediately next to the chamber wall (as shown in Fig. 2), well outside the main body of the plasma stream, and did not constitute mechanical obstructions to the flow.

We wish to acknowledge the suggestions and support pertaining to these experiments that have been given by J. L. Tuck and F. L. Ribe.

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]John Marshall, Phys. Fluids 3, 134 (1960).

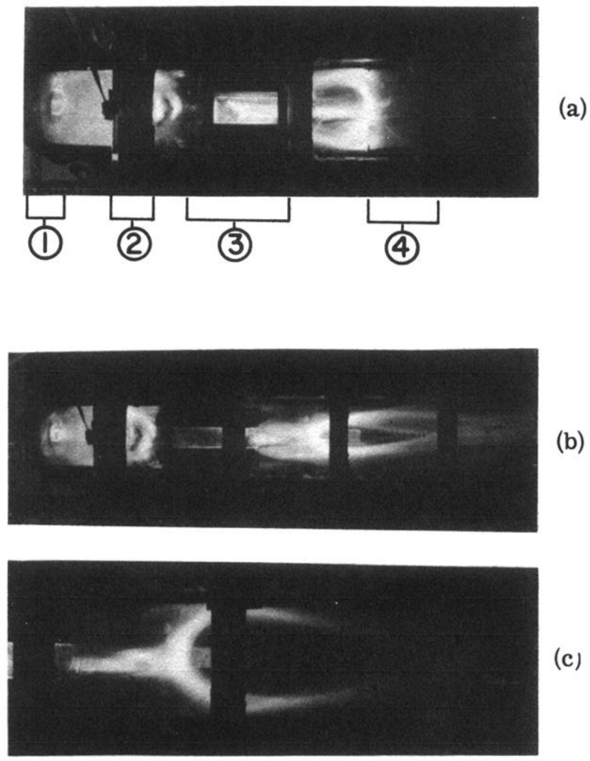

FIG. 1. (a) Time-integrated photograph showing the stopping of a plasma stream by a conducting liner. (1) End of coaxial plasma gun; (2) leading edge of the windings of the B-field coil ($\vec{B}$ out of paper); (3) E-field electrodes ($\vec{E}$ upward); (4) conducting liner (half-cylinder on wall away from the reader). (b) and (c) Over-all and close-up time-integrated photographs showing the exclusion of plasma flow found in the region of zero E-field produced by a conducting sheet of 4-cm height at the far chamber wall.