Letters to the Editor

OBSERVATION OF ION TWO-STREAM INSTABILITY IN TURBULENT HEATING OF A PLASMA

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MARSHALL and Stratton[1] have investigated collisions between two plasma jets in a longitudinal magnetic field. The plasmoid interaction observed by these authors was interpreted in terms of Coulomb scattering of the particles. This interpretation is reasonable since scattering due to collective plasma effects could not appear in these experiments. Theory predicts[2] that electric fields can arise in a plasma as a consequence of an instability due to the double-streaming motion of the ions (these fields would cause the jets to lose an appreciable amount of the kinetic energy of their directed motion); such fields appear only when the following approximate condition is satisfied:

$$T_i < \tfrac{1}{2}Mu^2 < T_e, \qquad (1)$$

where u is the relative velocity of the colliding plasmoids, M is the ion mass, T_i and T_e are the ion and electron temperatures. This condition was not satisfied in the experiments reported by Marshall and Stratton.

To observe anomalous scattering of plasma jets we have used turbulent heating to raise the electron temperature[3] in order to satisfy (1). The experimental arrangement is similar to that described by us in [4]. The plasma jets are produced by two titanium guns. The maximum plasma jet velocity is 1.4×10^7 cm/sec; the density is $2-5 \times 10^{13}$ cm^{-3}. The jets collide in a quartz tube 3.6 cm in diameter in a uniform magnetic field of 600 Oe and penetrate each other in the region of a resonant circuit that serves for turbulent heating of the electrons. The length of the circuit is 30 cm and the distance between guns is 95 cm. The low-Q circuit operates at 10 Mc and produces a radio-frequency field up to 1200 Oe at the axis of the plasma column. This field heats electrons to 300—400 eV within 0.2 μsec in the entire space between the guns.

With these values of the parameters the mean free path of a hydrogen ion for Coulomb scattering through an angle of $\pi/2$ is several meters.

The ion temperature is measured with a special probe. The probe is a metal plate (1 × 3 cm) oriented along the lines of force of the magnetic field in the plasma. The probe is connected to the metal electrodes in the guns through a load resistance of 50 ohms. Because of the great difference in the Larmor radii of the ions and electrons the number of ions reaching the probe from the plasma flux streaming past it is $\sqrt{T_i M/T_e m}$ greater than the number of electrons and the probe becomes charged to a positive potential with respect to the plasma; this potential is equal to the ion temperature T_i in electron volts. The voltage across the load resistance appears on an oscilloscope.

Using this probe we have measured the ion temperature in the plasma flux from the guns. This temperature is less than 5 eV when the kinetic energy associated with the translational motion of the protons in the plasmoids is as high as 100 eV. This same ion temperature is obtained when two plasma jets collide. When the jet density is increased one also observes a small increase in the probe readings (up to 10 V); this increase can be explained by Coulomb scattering of ions (cf. oscillogram 2 in Fig. 1). However, there is no noticeable change in the probe reading when the device used for turbulent heating of the electrons is triggered to operate at the instant of arrival of a single plasmoid in the working volume.

However, if the electrons are heated when one plasma jet moves through the other the probe readings indicate ion temperatures up to 50 eV. There are no readings corresponding to ion temperatures above 50 eV. This result is evidently due to the fact that with the present values of fixed magnetic field (600 Oe) the ion Larmor radius becomes comparable with the tube radius when $T_i \gtrsim 50$ eV.

In Fig. 1 we show oscillograms of the probe readings as a function of the delay in triggering the resonant circuit with respect to the gun pulse. The gun current stops in 3—4 μsec. The front of the plasmoid reaches the probe in 5—6 μsec; the plasmoid velocity in the probe region then diminishes with time. Hence the probe reading is reduced when the delay time is increased. In Fig. 2 we show the probe reading as a function of delay time. The experimental points represent data averaged over many experiments.

In this work we evidently observe a strong scattering of plasma jets by each other. This scattering cannot be attributed to Coulomb collisions and occurs only at high electron temperatures. It is

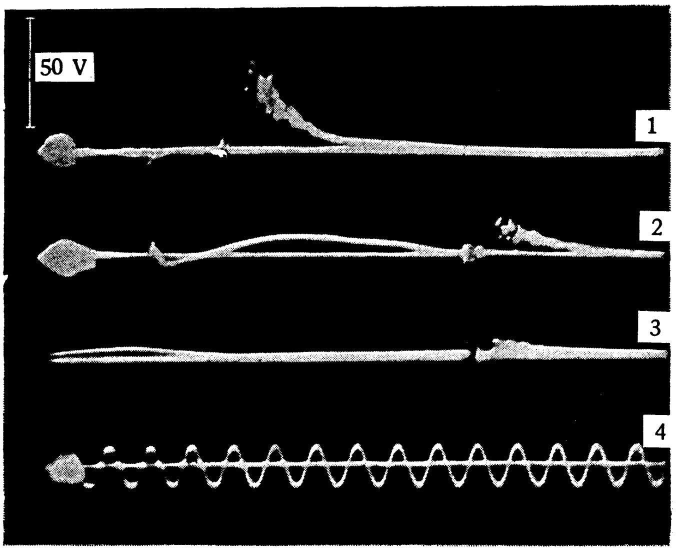

FIG. 1. Oscillogram showing probe readings obtained with different delay between the triggering of the resonant circuit and the gun pulse: 1) delay 7.5 μsec, 2) 20 μsec, 3) 35 μsec. In the last case the oscilloscope trigger is delayed by 15 μsec. The time marker separation is 2 μsec. The oscillogram readings give the ion temperature in electron volts. In 2 and 3 one notices the effect of transverse velocities of the ions due to Coulomb scattering. The gun voltage is 10 kV, the fixed magnetic field $H_0 = 600$ Oe, and the variable field $H_\sim = 1000$ Oe.

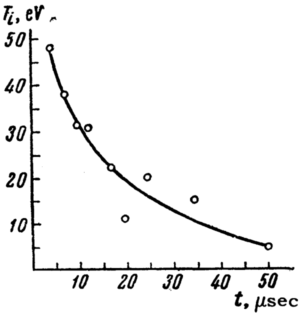

FIG. 2. The ion temperature T_i in eV as a function of the delay in triggering the circuit with respect to the gun operation pulse. The circuit delay time in microseconds is plotted along the abscissa axis while the ion temperature directly after triggering is plotted along the ordinate axis. The gun voltage is 10 kV, the fixed magnetic field $H_0 = 600$ Oe, and the variable magnetic field $H_\sim = 1000$ Oe.

reasonable to assume that the observed effect is associated with ion scattering on microelectric fields arising in the plasma as a consequence of the instability associated with the double streaming motion of the ions.

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[2] B. B. Kadomtsev, Fizika Plazmy (Plasma Physics) Vol. 4, AN SSSR 1958, p. 364.

[3] Babykin, Gavrin, Zavoiskiĭ, Rudakov, and Skoryupin, JETP **43**, 411 (1962), Soviet Phys. JETP **16**, 1092 (1963).

[4] Babykin, Gavrin, Zavoiskiĭ, Rudakov, and Skoryupin, JETP **43**, 1547 (1962), Soviet Phys. JETP **16**, 1092 (1963).

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ELECTRON PARAMAGNETIC RESONANCE OF Zr^{3+} *IN GLASSES*

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OF the compounds of elements of the palladium group those of trivalent zirconium are very unstable and have not been studied by EPR (electron paramagnetic resonance). The present note communicates the results of an EPR investigation of silicate glasses containing Zr^{3+}.

The measurements were made at frequencies of 450 and 9320 Mc and at temperatures 77 and 295°K. The samples of silicate glass of composition $20Na_2O \cdot 70SiO_2 \cdot 10ZrO_2$ (in mole percent at synthesis) were founded under strongly reducing conditions.

At 450 Mc and 77°K a narrow and symmetric EPR line was observed; the spectroscopic splitting factor $g = 1.89 \pm 0.01$ and the width between the maximum and minimum slope points was 5 Oe. With gradually increasing temperature from 77 to 295°K the line width increased monotonically until at 295°K it could no longer be observed.

At 9320 Mc and 77°K a broad, asymmetric EPR line is observed with $g_{eff} = 1.906 \pm 0.002$ and width 126 ± 6 Oe. At this frequency also there was no EPR signal at room temperature.

We assume that the magnetic ion Zr^{3+} in these glass samples is in an octahedral environment formed by six oxygen atoms. The energy levels of Zr^{3+} ($4d^1$, $S = 1/2$) are similar to the levels of Ti^{3+} ($3d^1$, $S = 1/2$). In these ions an octahedral crystalline field splits the five-fold orbital level