A peripheral theory of fireballs has by now been developed [8], and a comparison of the experimental results with its predictions is of particular interest.

1) A preliminary statistical reduction of our material has shown that the number of events in which one fireball is produced is equal to the number of two-fireball events, with 10% accuracy. This estimate of the probability of generation of different numbers of fireballs at 400 GeV is in good agreement with the prediction of fireball theory.

2) a. The theoretically-predicted distribution with respect to the squares of the 4-momenta transferred between the nucleons and the fireballs, for one-fireball cases, and between the nucleons and fireballs as well as between two fireballs for two-fireball cases, $\Delta_{i\ \mathrm{min}} = K^2$, is in good agreement with our experimental distribution (Fig. 2).

b. The theoretical calculations indicate that K^2 is practically independent of the total energy and its distribution has a maximum at $K^2 = 0.5$ GeV^2. Its mean value, however, is somewhat larger and amounts to 1 - 2 GeV^2. Our data give a most probable value $K^2 = 0.5$ GeV^2 and a mean value $\bar{K}^2 = 1.7$ GeV^2.

3) The value obtained by us for the fireball mass is in good agreement with the data of the Tien-Shan and the Polish groups [3, 6, 7], and does not disagree in principle with the theoretical value, which has so far been determined only for asymptotically high energies.

As seen from the foregoing, our experimental data are in good agreement both with the predictions of the fireball model based on kinematic singularities, and with the predictions of the fireball theory.

However, only appropriate theoretical calculations, or else simulation of the events by the Monte Carlo method, can resolve the question of the existence of fireballs.

[1] V.N. Akimov and I.M. Dremin, FIAN Preprint, 1966.
[2] I.M. Dremin, G.B. Zhdanov, I.M. Tret'yakova and M.M. Chernovskii, ZhETF Pis. Red. 4, 152 (1966) [JETP Lett 4, 104 (1966)].
[3] N.G. Zelevisnkaya, A.M. Lebedev, and S.A. Slavatinskii, Proc. Moscow Conference, 1970.
[4] E.L. Andronikashvili, L.I. Garibashvili, et al., in: Yadernye vzaimodeistviya pri vysokikh energiyakh (Nuclear Interactions at High Energies), Metsniereba, Tbilisi, 88, 1969.
[5] S.A. Slavatinskii, Trudy FIAN 46, 40 (1970).
[6] I. Gierula and M. Miesowicz, Nuovo Cim., 8, 116 (1958).
[7] I. Gierula and M. Miesowicz, Nuovo Cim., 18, No. 1 (1960).
[8] I.M. Dremin, I.I. Roizen, and D.S. Chernavskii, Usp. Fiz. Nauk 101, 385 (1970) [Sov. Phys.-Usp. 13, 438 (1971)].

OBSERVATION OF FAST ELECTRONS PRODUCED BY INJECTION OF A PLASMOID INTO A TRANSVERSE MAGNETIC FIELD

K.B. Kartashev, V.I. Pistunovich, V.V. Platonov, V.D. Ryutov, and E.A. Filimonova

Submitted 10 November 1971
ZhETF Pis. Red. 15, No. 1, 7 - 9 (5 January 1972)

When a plasma current enters a transverse magnetic field, the energy should become redistributed among the ionic and electronic components. This redistribution was considered theoretically by many workers [1 - 5], using as

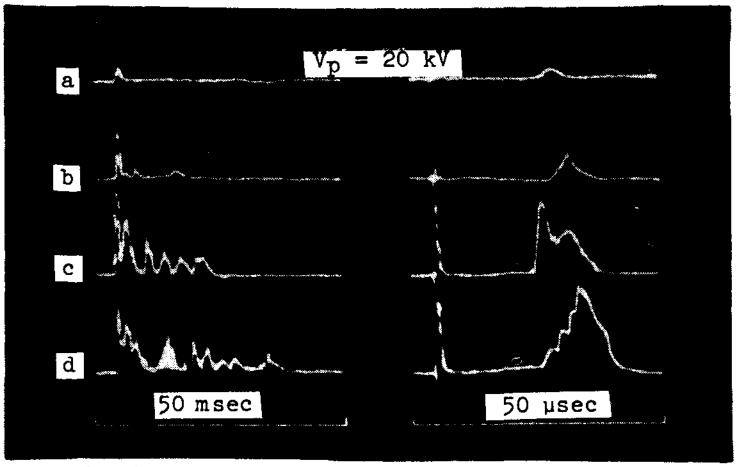

Fig. 1. Oscillograms of microwave radiation (left) and of x-rays at different values of the magnetic field: a - H_0 = 1.3 kOe, b - H_0 = 1.7 kOe, c - H_0 = 2.5 kOe; V_p - voltage across plasma-gun electrodes.

an example the one-dimensional model of an equilibrium boundary layer between the plasma and the magnetic field. In this model, the plasma current incident on the magnetic field is completely reflected from the "magnetic wall," and the electrons are accelerated in the transition layer produced by the charge separation, while the ions are decelerated.

We present here the results of the observation of the fast electrons produced when a plasmoid is injected into a transverse magnetic field H_0. The experiments were performed on the INES installation [6]. Hydrogen plasmoids of density $n_e \gtrsim 2 \times 10^{12}$ cm^{-3} and velocity $v_0 \simeq 1 \times 10^8$ cm/sec were produced by a coaxial plasma gun located outside the magnetic field. The magnetic field had a mirror-type configuration with a mirror ratio R = 2.5 and with maximum intensity 2.5 kOe at the center. The injection was along the radius of the trap in its central plane. The experiments were performed under conditions when the kinetic energy density of the moving plasmoid was less than the energy density of the magnetic field (otherwise the plasmoid should "blow away" the magnetic field).

Injection of the plasmoid into the magnetic field was found to be accompanied by x-rays having an energy on the order of the energy of the incident protons. This radiation was registered with a scintillation detector and came from the central region of the trap. The x-ray oscillograms obtained at different magnetic-field intensities and shown in Fig. 1 were obtained with an aluminum filter 1 mm thick, corresponding to attenuation of monochromatic radiation of energy ∿18 keV by a factor e. When the magnetic field intensity is increased from 1 to 2.5 kOe, the radiation intensity increases. No radiation was ever observed in the absence of a magnetic field. The first narrow radiation peak corresponds to the instant when the investigated plasmoid enters the magnetic field. The second broader peak occurs simultaneously with the start of the emission of the copper spectral line Cu I [6], i.e., with the instant when a plasmoid of velocity $v = 3 \times 10^6$ cm/sec and containing a large amount of impurities arrives in the trap from the plasma gun. The spectrum of the second x-ray peak was determined with a set of filters and was found to have the same form as the bremsstrahlung spectrum of Maxwellian electrons of temperature T_e = 5 keV.

Simultaneously with the x-radiation, we registered with the aid of a horn antenna electromagnetic radiation in the range λ = 4.6 - 0.8 cm (Fig. 1). Like the x-rays, the microwave radiation was never observed in the absence of a transverse magnetic field, and its intensity increased with increasing field. It was ascertained, by using waveguides operating beyond cutoff, that the microwave

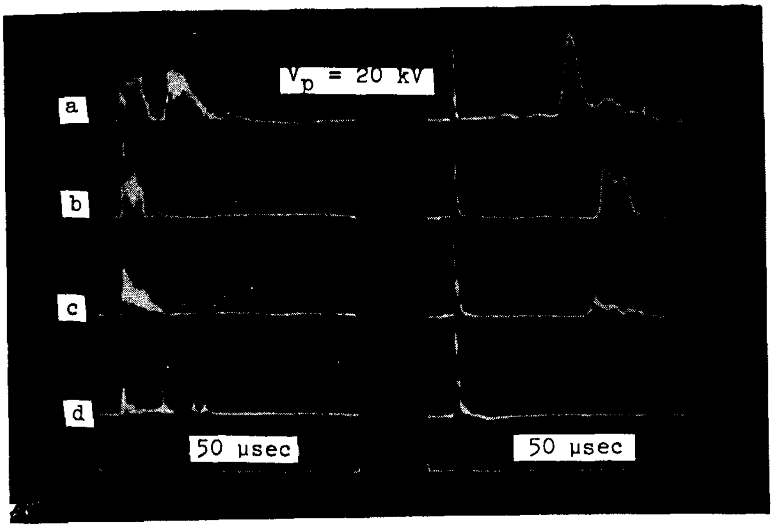

Fig. 2. Oscillograms of microwave radiation (left) and x-rays at different positions of the metal rod relative to the trap: a - 15 cm from the trap axis, b - 10 cm from trap axis, c - 5 cm from the trap axis, d - rod on trap axis.

spectrum has an end point on the short-wave side. The microwave radiation appears at the instant when the fast plasmoid arrived at the trap, and is observed up to the start of the second x-ray pulse, i.e., up to the instant when the impurities enter the trap. Intense radiation in the range of characteristic plasma frequencies and their harmonics is evidence of the presence in the trap of a plasma with a high oscillation level.

The second x-ray pulse indicates that the trap contains high-energy electrons, whose bremmstrahlung on the ions and atoms of the heavy impurities are observed by us. Assuming that the targets for the electrons are the copper ions and atoms, we can estimate electron density at $n_e \geq 3 \times 10^{11}$ cm^{-3} at a copper ion and atom density $n_{CU} \leq 10^{14}$ cm^{-3}. Consequently, when a fast plasmoid enters the transverse magnetic field, an appreciable fraction of the electrons gains energy and is captured in the trap. To prove that the second x-ray pulse is due to the presence of high-energy electrons in the central part of the trap, a metal rod was inserted in a direction opposite to the motion of the plasmoid. The results of the experiment are shown in Fig. 2. As the end of the rod approaches the axis of the magnetic trap, the second peak of the x-ray and microwave radiation decreases. The radiation disappears almost completely when the rod is at the center of the chamber. The target decelerating the fast electrons responsible for the appearance of first x-ray peak has not been identified as yet.

The experimental results cannot be fully explained within the framework of the one-dimensional stationary model [1 - 5].

[1] V.C.A. Ferraro, J. Geophys. Res. 57, 15 (1952).
[2] V.I. Veksler, Dokl. Akad. Nauk SSSR 118, 263 (1958) [Sov. Phys.-Dokl. 3, 84 (1958)].
[3] Yu.S. Sigov, ibid. 138, 1337 (1961) [6, 497 (1961)].
[4] V.I. Shabanskii, Zh. Eksp. Teor. Fiz. 40, 1058 (1961) [Sov. Phys.-JETP 13, 746 (1961)].
[5] Yu.S. Sigov, PMT No. 3, 25 (1967).
[6] I.N. Golovin et al. Paper CN-28/G-9, Fourth Internat. Conf. on Plasma Physics and Thermonuclear Research, Madison, Wisc., June 1971.