Scientific session of the Division of General Physics and Astronomy, USSR Academy of Sciences (29 October 1975)

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A scientific session of the Division of General Physics and Astronomy was held on October 29, 1975 at the conference hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. *S. I. Syrovatskiĭ*, Current Layers and Flare Processes in the Laboratory and in the Cosmic Plasma.

2. *I. S. Shapiro*, Bound and Resonant States of the Nucleon-Anti-nucleon System.

We publish below brief contents of the papers.

S. I. Syrovatskiĭ. *Current Layers and Flare Processes in the Laboratory and in the Cosmic Plasma.* About ten years ago, the Theoretical Section of the USSR Academy of Sciences Physics Institute began studies of the mechanism of particle acceleration in solar flares in connection with the problem of the origin of cosmic rays. This work led to a conception of the flare as a process in which a pulsed electric field arises on rapid disintegration (rupture) of a current layer in the plasma. This process is quite universal: it is also observed in heavy-current laboratory discharges, in the earth's magnetosphere, and very probably in remote cosmic-ray and nonthermal-emission sources.

The mechanism of the process is clarified by the scheme in Fig. 1. At time $t=0$, let the thin layer of plasma with current that separates the oppositely directed magnetic fields B_0 and $-B_0$ be removed. Electromagnetic waves (pulses) travel away from the layer in either direction, transforming the original magnetic field into a homogeneous electric field $E(x, t)=B_0\theta(c^2t^2-x^2)$, where $\theta(x)$ is a step function. In the presence of a plasma with density n, this will be only the initial stage: after a time

$$t_0 \approx \frac{1}{\omega_0}\sqrt{1+\frac{\omega_B^2}{\omega_0^2}}$$

the field E will create in the plasma a new current sufficient to concentrate the magnetic-field discontinuity in the skin layer (ω_0 and ω_B are the Langmuir and gyrofrequencies). During this time, particles at the center of the new layer acquire a momentum

$$p \approx mc\frac{\omega_B}{\omega_0}\sqrt{1+\frac{\omega_B}{\omega_0}}.$$

At $\omega_B^2/\omega_0^2=B^2/4\pi nmc^2 \gg 1$, the electrons (mass m) become ultrarelativistic. The problem can be solved rigorously in the limits $(\omega_B/\omega_0)^2 \ll 1$ and $\gg 1$, and is one of the few examples of exact allowance for the radiation reaction.[1–4]

In real applications, two basic questions arise: 1) How can a current layer be created in a plasma with a sufficiently large value of ω_B^2/ω_0^2? 2) How quickly must the layer be removed?

We now have a rather complete answer to the first question. The appearance of plasma current layers on magnetic-field zero lines has been studied theoretically,[3,5,6] calculated on a computer,[7] and brought about in laboratory experiments.[8–10] In many respects, current layers in plasma are similar to the shock waves of ordinary gasdynamics: in the first approximation, they can be treated as discontinuities (transitional between the rotational discontinuity, the slow MHD shock-wave, and the tangential discontinuity); they appear as a

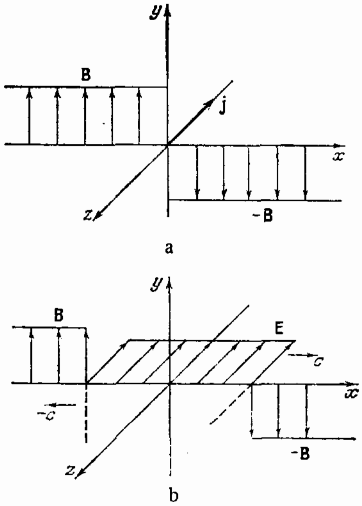

FIG. 1. Upon instantaneous removal of a current layer separating oppositely directed magnetic fields of equal value $|B|$ (a), an electromagnetic wave (pulse) appears and transforms the magnetic field B into a homogeneous electric field $E = n \times B$, where n is the direction of propagation (b).

result of nonlinearity and result in reduction of the scales to those in which dissipation comes into play. However, a strong magnetic field and the possibility of collisionless regimes result in new physical effects. That is to say, the current layer is a metastable configuration with a large magnetic energy excess. Disintegration (rupture) of the layer is accompanied by conversion of this energy (see above) into energy of directional motion of the accelerated particles ("dynamic dissipation").

The disintegration mechanism of the layer has thus far been given little study. The following picture appears most probable. The layer has a complex internal structure, e.g., regions of low density (thinnings; Fig. 2). In such regions, the current velocity of the electrons may reach a critical value (of the order of the thermal velocity) at which the plasma goes over quickly (during a time much shorter than the hydrodynamic times) into a turbulent regime with low conductivity.

FIG. 2. Holographic interferogram of current layer (see[10]), showing distribution of plasma in a cross section of the layer. The bands correspond to lines of equal plasma electron density. Note the current layer and the thinning in it on either side of the central dense filament.

Parameters of preflare current layer in the solar corona.

Parameter	Value
Initial plasma density n_0	$5 \cdot 10^8$ cm^{-3}
Gradient of external magnetic field in the neighborhood of the zero line h_0	$5 \cdot 10^{-7}$ G/cm
Layer length l	10^{10} cm
Layer temperature	$8 \cdot 10^4$ °K
External electric field on zero line	$4 \cdot 10^{-4}$ cgs esu
Layer width	$7 \cdot 10^8$ cm
Layer thickness	10 cm
Magnetic field near layer	340 G
Total current in layer	$6 \cdot 10^{11}$ A
Density in layer	$2 \cdot 10^{14}$ cm^{-3}
Excess magnetic energy associated with layer	10^{32} erg
Steady-state power dissipated in current layer	$8 \cdot 10^{27}$ erg/sec
Formation time of layer (initial phase of flare)	$3 \cdot 10^4$ sec
Dispersal time of layer (explosive phase of flare)	10^2 sec

This process may be promoted by failure of the steady-state regime, when the radiative cooling of the layer cannot keep up with the Joule heating.[11] At these points, the magnetic field realigns itself quickly and sets up forces that "disintegrate" the layer. The layer breaks at an Alfvén velocity $V_A = B/\sqrt{4\pi\rho}$, to which a pulsed electric field $E = (V_A/C)\, B$ corresponds.

The table gives the parameters of the layer before a powerful flare in the corona. Values were assigned to the parameters h_0, n_0, and l, and the remaining quantities were determined from the theory.[11]

Establishment of the role of current layers permits a more rigorous approach than had hitherto been possible to the problem of predicting solar flares. That is to say, it is necessary to concentrate our efforts in the following areas:

1) The search for magnetic-field zero and limiting[12] lines in data on the radial component $B_{\parallel}$. This requires a) a special solar magnetic field service; b) new methods of preparing and processing magnetic charts; c) development and use of low-lag magnetographs with high angular resolution, including extra-atmospheric models.

2) Exploration for and observation of current layers in the chromosphere and corona, an order that can be filled by: a) observations in the radio-, ultraviolet, and x-ray bands; b) observations of chromosphere and corona structure in lines of the optical spectrum; c) measurements of the total vector B at a fixed level; d) measurements of the components B at various levels in the solar atmosphere.

3) Development of a theory and laboratory experi-

ment with the object of establishing the quantitative conditions of disintegration of the layer and the nature of the processes accompanying disintegration.

There is reason to believe that studies in these directions will yield results that are important not only for the solar-flare problem, but also for many other problems of contemporary astrophysics and plasma physics.

The materials of the paper were published in[1–3,5–12].

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