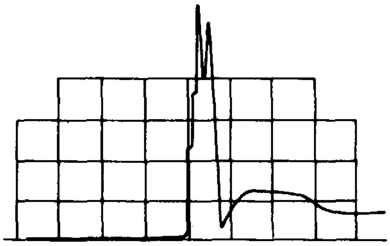


Shape of generation pulse. Each horizontal division equals 10 μsec.

The experiment has shown that the rate of formation of the fluorine atoms upon dissociation of the fluorine molecules under the influence of the radiation from the employed source was in most cases insufficient to produce lasing. To improve the conditions for the initiation of the reaction, an easily-dissociating fluorine-containing component was introduced in the mixture, in the form of molybdenum hexafluoride or other fluorine compounds. The MoF_6 pressure (several Torr) was set to make the characteristic time of the chemical reaction about 1 - 2 μsec.

The figure shows the form of the emission pulse of the chemical laser at an approximate wavelength 10.6 μ. As a rule, lasing occurred 5 μsec after the start of the light pulse and lasted 7 - 10 μsec. Spikes of approximate duration 1 μsec were occasionally observed at the peak of the pulse. The energy in the emission pulse ranged from 5 to 15 J, depending on the composition of the gas mixture.

The authors consider it their pleasant duty to thank A.V. Pankratov, V.S. Zuev, V.L. Tal'roze, P.G. Grigor'ev, L.V. Kulakov, V.T. Galochkin, V.V. Gromov, B.L. Borovich, and G.K. Vasil'ev for help with the work.

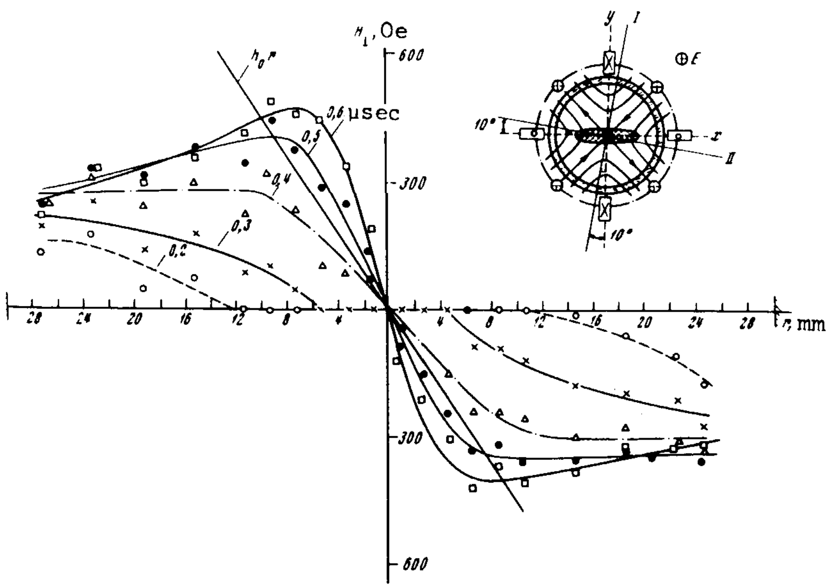
[1] J.V.V. Kasper and G.C. Pimentel, Phys. Rev. Lett. 14, 352 (1965).
[2] K.L. Kompa and G.C. Pimentel, J. Chem. Phys. 47, 857 (1967).
[3] J.H. Parker and G.C. Pimentel, J. Chem. Phys. 48, 5273 (1968).
[4] R.W.F. Gross, N. Cohen, and T.A. Jacobs, J. Chem. Phys. 48, 3821 (1968).
[5] O.M. Batovskii, G.K. Vasil'ev, E.F. Makarov, and V.L. Tal'roze, ZhETF Pis. Red. 9, 341 (1969) [JETP Lett. 9, 200 (1969)].
[6] N.G. Basov, L.V. Kulakov, E.P. Markin, A.I. Nikitin, and A.N. Oraevskii, ibid. 9, 613 (1969) [9, 375 (1969)].
[7] N.G. Basov, A.N. Oraevskii, and V.A. Shcheglov, Zh. Eksp. Teor. Fiz. 12, 243 (1967) [sic!].
[8] H.L. Chen, J.C. Stephenson, and C.B. Moore, Chem. Phys. Lett. 2, 593 (1968).
[9] C.B. Moore, R.E. Wood, B.L. Hu, and I.T. Yardley, J. Chem. Phys. 46, 4222 (1967).
[10] R.W.F. Gross, J. Chem. Phys. 50, 1889 (1969).
[11] N.G. Basov, V.V. Gromov, E.L. Koshelev, E.P. Markin, and A.N. Oraevskii, ZhETF Pis. Red. 10, 5 (1969) [JETP Lett. 10, 2 (1969)].
[12] N.G. Basov, V.T. Galochkin, L.V. Kulakov, E.P. Markin, A.I. Nikitin, and A.N. Oraevskii, Kratkie soobshcheniya po fizike (Brief Reports of Physics), 1, No. 7 (1970)].
[13] N.G. Basov, B.L. Borovich, V.S. Zuev, and Yu.Yu. Stoilov, Zh. Tekh. Fiz. 38, 2079 (1968) [Sov. Phys.-Tech. Phys. 13, 1665 (1969)].
[14] N.G. Basov, B.L. Borovich, V.S. Zuev, V.B. Rozanov, and Yu.Yu. Stoilov, ibid, 40, 516 and 805 (1970) [15, 399 and 624 (1970)].

DEVELOPMENT OF A CURRENT LAYER WHEN PLASMA MOVES IN A MAGNETIC FIELD WITH A NEUTRAL LINE

S.I. Syrovatskii, A.G. Frank, and A.Z. Khodzhaev
P.N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 21 December 1971
ZhETF Pis. Red. 15, No. 3, 138 - 142 (5 February 1972)

Studies of the formation of current layers in a plasma are of interest in connection with astrophysics problems (solar chromosphere flares, the loop of

Fig. 1. Distortion of quadrupole magnetic field at different instants of time after application of an electric field E_z to the plasma. The magnetic probe was moved along line I, and the component of the magnetic field perpendicular to the probe motion was measures (h_0 = 440 Oe/cm, the plasma was produced by discharge in helium, E_z = 150 V.cm).



the earth's magnetosphere), and also in connection with the problem of particle acceleration in a plasma. As shown theoretically [1], current layers can appear when a well-conducting magnetized plasma moves in a magnetic field with a neutral line. Formation of a current layer should lead to an appreciable increase of the magnetic-energy density in the vicinity of the neutral line [2]. The production of such a current layer under laboratory conditions encounters great difficulties, owing to the development of instabilities in the plasma, the appearance of anomalous resistance, and failure to satisfy the condition for the freezing-in of the magnetic field in the medium [3]. We describe in the present communication an experiment in which we succeeded in producing a current layer in which the magnetic-field gradient was much larger than the gradient of the initial field.

The formation of a current layer in the case of two-dimensional motion of a plasma in the vicinity of a neutral line of a magnetic field was investigated with a laboratory setup with a quasistationary magnetic field of quadrupole configuration, with a gradient 5×10^3 Oe/cm. The neutral line of the magnetic field was aligned with the axis of a cylindrical glass vacuum chamber of 60 cm diameter and 80 cm length. To produce a plasma in a chamber filled with the investigated gas to a pressure 10^{-1} - 10^{-2} Torr, an induction θ-discharge was excited in the quadrupole field. The density of the produced plasma exceeded 2×10^{13} cm^{-3} under the working conditions. After filling the chamber with plasma, the inducing electric field E_z with intensity up to 500 V/cm was turned on, and the direction of this field coincided with the neutral line of the quadrupole magnetic field and with the axis of the vacuum chamber. The electric field caused the plasma to move and produced a current in it, and consequently distorted the initial quadrupole magnetic field. The additional magnetic field, i.e., the field connected with the currents in the plasma, was measured with magnetic probes that could be moved in the (x, y) plane along straight lines I or II which interesected the neutral line at an angle ∿10° to the y or x axes (see Figs. 1 and 2). We measured two components of the magnetic field in the (x, y) plane: along the direction of displacement of the magnetic field, and perpendicular to it.

The spatial distribution of the additional magnetic field at different instants of time following the application of the electric field E_z is shown in Figs. 1 and 2. As seen from the figures, the application of an electric

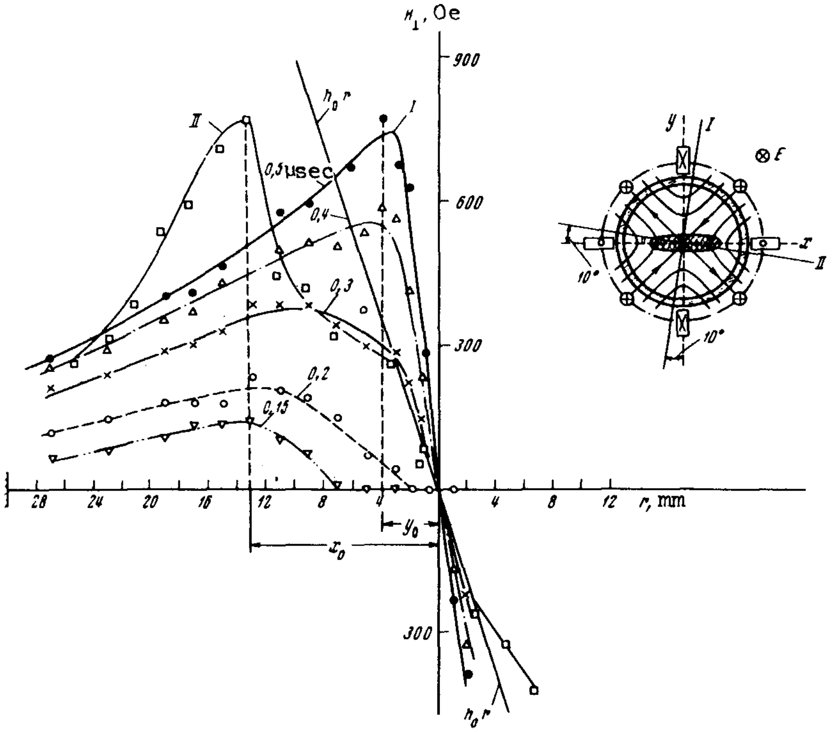


Fig. 2. Distortion of quadrupole magnetic field at various instants of time following the application of an electric field E to the plasma. The magnetic probe was moved either along the line II (curve II) or along the line I (all other curves). We measured the magnetic field component perpendicular to the probe motion (h_0 = 920 Oe/cm, plasma produced by discharge in He, E_z = 150 V/cm).

field to a plasma situated in a quadrupole magnetic field distorts the magnetic field at the plasma boundaries, and this distortion propagates subsequently in the form of a convergent wave towards the center of the chamber, i.e., to the neutral line. After the leading front of the wave reaches the center, a current is produced on the neutral line and the density of this current increases with time.

During the first stage, when the wave propagates from the plasma boundaries to the center, the perturbation of the magnetic field is small compared with the initial quadrupole magnetic field. This is seen directly from Figs. 1 and 2, in which the straight line $H = h_0r$ characterizes the value of the quadrupole field. As the leading front approaches the neutral line, the magnetic field in the wave increases. The radial converging wave has only one magnetic field component H_ϕ, perpendicular to the propagation direction; there is no H_r component in the wave - it appears only after the current on the neutral line begins. Measurements in two mutually perpendicular directions (along lines I and II) have shown that the distribution of the additional magnetic field in the wave is symmetric with respect to rotation through $\pi/2$. The propagation velocity of the wave front at each point depends on the local value of the magnetic field and the wave velocity increases with increasing magnetic field. It is seen from Fig. 1 that in a magnetic field with initial gradient h_0 = 440 Oe/cm, the wave reaches the center of the chamber at an instant $t \approx$ 0.4 μsec, whereas in a magnetic field with a gradient h_0 = 920 Oe/cm the wave converges to the neutral line already at $t \lesssim 0.25$ μsec (Fig. 2). In addition, the wave velocity at the plasma boundaries, i.e., in the region of strong magnetic fields, is higher than near the neutral line.

The foregoing peculiarities suggest that the observed wave is a fast magnetosonic wave that converges symmetrically to the neutral line of the quadrupole magnetic field. Its properties are in good agreement with the solution obtained in [4].

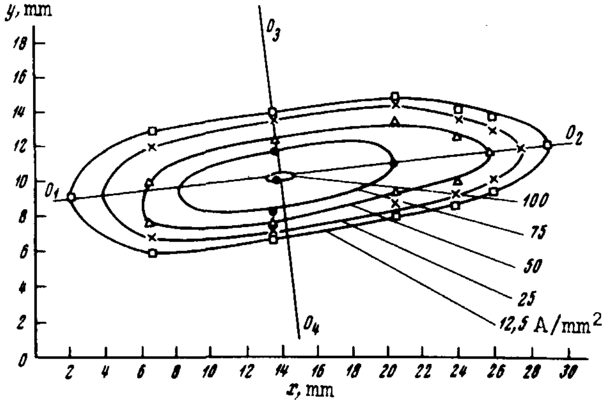


Fig. 3. Distribution of current density over the chamber cross section at the instant t = 0.5 μsec (h_0 = 920 Oe/cm, discharge in He, E_z = 250 V/cm.

After the wave front arrives at the center, the second stage of the process begins, namely formation of the current region in the vicinity of the neutral line of the magnetic field. The current density j_z on the neutral line increases rapidly with time, as seen from the increased slope of the curves of Fig. 1 ($t \geq 0.4$ μsec) and Fig. 2 ($t \geq 0.3$ μsec). This is confirmed also by current-density measurements made with a miniature Rogowski loop. The current distribution in the (x, y) plane is no longer symmetrical with respect to rotation through $\pi/2$, and the current region is elongated along the axis and compressed in the y direction. Figure 2 shows curves I and II pertaining to the same instant of time, t = 0.5 μsec, but obtained by moving the magnetic probe in two mutually perpendicular directions (I and II, respectively). It is seen from a comparison of the curves that the dimension of the current region along the x axis (x_0 = 13 mm) is ∿3.3 times larger than its dimension in the y direction (y_0 = 4 mm). Direct measurements of the distribution of the current j_z in the (x, y) plane (Fig. 3) show clearly that a current layer is produced in the region of the neutral line. The width of the layer, i.e., its dimension along x, increases with increasing time. The width of the current layer increases also with increasing electric field E_z. The magnetic field near the current layer is much larger than the initial quadrupole field. As seen from Fig. 2, at a distance ∿4 mm from the neutral line, the additional magnetic field due to the current flowing in the plasma is about double the initial field at the same time, i.e., the magnetic field and the gradient approximately triple over the thickness of the layer.

As shown in [3], the development of turbulence in the plasma makes it difficult to obtain a current layer capable of noticeably changing the configuration of the quadrupole field. In the described experiment, the plasma density was larger by approximately one order of magntidue than in [3], making it possible to increase the turbulent conductivity of the plasma to a value $\sigma_{turb} \simeq 2 \times 10^{13}$ cgs esu and to obtain a current layer with a total current ∿10 kA and with a considerable increase of the magnetic field in the vicinity of the layer.

It has thus been shown experimentally that an electric field directed along a neutral line of the magnetic field gives rise to a current layer that separates oppositely directed magnetic fields. This layer results from cumulation of a converging fast magnetosonic wave whose amplitude increases as its front approaches the neutral line. The developing current layer distorts appreciably the initial magnetic field and produces a considerable excess of magnetic energy in the vicinity of the neutral line.

The authors thank G.M. Batanov and M.S. Rabinovich for useful discussions and E.F. Bol'shakov for help with the experiment.

[1] S.I. Syrovatskii, Zh. Eksp. Teor. Fiz. 60, 1727 (1971) [Sov. Phys.-JETP 33, 933 (1971)].

[2] S.I. Syrovatskii, Astron. zh. 43, 340 (1966) [Sov. Astron.-AJ 10, 270 (1966)].
[3] S.I. Syrovatsky, A.G. Frank, and A.Z. Khodzhaev, Proc. IV, Europ. Conf. on Contr. Fus., Rome 1970, p. 66.
[4] S.I. Syrovatskii, Zh. Eksp. Teor. Fiz. 50, 1133 (1966) [Sov. Phys.-JETP 23, 754 (1966)].

EXPERIMENTAL INVESTIGATION OF X RADIATION OF ULTRARELATIVISTIC ELECTRONS IN MAGNETIC ONDULATORS

A.I. Alikhanyan, S.K. Esin, K.A. Ispiryan, S.A. Kankanyan, N.A. Korkhmazyan, A.G. Oganesyan, and A.G. Tamanyan
Submitted 22 December 1971
ZhETF Pis. Red. 15, No. 3, 142 - 146 (5 February 1972)

The radiation of fast electrons passing through periodic electric or magnetic fields (ondulators) was considered theoretically in [1 - 3]. Experimental studies of electrons in magnetic ondulators were made only at millimeter and optical frequencies (cf. [3]). We present here preliminary results of an experimental investigation of emission from 3.6-GeV electrons in a magnetic ondulator at x-ray frequencies ($\hbar\omega$ = 10 - 125 keV).

The emission of ultrarelativistic electrons in magnetic ondulators at x-ray frequencies was investigated theoretically in [4, 5]. It was shown that in the case of a sinusoidal distribution of the field in the ondulator, the emission of the fast electrons consists of different "harmonics," each of which has a frequency interval

$$\omega_{1m} = \frac{m\Omega}{2} \leqslant \omega \leqslant 2m\Omega\gamma^2 = \omega_{2m}. \tag{1}$$

where m is the number of the harmonic, $\gamma = (1 - \beta^2)^{-1/2}$, $\Omega = 2\pi c/\ell$ (ℓ is the period of the magnetic field).

The number of quanta emitted in the frequency interval $d\omega$ per unit path length is given by ($\beta \to 1$)

$$\frac{dN_m}{d\omega} = \frac{e^2}{\hbar c}\,\frac{1}{2\pi c}\int_0^{2\pi}\left(\frac{\sigma_m^2}{\sin^2\theta_m\cos^2\phi} - \frac{1}{\beta^2\gamma^2}\right) I_m^2(a_m)\,d\phi\,, \tag{2}$$

where

$$\sigma_m = \frac{m\Omega}{\beta\omega}, \quad \cos\theta_m = \frac{1}{\beta} - \sigma_m, \quad a_m = \frac{\omega e H_0}{\gamma\Omega^2 Mc}\sin\theta_m\cos\phi\,,$$

$$\omega^2\sin^2\theta_m = \frac{1}{\gamma^2}(\omega - \omega_{1m})(\omega_{2m} - \omega),$$

I_m is a Bessel function, H_0 the amplitude of the magnetic field, and M the mass of the passing particle.

Formula (2) is valid if the following conditions are satisfied:

$$\left(\frac{M}{M_e}\right)^2\gamma^2 >> 10^{-8}H_0^2\ell^2\,, \quad \frac{2}{3}\left(\frac{e^2}{Mc^2}\right)^2 H_0^2 L\gamma << Mc^2, \tag{3}$$