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# FAST PARTICLES IN A PARAMETRICALLY UNSTABLE PLASMA

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The theory of parametric action of radiation of high intensity on a plasma has made it possible to reveal the conditions under which parametric instabilities occur [1, 2], to predict the phenomenon of anomalously rapid transfer from the field to the plasma [1, 3], and to determine in a number of cases the anomalous high-frequency conductivity of the plasma [3, 4]. The predictions of the theory were confirmed by experiment and the physical picture of the development of the parametric instabilities came into extensive use for the interpretation of the experimental data. In this communication we wish to touch upon the question of the formation of rapid particles in a parametrically unstable plasma, bearing in mind the fact that the experimental study of the reaction of high-power radiation on the plasma has come to be accompanied frequently with measurement of the particle velocity distribution. The corresponding capabilities of the theory were revealed in [1, 3, 5]. However, the concrete results of the theory have so far been limited in fact to the approximation of a Maxwellian distribution, in which the cause of the temperature rise was the development of parametric instabilities [3, 6].

We wish to call attention below to such a cause of the appearance of fast particles in experiments with powerful electromagnetic fields, such as Cerenkov interaction of waves with particles. It is precisely such an interaction which is taken into account by the main equation of the quasilinear approximation of the theory of parametrically unstable plasma [3]. Bearing in mind the inertia of the ions, we shall assume their distribution to be Maxwellian and constant in time. To consider the evolution of the electron distribution $F_e(\vec{v}, t)$ and of the field $\vec{E}(\vec{k}, t)$, we use the system of equations (e and m are the charge and mass of the electron):

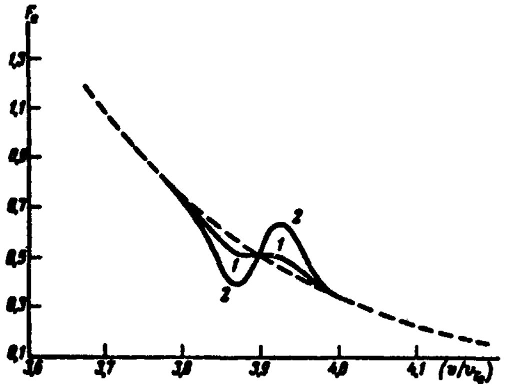
$$\frac{\partial F_e}{\partial t} = \frac{\partial}{\partial v_i} D_{ij}(v, t) \frac{\partial F_e}{\partial v_j}; \tag{1}$$

$$\frac{\partial}{\partial t} |\mathbf{E}(\mathbf{k}, t)|^2 = 2\gamma(\mathbf{k}, t) |\mathbf{E}(\mathbf{k}, t)|^2 . \tag{2}$$

To illustrate the consequences ensuing from this system of equations, we assume the parametric-instability increment in the form (see [2]):

$$\gamma = \frac{1}{4}(k r_E)^2 \frac{\omega_{Li}^2 \omega_0 \Delta\omega_0 \tilde{\gamma}}{[(\Delta\omega_0)^2 + \tilde{\gamma}^2]^2} .$$

Here $r_E \equiv (\vec{e}\cdot\vec{E}_0/m\omega_0^2)$ is the amplitude of the oscillations of the electrons in the field of the pump wave $\vec{E}_0 \sin\omega_0 t$, $\Delta\omega_0$ is the difference between the frequencies of the external pump field and the high-frequency plasma wave ($\Delta\omega_0 > 0$), $\tilde{\gamma}$ is the damping decrement of the high-frequency plasma wave, and



Distribution function of the electrons $E_0$ with respect to the velocity v in a parametrically unstable plasma with $N_e r_{D_e}^3 = 10^7$ particles in the Debye sphere, with an electron Debye radius $r_{D_e} = 0.29\ k_m^{-}$, and an electron Langmuir frequency $\omega_{L_e} = 0.876\omega_0$ for three different instants of time.

$\omega_{L_i} \equiv (4\pi N_i e_i^2/M)^{1/2}$ is the ion Langmuir frequency. In the case of a relatively weak pump field, when the electron oscillation amplitude is small compared with the plasma wavelength $(\vec{k}\cdot\vec{r}_E) \ll 1$ and the Debye radius of the electrons ($r_E^2 \ll r_{D_e}^2$), the diffusion coefficient in velocity space takes the form

$$D_{ij}(\mathbf{v},t) = \frac{\pi}{16}\frac{e^2}{m^2}\omega_0^2 \times \int \frac{dk}{(2\pi)^3}\frac{\omega_{L_i}^4}{\omega^4}\frac{k_i k_j}{k^2}|\mathbf{E}(\mathbf{k},t)|^2\frac{(\mathbf{k}\,\mathbf{r}_E)^2}{(\Delta\omega_0)^2+\tilde{\gamma}^2}\{\delta(\omega_0+\mathbf{k}\,\mathbf{v}) + \delta(\omega_0-\mathbf{k}\,\mathbf{v})\}.$$

We took into account here the fact that the frequency $\omega$ of the low-frequency oscillations, which grow in a parametrically unstable plasma, is small compared with the frequency of the pump field ($\omega \ll \omega_0$).

A relatively simple numerical integration of the system of equations (1) and (2) leads to a time variation of the electron velocity distribution, as is reflected in the figure, which shows two electron distributions at times $\omega_0 t = 330\,(r_{D_e}/r_E)^2$ (curve 1) and $\omega_0 t = 385(r_{D_e}/r_E)^2$ (curve 2), and where the dashed curve shows the Mexwellian distribution ($\omega_0 t = 0$) with thermal velocity $v_{T_e}$. It is seen from the figure that in the vicinity of the velocity $v_0 = (\omega_0/k_m)$, where the wave number $k_m$ corresponds to the maximum of the increment $\gamma$, a redistribution of the particle velocity takes place and leads to an increase in the number of particles with high velocities. We note that the observed tendency of variation of $F_e$ differs qualitatively from the particle redistribution that takes place in the case of the usual quasilinear relaxation of beams in a plasma [7]. It must also be emphasized that the redistribution of the particles in the velocity region $\sim(\omega_0/k_m)$ changes rapidly the value of the increment and is fundamental in the near-threshold region of the parametric instability, compared with the influence exerted on the increment by a rise of the electron temperature [6].

The observed tendency of the number of fast particles in the plasma to increase at large pump-field amplitude, as follows from the equations in [3], is important also for still larger velocities $\sim(n\omega_0/k_m)$, corresponding to harmonics of the pump field (n is an integer). The redistribution of the particles with respect to the velocities, following the appearance of a large number of accelerated particles, becomes particularly appreciable under conditions when the regions of the Cerenkov interaction with higher overtones overlap. We note, finally, that the Cerenkov interaction of the plasma waves with the ions in a parametrically unstable plasma leads to the occurrence of accelerated ions.

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## ERRATUM

In the article by N. P. Gadetskii et al., Vol. 14, No. 3, p. 101, the sentence beginning on the last line of the text reads: "The N and O admixtures..." It should read "The Ne and Ar admixtures..."