When $(\Delta - \Omega)/2 < \lambda$, we can omit the third term in (3) compared with the second, and then the problem reduces to that considered in [3], again with $\Delta$ replaced by $\tilde{\Delta}$. Consequently, when the wave is applied, it is necessary to replace $\Delta$ by $\tilde{\Delta}$ in the foregoing conditions and in the criterion (1). If the initial distance $\Delta \sim 1$ eV between the levels is effectively reduced in this manner by one or two orders of magnitude, then the probability of an instability associated with the phase transition increases rapidly, even if the initial system was far from unstable.

To satisfy the condition $\lambda > \tau^{-1}$ at the values $\tau \sim 10^{-12} - 10^{-14}$ sec characteristic of solids, the required field intensity of the light wave is $E_0 \sim 10^4 - 10^6$ V/cm.

Suitable substances in which one can attempt to produce a phase transition are, for example, semiconductors and dielectrics containing ions of rare-earth and transition elements (see the reviews [5, 6]). In such substances there exist narrow exciton lines corresponding to transitions with energy 0.1 - 1 eV in the d- or f-shells of the indicated ions. Generally speaking, these transitions are parity- or spin-forbidden. In crystals, however, such a forbiddenness is frequently violated, and many transitions are allowed in the dipole approximation [6].

Transitions in d- and f-shells frequently occur with optical phonons taking part, thus indicating a sufficiently strong electron-phonon interaction.

Illumination with a strong wave can maintain the system at a temperature comparable with $T_k$.

The phase transition can be revealed by displacements in the lattice (in some cases by the appearance of a spontaneous dipole moment), by shifts of the energy levels of the electrons, and also by the change of the electric conductivity of the system.

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## INFLUENCE OF INHOMOGENEITY OF PLASMA ON THE RELAXATION OF AN ULTRARELATIVISTIC ELECTRON BEAM

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An experiment for producing and heating plasma by ultrarelativistic electrons using a beam interacting with a solid target was proposed in [1]. The preliminary estimates given in that paper lead to the following two conclusions: 1) An acceptable beam deceleration length ($L \lesssim 1$ cm) can be reached only if the relaxation of the beam is caused by collective processes which result from the two-stream instability. 2) It is difficult to heat the plasma within a time much less than the time of its free expansion, i.e., the plasma in this experiment must be greatly inhomogeneous.

On the other hand, as shown by the authors in [2], the relaxation of a nonrelativistic beam in an inhomogeneous plasma is much less effective than in a homogeneous one, and in many cases does not appear at all. For this reason, it is of interest to consider the influence of the inhomogeneity on the relaxation of an ultrarelativistic beam.

Let a beam with concentration $n_b$ and particle energy $E \gg mc^2$ be injected in a plasma whose concentration $n \gg n_b$ is a function with a characteristic scale L[1]. If the initial scatter of the beam particles relative to the angle $\theta$ in momentum space satisfies the condition

$$\Delta\theta \gtrsim (n_b/n)^{1/6}(mc^2/E)^{1/3}, \tag{1}$$

then the two-stream instability is kinetic. On the other hand, if this condition is not satisfied, then a hydrodynamic instability will develop during the first stage of the relaxation; this instability, as shown in [3], rapidly increases the angle scatter of the beam to values satisfying the inequality (1), without a noticeable energy loss. We should therefore assume that the inequality (1) is satisfied.

The relaxation process is due to the Cerenkov interaction of the beam particles with the waves that are built up by the beam. The condition for Cherenkov resonance for an ultrarelativistic particle is given by

$$\omega_p - c\,\frac{k_\parallel p_\parallel + k_\perp p_\perp \cos\phi}{(p_\parallel^2 + p_\perp^2)^{1/2}} = 0, \tag{2}$$

where $k_\parallel$ and $k_\perp$ are the longitudinal and transverse components of the wave vector, relative to the beam axis, $p_\parallel$ and $p_\perp$ are the corresponding components of the particle momenta, and $\phi$ is the angle between $k_\perp$ and $p_\perp$.

If the angle scatter in the beam is small ($\Delta\theta \ll 1$), then it is seen from relations (2) that it can interact with waves for which $k_\parallel$ lies in the interval

$$\left| k_\parallel - \frac{\omega_p}{c} \right| < \frac{\omega_p}{c}\,\Delta\theta^2 + k_\perp \Delta\theta. \tag{3}$$

For such waves, the instability increment $\gamma$ can be estimated from the formula

$$\gamma \sim \frac{\omega_p}{\Delta\theta^2}\,\frac{n_b}{n}\,\frac{mc^2}{E}\,\frac{\omega_p^2}{\omega_p^2 + k_\perp^2 c^2}. \tag{4}$$

In an inhomogeneous plasma, the longitudinal component of the wave vector of each oscillation changes as the beam propagates along the z axis in accordance with the equation

[1]In the numerical estimates we shall use the beam and plasma parameters indicated in [1], namely $n \sim 10^{22}$ cm$^{-3}$, $n_b \sim 10^{18}$ cm$^{-3}$, $E \sim 10$ MeV, and $L \sim 0.2$ cm.

$$dk_{\parallel}/dt = -\partial\omega_p/\partial z .$$

Within a time $\Delta t$, the wave vector changes by an amount $\Delta k_{\parallel} \sim (\omega_p/L)\Delta t$. Bearing this circumstance in mind, we can estimate the time during which the oscillation is at resonance with the beam:

$$\Delta t \sim \frac{L}{c}\Delta\theta^2 + \frac{k_\perp L}{\omega_p}\Delta\theta . \tag{5}$$

In a time $\Delta t$ the energy of the oscillation should increase from the initial (thermal) level to a level greatly exceeding the initial one (otherwise oscillations with a given k cannot exert a noticeable influence on the beam). This condition can be written in the form

$$\gamma\Delta t > \Lambda, \tag{6}$$

where $\Lambda$ is the Coulomb logarithm. Combining relations (3) - (6), we obtain the condition under which the oscillations with given $k_\perp$ can play a role in the beam relaxation process:

$$\frac{n_b}{n}\frac{mc^2}{E}\frac{L\omega_p}{c}\frac{1+(k_\perp c/\omega_p\Delta\theta)}{1+(k_\perp c/\omega_p)^2} > \Lambda . \tag{7}$$

At specified parameters of the beam and of the plasma, there exists a maximum value of $\Delta\theta$, at which the inequality (7) can still be satisfied for at least one value of $k_\perp$:

$$\Delta\theta_{max} \sim \frac{L\omega_p}{c}\frac{n_b}{n}\frac{mc^2}{E\Lambda} . \tag{8}$$

If the quantity $\Delta\theta_{max}$, formally calculated in accordance with the relation (8), satisfies the inequality $\Delta\theta_{max} \gtrsim 1$, then the inhomogeneity of the plasma does not exert a decisive influence on the relaxation process (a large value of $\Delta\theta_{max}$ corresponds, as seen from formula (8) to a large inhomogeneity scale, i.e., to the limiting case of a homogeneous plasma).

On the other hand, if $\Delta\theta_{max} \gtrsim 1$, then the inhomogeneity of the plasma is significant, since the beam with an angle scatter $\Delta\theta > \Delta\theta_{max}$ cannot lose any appreciable fraction of its energy on passing through the plasma (the condition for the growth of the oscillations (7) is not satisfied when $\Delta\theta > \Delta\theta_{max}$ for any value of $k_\perp$).

For the concrete parameters proposed in [1] for the beam and for the plasma, $\Delta\theta_{max}$ turns out to be $3 \times 10^{-2}$, i.e., the limitation on the angle spread of the beam is quite stringent from the experimental point of view.

A similar investigation of the relaxation of the beam in the case of a small initial spread ($\Delta\theta < \Delta\theta_{max} \lesssim 1$) will be published later. We indicate here only that as a result of such a relaxation, the beam reaches an angle spread $\Delta\theta \sim \Delta\theta_{max}$ and releases in the plasma an energy $\Delta E \sim E\Delta\theta_{max} \lesssim E$.

Recognizing that in the experiment of [1] $\Delta\theta_{max} = 3 \times 10^{-2}$, we can state that even if the initial angle spread of the beam is much smaller than $3 \times 10^{-2}$, the beam can deliver to the plasma in such an experiment not more than 10% of its energy.


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## E R R A T U M

In the article by A.M. Bonch-Bruevich et al., Vol. 11, No. 9, p. 291, the letter sequence in Fig. 1 reads downward, but should read upward. In the same figure, on the right side, read $10^{-2}$ rad in place of $10^{-2}$ deg.