Letters to the Editor

EFFECT OF RADIATION ON A CHARGED PARTICLE MOVING THROUGH A MAGNETOACTIVE PLASMA

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IN analyzing the stopping power of a plasma for fast particles one usually neglects external radiation [1] or assumes that the radiation is in equilibrium. [2]

Suppose that a magnetoactive plasma is exposed to high-density external radiation that interacts weakly with the plasma (region of transparency). The radiation can still interact intensely with fast particles that pass through the plasma because the plasma-retarded waves absorb and radiate particles (induced Cerenkov radiation and absorption). [3-5]

In the present note we wish to call attention to a number of interesting physical consequences and to the possibility of using the effect of radiation on a charged particle passing through a magnetoactive plasma to explain a number of phenomena.

Considering the transparent region of a plasma and neglecting spatial dispersion and spontaneous variations we obtain the following expressions for the change in the energy of a particle E and its angle with respect to the magnetic field $\theta = v_\perp/v_z$ under the effect of radiation ($\theta \ll 1$ and $v_z, v_\perp \ll 1$; $\hbar = c = 1$):

$$\frac{dE}{dz} = \frac{e^2\omega_{0e}^3}{2mv_z^4}\int u\,du\left\{\frac{|\varepsilon_z|}{\varepsilon^2}\left(\frac{m_e}{m}h + \frac{m}{m_e}\frac{u^2}{h}\right)(\overline{N}_- - \overline{N}_+) - \frac{|\varepsilon_z|}{\varepsilon^2}2u(\overline{N}_- + \overline{N}_+) - \frac{2u}{|\varepsilon|}\left(\overline{N}_0 + \frac{u\omega_{0e}}{2v_z}\frac{\partial \overline{N}_0}{\partial k_z}\right)\right\},$$

$$\overline{N}_\nu = \overline{N}(\omega, k_z, k_\perp) \quad \text{for } k_\perp = \sqrt{-\frac{\varepsilon_z}{\varepsilon}}\,k_z,$$

$$k_z = \frac{\omega + \nu\omega_H}{v_z}, \qquad \nu = 0, \pm 1; \tag{1}$$

$$\frac{d\theta^2}{dt} = \frac{e^2\omega_{0e}^3}{2m^2v_z^6}\int\frac{du\,|\varepsilon_z|}{\varepsilon^2}\left\{\left(u - \frac{m_e}{m}h\right)^2\overline{N}_- + \left(u + \frac{m_e}{m}h\right)^2\overline{N}_+\right\}. \tag{2}$$

Here, $\overline{N}(\omega, k_z, k_\perp)$ is the number of photons of frequency ω and momentum **k** averaged over the angle $\varphi = \tan^{-1}(k_x/k_y)$; $k_\perp^2 = k_x^2 + k_y^2$; v_z and $v_\perp$ are the velocity components of the particle along the field and perpendicular to the field; $\epsilon_z = 1 - u^{-2}$, $\epsilon = 1 - (u^2 - h^2)^{-1}$ are the diagonal components of the plasma dielectric tensor; $u = \omega/\omega_{0e}$, $h = \omega_{He}/\omega_{0e}$; $\omega_H = m_e\omega_{He}/m = eH/m$; m is the particle mass and m_e is the mass of the electron. The region of integration over frequency corresponds to the condition for spontaneous Cerenkov radiation: [6]

$$0 < u < h, \quad 1 < u < \sqrt{h^2+1} \quad \text{for } h < 1;$$
$$0 < u < 1, \quad h < u < \sqrt{h^2+1} \quad \text{for } h > 1.$$

When $u \to \sqrt{h^2+1}$ the macroscopic description no longer holds so that the integration in (1) and (2) must be carried out up to u_{max}:

$$\frac{h^2}{h^2+1-u_{max}^2} = \frac{k_{max}^2 v_z^2}{\omega_{0e}^2}\left(1 + \frac{\nu m_e}{m}\frac{h}{\sqrt{1+h^2}}\right)^{-2}. \tag{3}$$

The relations in (1) and (2) apply when

$$\theta\left|\frac{\omega + \omega_H\nu}{\omega_H}\right|\sqrt{\frac{-\varepsilon_z}{\varepsilon}} \ll 1,$$

and this sets a lower limit on the integration over the frequency.

We first direct attention to the fact the effect of radiation is always to increase the angle θ. At small angles this increase is determined primarily by the effective radiation since spontaneous variations in the angle tend to zero as $\theta^2 \to 0$. The region of angles in which the variations are determined primarily by radiation can be obtained, for example, if the frequency region in which the radiation density is nonvanishing is given by the condition $\Delta u \sim h \sim 1$:

$$\frac{d\theta_{sp}^2}{dz} \approx \frac{8e^2\omega_{0e}^2}{mv_z^4}\theta^2\int\frac{|\varepsilon_z|}{\varepsilon^2}u\,du, \qquad \theta^2 < \omega_{0e}\overline{N}/2mv_z^2.$$

Second, we note that although the sign of the change of the particle energy under the effect of radiation can vary, in practice, in the most interesting case (in which the number of waves in the medium is reduced because of the higher refractive index) the particle is accelerated by the radiation. The critical radiation density ρ_{cr} (starting with which the acceleration becomes greater than the spontaneous retardation) is easily estimated by comparing (1) with the well-known retarding force. Analysis shows that for the frequencies important in (1) and (2) there are no "resonance" frequencies and that the most favorable are those for which $\Delta u \sim h \sim 1$. Estimates show that the proportionality of the acceleration force and the radiation density is maintained up to $\rho \ll \rho_{max}$; at this value the order of magnitude of ρ_{max} is λ/r_0 times greater than ρ_{cr}, where λ is the characteristic wavelength of the radiation and r_0 is the classical radius of the particle. For example, in the second radiation belt electrons with energy 10^5-10^6 eV move in a gas with a density of 10^3 particles/cm^3 and the critical density of radio radiation at a wavelength $\lambda \sim 1/\omega_{He} \sim 0.1-1$ km is $10^{-20}-10^{-23}$ erg/cm^3. Although no data are available for these wavelengths we can, for the purposes of estimates, make extrapolations from the data for 10—20 m. We then find that even the radio radiation from the sun is capable of accelerating the fast electrons in the radiation belt. Under the most favorable conditions the radio radiation from the galaxy can accelerate electrons (lose energy) for tens of days.[1)]

Finally, we wish to point out that for heavy ions (mass $m \gg m_e$ and charge Ze) the accelerating force

$$\frac{dE}{dz} = \frac{Z^2e^2\omega_{0e}^3}{2m_e v_z^4}\int u^3du \frac{|\varepsilon_z|}{\varepsilon^2 h}(\overline{N}_- - \overline{N}_+) \tag{4}$$

is proportional only to the square of the charge of the particle (the dependence on m_i disappears when $\overline{N}_- \gg \overline{N}_+$); in other words, the acceleration of heavy ions is favored. The acceleration mechanism being considered here is statistical, as is that proposed by Fermi, and can be described by a diffusion equation in energy space. Explosions of supernovae, which appear as a source of cosmic rays in the galaxy,[7] are accompanied by intense radiation fluxes. A comparative estimate of the acceleration time for the Fermi mechanism and for the radiation mechanism described here shows that the radiation effect can predominate in the early stages of expansion and can be regarded as an injection mechanism for Fermi acceleration. The effect of radiation on fast particles in a medium should evidently be considered in a number of other astrophysical problems (theory of comet tails etc.).

1)The larger angle can increase the particle lifetime in the radiation belt.

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50

NUMBER OF NEUTRONS EMITTED BY U^{236} *IN REGIONS OF SYMMETRIC FISSION*

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THE sum of the kinetic energies of fission fragments and of their excitation energies calculated by the semi-empirical formula of Cameron[1] changes little with the fragment mass ratio near symmetric fission. Until very recently it was thought that the total kinetic energy of fragments is maximum for symmetric fission and decreases slowly with increasing mass ratio. Recent works[2,3] indicate convincingly that this assumption is false in the case of U^{233}, U^{235} and Pu^{239} fission by thermal neutrons. The kinetic energy reaches a maximum of ~ 180 MeV for a 1.25 mass ratio and decreases to ~ 40 MeV for symmetric fission. This situation forces us to review our previous notions concerning the balance of energy during fission. Although it could turn out that the semi-empirical formula gives incorrect results for a nucleus which is far off β-stability, it seemed more probable that the total excitation energy of the fragments changes sharply near symmetric fission, thereby neutralizing the change in the kinetic energy.

In this connection, measurement of the number of neutrons emitted in fission at different mass ratios has become particularly interesting. Similar research on U^{233}[4] and U^{235}[5] was already carried out before. In [5] there was even observed a slight increase in the number of neutrons in the mass ratio range 1.10 — 1.20, but the accuracy of both researches in regions of interest to us was clearly insufficient.