ENERGY DEPENDENCE OF DYNAMIC STRESSES PRODUCED WHEN RELATIVISTIC CHARGED PARTICLES PASS THROUGH A SOLID

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The excitation of mechanical oscillations in solids by passage of relativistic charged particles has been the subject of a large number of experimental [1 - 2] and theoretical studies [3 - 5]. It is indicated in these studies that ultrasonic waves are produced in the target, but the mechanism of excitation of the oscillations has not yet been fully studied [4, 5]. It is shown in [6] that the ratio of the energy lost by a fast particle and consumed in the excitation of acoustic oscillations to the ionization loss is a very small quantity

$$\frac{\Delta E_{ac}}{\Delta E_{ion}} = \frac{1}{2\ln\frac{m^3}{\pi N_e e^2}}(a\kappa)^{-4} << 1, \qquad (1)$$

where N_e is the average number of electrons per unit volume, a is the average distance between atoms, and $\kappa = me^2Z^{1/3}$ ($\hbar = c = 1$) is the reciprocal screening radius of the atomic potential. No account was taken in these investigations, however, of the direct generation of a stress tensor by the electromagnetic field of the passing particle.

We consider in this connection the excitation of mechanical vibrations in a thin metallic target by passage of relativistic charged particles. We write down the equation for the longitudinal oscillations in a thin plate [7]

$$\Delta u_\rho - \frac{1}{s^2}\frac{\partial^2 u_\rho}{\partial t^2} = \frac{2(1+\sigma)}{E}F(\rho, t), \qquad (2)$$

where u_ρ is the radial displacement, s is the speed of sound, E is Young's modulus, and σ is the Poisson coefficient; $F(\rho, t)$ is the force per unit volume of the material. Thus, the main problem of the interaction between charged particles and elastic waves reduces to a determination of the explicit form of the force $F(\rho, t)$. The force with which the passing particle acts on the target can be written as the devergence of the stress tensor or

$$F_i = \oint \sigma_{ik} n_k df. \qquad (3)$$

The stress tensor σ_{ik} is determined by the electromagnetic field of the passing particle

$$\sigma_{ik} = \frac{1}{4\pi}(E_i E_k - \frac{E^2}{2}\delta_{ik}). \qquad (4)$$

Substituting (4) in (3) and integrating over the closed surface passing through the front and rear planes of the target, we can find the force per unit surface area of the target

$$\mathbf{F}(\rho, t) = \frac{1}{4\pi}\oint \{ \mathbf{E}(\mathbf{E}\mathbf{n}) - \frac{1}{2}\mathbf{E}^2\mathbf{n} \} df. \tag{5}$$

The electric field of the particle on the front plane of the target is determined by the field in the vacuum, which is conveniently represented in the form

$$\mathbf{E}_1(\mathbf{r}, t) = \int e^{i\mathbf{k}\mathbf{r} - i\omega t} d^3\mathbf{k}\, d\omega \frac{ie}{2\pi^2}\left[\frac{\omega \mathbf{v}}{c^2} - \mathbf{k}\right] \frac{\delta(\omega - \mathbf{k}\mathbf{v})}{k^2 - \frac{\omega^2}{c^2}}, \tag{6}$$

whereas on the rear plane of the target the electric field of the particle coincides with the field produced by the passing particle in the target material

$$\mathbf{E}_2(\mathbf{r}, t) = \int e^{i\mathbf{k}\mathbf{r} - i\omega t} d^3\mathbf{k}\, d\omega \frac{ie}{2\pi^2}\left[\frac{\omega \mathbf{v}}{c^2} - \frac{\mathbf{k}}{\epsilon(\omega, \mathbf{k})}\right] \frac{\delta(\omega - \mathbf{k}\mathbf{v})}{k^2 - \frac{\omega^2}{c^2}\epsilon(\omega, \mathbf{k})}, \tag{7}$$

where $\varepsilon(\omega, \vec{k})$ is the dielectric constant of the target material. The target thickness should exceed the length over which the field is altered, called the formation zone in the theory of transition radiation [8]. The resultant force due to the passing particle will be directed along the velocity, so that if we take into account the direction of the outward normal for the differential of the surface, we obtain an explicit expression for the force acting on the surface element df

$$\mathbf{F}(\rho, t) = \frac{\mathbf{v}}{v} (8\pi)^{-1} \int (\mathbf{E}_1^2 - \mathbf{E}_2^2) df. \tag{8}$$

Averaging (8) over the time, we can easily determine the average force with which the particle acts on the target

$$\overline{\mathbf{F}(\rho)} = \frac{\mathbf{v}}{v} \frac{e^2}{(2\pi)^2} \times$$

$$\times \int d\omega \int d^2q \left\{ \frac{q^2}{\left[q^2 + \omega^2\left(\frac{1}{v^2} - \frac{1}{c^2}\right)\right]^2} - \frac{q^2}{|\epsilon(\mathbf{k}, \omega)|^2 \left[q^2 + \omega^2\left(\frac{1}{v^2} - \frac{\epsilon(\omega, \mathbf{k})}{c^2}\right)\right]^2} \right\}. \tag{9}$$

In expression (9) for the average force, the effective contribution is made by $\omega_{eff} \sim \omega_p(1 - v^2/c^2)^{-1/2}$ and $q_{eff} \sim \omega_p/v$, where $\omega_p^2 = 4\pi N_e e^2/m$. Integration of (9) leads to the following expression for the average force per unit time

$$\overline{\mathbf{F}} = \frac{\mathbf{v}}{v^2} \frac{e^2}{4} \omega_p \left(1 - \frac{v^2}{c^2}\right)^{-1/2}. \tag{10}$$

Thus, the passing particle acts on a thin target with an average force proportional to the energy of the incident particle. This is to be expected, for at relativistic energies the field of the particle increases in proportion to (E/m), but the duration of the action of the field is $\tau \sim (m/E)$, i.e., it decreases with energy. The force of the electromagnetic field is determined by the Maxwellian stress tensor (4), which is proportional to the square of the electric field intensity. For relativistic particles, averaging of the stress tensor over the time keeps the energy dependence linear in the expression for the average force.

The use of expression (10) for the force in the equation of the elastic oscillations of the target (2) makes it possible to determine the amplitude of the acoustic oscillations generated by relativistic particles in a solid. According to (10), the amplitude of the acoustic oscillations increases linearly with the energy of the incident particles. The total force due to passage of a beam of charge particles in proportional to the number of particles in the pulse, as is observed in experiment [1 - 2].

The expression (10) obtained for the force exerted by the passing particle on the target, at a fixed target thickness L, can exceed, with increasing energy, the force due to the ionization loss [6]

$$F_{ion} = \frac{4\pi e^4 N_e}{mv^2} \frac{L}{(a\kappa)^4} \ln \frac{m^3}{\pi N_e e^2} . \quad (11)$$

The linear energy dependence of the acoustic-oscillation amplitude makes it possible to use the indicated mechanism to register the energy of high-energy particles.

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SPECTRUM OF PHOTONS EMITTED AT LARGE ANGLES IN e^+e^- COLLISIONS AT HIGH ENERGIES

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In view of reported designs of installations with colliding beams of high-energy leptons (up to 10^2 - 10^3 GeV; see, e.g., [1, 2]), possible physical experiments with such accelerators have been under discussion recently (e.g., [3]).

Great interest attaches here to the possibility of investigating weak interactions by measuring the process