1, a - d), then the walls move relatively smoothly and have more or less smooth shapes; conversely, if the volume of this phase decreases (Fig. 1, e - h), then the walls move very unevenly jumpwise) and have a clearly pronounced shoppy shape. The asymmetry effect is observed also if only one flat boundary is produced in the sample (Fig. 2). Upon passage through one and the same section of the sample in one direction, the local coercivity of the domain wall, H^+_{cw}, is high and reaches 20 - 30 Oe, whereas in the opposite direction, H^-_{cw} is much smaller (about 2 Oe). Accordingly, the shape of this wall is also different, depending on whether it had moved before from right to left (Fig. 2a) or from left to right (Fig. 2b). The picture of the magnetization reversal of the layer is reversed (Fig. 2, c, d).

The effect of the asymmetrical motion of the wall appears also when a shadow DS is present in the surface layer. The effect vanishes after ion polishing of the surface or after suitable heat treatment of the sample. However, even in this case one can observe an appreciable asymmetry of the local coercivity at individual defects.

It is possible that the singularities observed by us in the behavior of the domain walls are due to the manifestation of unidirectional anisotropy caused by exchange interaction between individual sections in the surface layer and the internal part of the crystal adjacent to this layer. It is likewise not excluded that the described effect is connected with the asymmetry of the distribution of the magnetization in the domain wall near the surface, and hence with differences in the magnetoelastic interaction with the defects.

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THERMOELASTIC EFFECT OF A FAST PARTICLE IN A SOLID

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We estimate the acoustic impulse produced in a solid by a gamma quantum of ultrahigh energy or by a relativistic multiply-charged ion. We discuss the possibility of acoustic registration of single gamma quanta and relativistic multiply-charged ions.

Considerable interest has recently been evinced in the registration of gamma quanta [1] and in the search for superheavy elements [2] among primary cosmic rays.

A procedure for acoustic registration of particles of ultrahigh energy was proposed in [3] and is applicable in principle also to the open outer cosmic space.

We present here theoretical and experimental estimates of the acoustic effects produced in two cases: a) by a cascading particle of ultrahigh energy, and b) by a relativistic multiply-charged ion. We shall discuss the possibility of their experimental observation.

Let the region of significant energy release in a track or in an electron-photon cascade be characterized by a radius R. During the time of the electron-ion relaxation, τ_0 N 10^{-10} - 10^{-9} sec, there is established in this region a temperature field that leads to thermal expansion of the medium and to excitation of cylindrical acoustic waves. The ensuring thermoelastic stresses are characterized by a bulk thermoelastic force

$$\mathbf{F}(\mathbf{r}, t) = -\Gamma \nabla P(\mathbf{r}, t), \qquad (1)$$

where Γ is the Gruneisen parameter of the target material and $P(\vec{r}, t)$ is the density of the released energy.

Using the wave equation for the longitudinal oscillations of the medium

$$\frac{\partial^2 \mathbf{u}(\mathbf{r},t)}{\partial t^2} - s_l^2 \Delta \mathbf{u}(\mathbf{r},t) = \frac{\mathbf{F}(\mathbf{r},t)}{\rho}, \quad (2)$$

we obtain for the maximum amplitude of the acoustic signal the approximate expression

$$u_{max} \approx \frac{F}{\rho} \frac{R^2}{s_l^2} \sqrt{\frac{R}{r}}. \quad (3)$$

Here s_ℓ and ρ are the longitudinal sound velocity and the density of the target material, while r is the distance from the axis of track or the cascade to the detector of the acoustic oscillations.

Let us estimate the acoustc effect due to an electron-photon cascade produce by a gamma quantum or by an electron of ultrahigh energy. The region where most cascade energy is released can be approximated by a cylinder of radius $R = 5\times10^{-3}$ to 3×10^{-2} cm [4] and of length L that can be calculated by using the cascade theory of showers. Allowance for the Landau-Pomeranchuk effect, which increases the photon range at ultrahigh energies [5], leads only to a shift of the entire cascade into the interior of the medium, without changing L appreciaably.

For a lead target and for $E_\gamma = 10^{14}$ eV we obtain, using (1) and (3), an acoustic displacement $u_{max} = (1.7 - 4.4)\times10^{-10}$ cm. Figure 1 shows the energy dependence of the amplitude of the acoustic signals for different materials at $r = 10^2$ cm.

The upper frequency limit of the acoustic signal is of the order of $\omega_{lim} \approx s_\ell/R = (0.6 - 4)\times10^7$ sec^{-1}. At such frequencies, the damping of the sound in the material should already come into play, so that the spectrum of the arriving signal will contain only harmonics with $\omega < \omega_{max}$, where ω_{max} is the maximum frequency that can be transmitted by the system. For real materials and at $r = 10^2$ cm we have $\omega_{max} \approx 3\times10^6$ sec^{-1}, so that in the case of a broadband detector with bandwidth $0 \le \omega \le \omega_{max}$ the recorded signal will be suppressed by a factor $\omega_{lim}/\omega_{max} \approx 2 - 10$. An analysis of the experimental capabilities shows that the minimum displacement that can be measured by the usual procedure is $u \approx 10^{-12}$ cm, so that we can observe an acoustic signal from a cascading particle of energy $E_\gamma = 10^{14}$ eV at distances $r \approx 2\times10^3$ cm.

Let us estimate the acoustic effect from an ultrarelativistic multiply-charged ion. The bulk thermoelastic force produced when a charged particle passes through the target material is of the order of

$$F = \frac{\Gamma}{\pi R_0^3}\left(\frac{dE}{dx}\right)_{ion} \quad (4)$$

$(dE/dx)_{ion}$ is the ionization loss of the particle per unit path. The track radius R of the charged particle is determined by the diffusion of the δ-electrons during the electron-ion relaxation time τ_0:

$$R_0 \approx \sqrt{D\tau_0}, \quad (5)$$

where D is the diffusion coefficient of the δ-electrons. An estimate of R_0 yields a value on the order of 10^{-4} cm. Assuming Z = 100, $\Gamma = 2.5$, $s_\ell = 2\times10^5$ cm/sec, $r = 10^2$ cm, and $(dE/dx)_{ion} = 2\times10^{11}$ eV/cm, we obtain for the maximum amplitude of the acoustic signal from a fast ion a value $u_{max} \approx 10^{-11}$ cm.

Measurement of the dependence of the amplitude of the acoustic signal on the energy E of the electron beam was performed with the 2-GeV linear accelerator of the Physico-technical Institute of the Ukrainian Academy of Sciences. The electron beam from the accelerator passed first through a magnetic analyzer and then through a secondary-emission monitor, which made it possible to measure the beam current, and was incident on a lead target measuring 20 × 10 × 5 cm. At the center of the

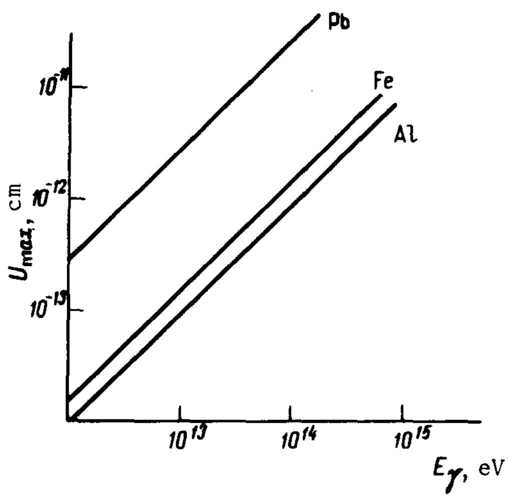

Fig. 1

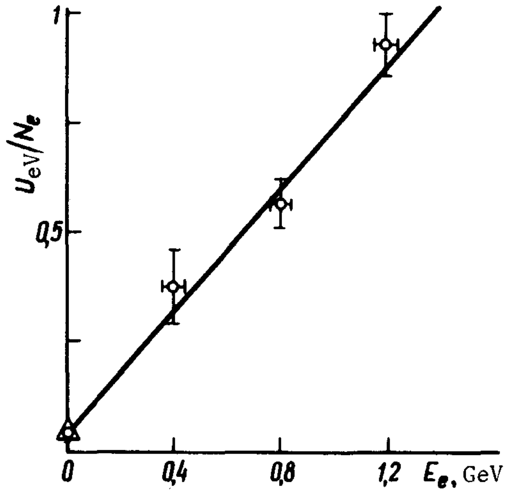

Fig. 2

small face of the target there is mounted a piezoelectric small-displacement detector made of TsTS-19 ceramic and having a sensitive area 6.75 cm^2. A beam of one microsecond duration and containing $N_e = 10^5$ - 10^7 electrons was incident on the center of the largest or middle face of the target, in which it excited acoustic oscillations. The electron-beam diameter d did not exceed 1 cm on the target surface. The electric signal from the piezoacoustic detector was amplified by a broadband transistor detector (mean working frequency approximately 0.3 MHz) and was applied through an emitter follower to the input of the internal amplifier of an IO-4 oscilloscope, the driven sweep of which was triggered by a synchronizing pulse from the accelerator. The measurements were performed at electron energies E_γ = 0.4, 0.8, and 1.2 GeV, so that the depth of the region of penetration of the cascade was much smaller than the linear dimensions of the target.

Figure 2 shows the energy dependence of the amplitude of the acoustic signal, normalized to one electron. The solid line in the figure represents the assumed linear relation $u/N_e \sim E_\gamma$. It is possible to establish with the aid of these measurements that the value of the minimum electron energy that can be detected with this apparatus is on the order of 10^{14} eV.

An experimental estimate shows that at $E_\gamma = 10^{14}$ eV and r = 10 cm, the acoustic displacements due to a single particle ar equal to the threshold of the apparatus $u \simeq 10^{-12}$ cm. On the other hand, a theoretical estimate yields displacements of the same order already at $E_\gamma \simeq 5\times10^{12}$ eV. The difference is due to the incoherence of the signals from different cascades of the beam at high frequencies, which leads to an appreciable suppression of signals with frequencies $\omega >> s_\ell/d_0$. Allowance for such a suppression of high frequencies in the experimental determination of the minimum detectable particle energy E_γ leads to good agreement with the theoretical estimate. We emphasize that the acoustic procedure of recording charged-particle tracks meets with the requirements stipulated in [2] for track apparatus.

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FAST SCALING IN THE MUTIPERIPHERAL MODEL

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The diligently pursued recent and numerous theoretical and experimental investigations have shown that the scaling hypothesis [1], according to which the inclusive spectrum $Ed^3\sigma/d^3p$ depends at high energies only on the momentum fraction $x = p/p_{max}$ carried away by the detected particle and does not depend on the total energy, is far from trivial.

Although the scaling hypothesis was originally advanced for asymptotic energies, it has turned out that in many cases it is approximately valid alread at E $\sim$ 10 - 30 GeV (fast scaling), e.g., in the reactions $p \to p$, $p \to K^+$, $p \to \pi$, or $\pi \to \pi$. We shall omit the labels of the targets, since principal attention will be paid to the fragmentation region. At E $\sim$ 10 - 30 GeV, when fast scaling is already present, almost the entire spectrum consists of fragmentations. At the same time, there are reactions, e.g., $p \to \bar{p}$ or $p \to K^-$, in which the tendency to scaling is observed only at ISR energies (E $\sim 10^3$ GeV) [2].