Acoustic registration of high-energy neutrinos

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We demonstrate the feasibility of registering high-energy neutrinos by means of an acoustic pulse from a hadron shower produced by the neutrino at large depths.

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The registration of high-energy neutrinos ($> 10^{13}$ eV), which are quite rare, calls for detectors of very large mass (10^9—10^{11} tons). The use of Cerekov light to register hadron showers from such neutrinos at large depths in the ocean[1] is difficult in practice because of the required large number of photomultipliers, in view of the short light-absorption lengths (~ 20 m).

The acoustic registration of such neutrinos proposed by us[2] is more effective, because of the larger sound absorption length (hundreds of meters and more), and makes it possible to increase appreciably the registration volume and make the apparatus cheaper. Radiation of ultrasound and hypersound from charged particles in dense media as a result of local heating, and production of microcavities in particle tracks was first considered in[3], and the use of this sound for particle registration was proposed. The sound radiation is due to the pulsed expansion of the medium as it becomes heated and to the production of cavities at points with large specific ionization—in the tracks of δ electrons, nuclear particles, stars, recoil nuclei, etc. The radiation of sound from the averaged expansion of the volume of the hadron shower $V \approx \pi a^2 L$, where $a \sim 2$—3 cm is the radius and $L \approx 5$ m is the length, at energies 10^{16} eV, can be estimated in the near wave zone ($L \ll R \ll L^2/\lambdabar = R^*$) in the case $\lambda \gtrsim 2a$. The pressure is

$$p_{\text{eff}} \simeq p_\omega \omega \approx \frac{\omega^2}{4\pi^{3/2}} \frac{a}{C} \frac{Q}{\sqrt{RR^*}} \approx \frac{A}{\sqrt{R}} \frac{Q}{L},$$

where α is the volume expansion due to the nuclear-ionization action, the fundamental frequency is $\omega \approx \pi c_s/a \approx 3 \times 10^5$ rad/sec, and Q is the energy released. For example, at $\alpha > \alpha_T \approx 10^{-4}$ deg^{-1} (thermal expansion of sea water at 4 °C) and at a heat capacity $C \approx$ cal/g-deg we obtain $p_{\text{eff}} > (Q[\text{eV}]/10^{16})(1/\sqrt{R})$ dyn/cm^2, which is sufficient for reception at $R \approx 100$ m. It is possible that $\alpha \gg \alpha_T$ because of the dissolved gases and the specific features of the ionizing action. The sound pressure from each cavity of volume v and of lifetime τ is $p_\omega > \rho \ddot{v}_\omega e^{i\Phi\omega}/2\pi R$, where $\ddot{v}_\omega = i\omega v_m/2\pi$ at $\omega\tau > 1$; and $\ddot{v}_\omega = -\omega^2 v_m \tau/2\pi$ at $\omega\tau < 1$. The radiation from the cavities can be hundreds of times larger than the thermoacoustic radiation, especially at low hydrostatic pressure.

Following the delivery of our report,[2] experiments were performed at Brookhaven and a sound pulse from a proton beam in water $p \approx 3 \times 10^{-14}$ (dyn/cm^2)/(eV/cm) was measured at a distance of 1 m. (The earlier paper[4] on the sound produced from radiation in liquid does not cite the absolute magnitude of the signal.)

This demonstrates the feasibility of recording neutrinos deep in a sea or a lake (such as Baikal) by a system of 10^5 hydrophones (for a mass 10^{11} tons). Since the radiation of the sound propagates in a disk with an axis that coincides with the shower axis (the difference is $\Delta\theta \sim \lambdabar_s/L$) we can determine the angle of arrival of the neutrino. The low noise level at large depth and the possibility of selecting the pulses by reduction facilitates the registration of the rare events.

With the aid of such an installation it is possible not only to register neutrinos with energy $> 10^{15}$ eV, produced in galactic and interstellar space ($\gtrsim 10^3$ events per year in a mass $\sim 10^{11}$ tons), but also to measure the cross section for the interaction of such neutrinos, by using the fact that the earth's sphere is not transparent[6] (by comparing the fluxes of the horizontal and vertical neutrinos); it is also possible to search for the W boson[7] in the resonant reaction $\tilde{\nu} + e \rightarrow W$ at $E_\nu \sim 10^{16}$ eV.

[1] H. Blood, T. Lerded, F. Reines, and A. Roberts, DUMAND, The ocean as a neutrino detector, Preprint Fermilab-Pub. 76/51/Exp. 1976.
[2] G. A. Askar'yan and B. A. Dolgoshein, Report on the 1976 DUMAND Summer Workshop Hawaii, September, 1976; Preprint Fiz. Inst. Akad. Nauk No. 160, 1976.
[3] G. A. Askar'yan, At. Energ. **3**, 152 (1957).
[4] V. D. Volovik and T. F. Popov, Pisma Zh. Tekh. Fiz. **1**, 601 (1975) [Sov. Tech. Phys. Lett. **1**, 270 (1975)]
[5] L. Sulak et al., Report on Fermilab DUMAND Meeting November 20, 1976.
[6] V. S. Beresinskii and G. T. Zatsepin Proc. of 1976 DUMAND Summer Workshop Hawaii, September, 1976.
[7] V. S. Berezinskii and A. E. Gazizov, Pis'ma Zh. Eksp. Teor. Fiz. this issue, p. 276 [JETP Lett. this issue, p. 254].