Some possibilities of detecting muons and neutrinos

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The possibilities are considered of deep-water muon and neutrino detectors using systems for Cerenkov-light gathering fiber optics, and semiconductor receivers.

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1. In 1960 Markov[1] proposed to detect high-energy neutrinos by placing deep in the ocean or in an underground lake apparatus that detects the products of neutrino reactions by the Cerenkov radiation of charged particles. Still earlier, Markov's idea of underground neutrino experiments was developed in[2], where the first estimates of the fluxes of atmospheric neutrinos and of the effects produced by them in soil were obtained. Similar estimates were obtained also in[3]. An additional analysis of the possibilities of underground neutrino experiments[4–6] has found them to be advantageous, and a few years later atmospheric neutrinos were registered.[7] Underground (underwater) neutrino experiments with large-mass detectors could turn out to be important not only for the solution of fundamental problems of weak-interaction physics, but also to gain astrophysical information.[1–4,8], for example, to detect high-energy neutrino fluxes produced in supernova envelopes.[2,4,8].

A project extensively discussed in recent years is the development of a deep-water muon and neutrino detector with mass 10^7–10^9 tons, with photomultipliers as the elements that register the Cerenkov light,[9,10] or having even a larger mass and using an acoustic method of registration of particles of energy higher than 10^3 TeV.[11] The main difficulty in the realization of the project of[10] is that $>3\times10^4$ photomultipliers with cathode diameters $\sim$25 cm are necessary. The boxes with the photomultipliers must furthermore withstand a pressure of hundreds of atmospheres.

2. At the same time, much progress has been made in recent years in the development of very sensitive semiconductor photoreceivers with planar silicon technology. The semiconductor photoreceivers have a large quantum efficiency ($>40\%$) and are capable of recording radiation $\sim10^{-12}$ W/cm^2 in the optical band.[12] Semiconductor

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receivers with such parameters, including an integration time ~ 500 nsec, can register Cerenkov radiation at a level $N_k \sim 10$ quanta.

Under deep-water conditions, the advantages of semiconductor photoreceivers over photomultipliers are obvious: they are capable of withstanding high pressure, and their energy consumption is smaller by many orders than of photomultipliers. However, the small area of the sensitive semiconductor photoreceivers ($\lesssim 3$ cm^2) makes it necessary to gather the light quanta either with mirrors or with special optical traps.

Let us consider some possibilities.

3. The optical quanta emitted by charged particles in water can be registered with a mosaic plate made of semiconductor photoreceivers and placed in the focus of a parabolic mirror. From the image on the plate we can determine the direction from which the light arrives and obtain information on the particle trajectory. The information can be transmitted ashore by modulating the signal from a shore-based laser (e.g., YAG : Nd, $\lambda = 1.06\ \mu$m) and transmitted over low-loss fiber optics. The module that records the radiation can be constructed in the form of a spherical surface made up of mirror cells.

In this scheme, the flux arriving at the focus of the mirror is

$$N \approx \frac{2 \cdot 10^4 d^2}{\pi l} \exp\left(-\frac{l}{L}\right) \text{ quanta} ,$$

where d is the mirror dimension, l is the distance from the mirror to the point of light emission, L is the path of the light in the water, and 2×10^4 quanta/m is the constant of Cerenkov radiation in water in the 0.4–0.7 μm band. In pure sea water or in the water of the Lake Baikal, $L \sim 40$ m. At $d = 1$ m and $l = 40$ m we have $N \approx 10^2$ quanta, i.e., $N > N_k$. If each mirror on the area of the semiconductor photoreceiver plate can receive radiation at angles $\pm 10°$ from the axis, then the module will contain ~ 120 mirrors. At $l = 40$ m, each module can receive radiation from a water mass $\sim (4\pi/3) l^3 \approx 2 \times 10^5$ tons.

The gathering of quasiparallel beams of light with the aid of mirrors in particularly effective if the studied particles move in definite directions. This raises hopes of being able to use systems of mirrors set at appropriate angles to study a muon-physics data (absorption curve, muon beams, etc.) at large depths, which the muons reach only at angles close to vertical.

4. Let us consider the possibility of gathering light with the aid of the so called light traps. These can be made of plastic or liquid with luminescent additives,[10] in which part of the isotropically reradiated light with large wavelength is trapped as a result of total internal reflection. We propose to use fiber optics with luminescent additives. The trap can be made in the form of a glass rod, with the filament ends gathered together and connected to the semiconductor photoreceiver. If it is assumed that the filaments trap ~ 0.1 of the isotropically radiated light and take into account the losses in the fiber optics, then the semiconductor receiver can gather ~ 0.03 of the light incident on a carpet-like light trap. In this case, at $N_k = 10$ it possible to register ~ 300 incident on the carpet. To product a setup equivalent to the 25-cm photomulti-

plier of the project of[10], the carpet area should be ~1 m², and the semiconductor photoreceiver area several cm². We note that by increasing the trap area we can greatly decrease the total number of modules of the detector (the module in this case consists of the light trap + the semiconductor photoreceiver).

One can also imagine a recording module made up of mirrors, of glass-fiber carpets of area ~0.1 m² located in its focus. The fibers of these carpets converge to a single semiconductor photoreceiver.

5. Is it possible to gather a sufficient number of light quanta in a glass fiber of area ~1 mm² and then transport them to a photodetector having the same area? To this end we propose to use double re-radiation, wherein the light gathered by the carpet is directed to a glass fiber of ~1 mm diameter with luminescent additives that shift the light into a longer-wavelengths, region in which the losses in the glass fiber are minimal. By way of estimate it can be assumed that the fibers gather ~0.001 of the light incident on a carpet of area ~10 m². The light gathered in this manner can be transported over considerable distances through a glass fiber to a detector of small area.

6. Further increase of the sensitivity of the semiconductor photoreceiver, for example by using III-V or SiC structures, and the increase of their area, will permit a substantial decrease in the number of modules in the detector variants considered above. Of course, the future development of inexpensive semiconductor photoreceivers of large area will make it possible to construct underwater muon and neutrino detectors without the use of systems for light gathering. It is not excluded, however, that the possibilities considered above can also be promising. At any rate, they should be borne in mind when underwater detection of muons and neutrinos is considered.

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