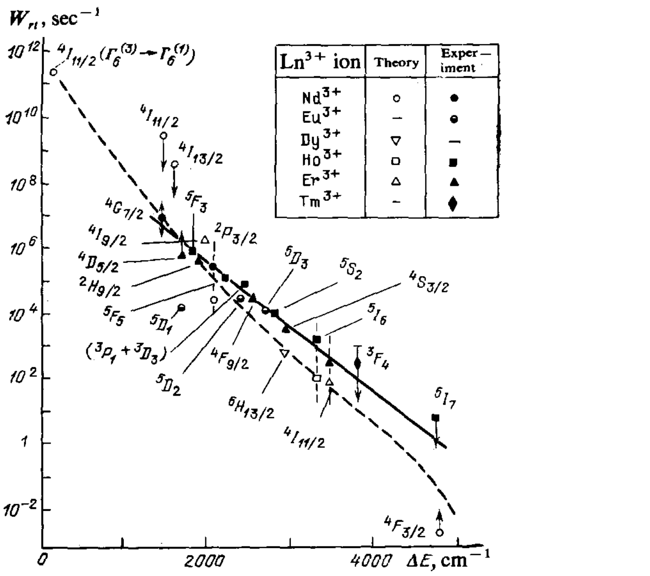


FIG. 3. Probability of radiationless transitions at $T = 0$ of $Ln^{3+}$ ions in a $YAlO_3$ crystal as a function of the gap energy. The experimental points are from Ref. 23.

surements are used to find the fraction of radiation associated with a given inter-Stark transition. Multiphonon radiationless transitions are most often studied on the basis of the dependence of their probability on the energy (the energy-gap law).[19] The empirical nature of these methods does not bring out the relation of the measured characteristics to the microstructure of the $Ln^{3+}$ center, knowledge of which is extremely important in the directed search for new laser media. For a number of years the theory of the questions enumerated above has been developed in many laboratories, and the first concrete calculations were made recently with our participation with application to the widely used laser crystals $Y_3Al_5O_{12}$ and $YAlO_3$ with $Ln^{3+}$ ions.

In a medium with an isotropic refractive index $n(\nu_{ij})$ the probability $A_{ij}$ of an inter-Stark transition is given by the formula

$$A_{ij}=\frac{32\pi^3 n(\nu_{ij})}{3hc^3}\nu_{ij}^3\sum_{\gamma}|\langle i|D'_{\gamma}|j\rangle|^2 \qquad (1)$$

where $D'_{\gamma}$ is the effective-dipole-moment operator. To determine this probability in Ref. 20 we calculated the local field at the $Nd^{3+}$ ion and the dipole polarization of the $Y_3Al_5O_{12}$ lattice in the field of an electromagnetic wave and calculated the parameters of the static and dynamic crystal fields. In Fig. 2 the results of this calculation are compared with experiment. For $W_{ij}$ between the levels of two multiplets the following expression was obtained in Ref. 21:

$$W_{ij}=\sum_{f}A_{nf}^2\int_{-\infty}^{\infty}e^{i\Omega_{ij}t}\,D_f(t)]^n\,dt, \qquad (2)$$

where $\Omega_{if}$ is the Bohr frequency of the transition, $A_{nf}$ is a factor describing the wave functions of the levels, and $D_f(t)$ is a parameter which takes into account the dynamic properties of the matrix-base in terms of which the phonon integral is written:

$$D_f(t)=\frac{\hbar}{6NSm_f}\int_0^{\max}\omega^{-1}\rho(\omega)\{[\bar{n}(\omega)+1]e^{i\Omega t}+\bar{n}(\omega)e^{-i\Omega t}\}\,dt, \qquad (3)$$

where $N$ is the number of unit cells in the crystals, $m_f$ is the mass of atom $f$ in the cell ($f = 1, \ldots, S$), $\bar{n}(\omega)$ is the Planck *rms* value of the phonon filling number, and $\rho(\omega)$ is the effective phonon density in the definition of Ref. 22. For $YAlO_3$–$Ln^{3+}$ the results of the calculation are summarized in Fig. 3.

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**G. A. Gusev and I. M. Zheleznykh.** *On the possibility of detection of neutrinos and muons on the basis of radio radiation of cascades in natural dielectric media (antarctic ice sheet and so forth).*

*1) Detectors of ultralarge size and problems of high-energy physics and astrophysics.* Detectors of extensive air showers (EAS) operating in our country and abroad have areas of several tens of km$^2$ (at Yakutsk, Havera Park, etc.), and the volumes of underground detectors exceed $10^3$ m$^3$ (the Baksan scintillation telescope, the IMB detector, and so forth). However, the study of elementary-particle physics of ultrahigh energies, the search for new phenomena and particles predicted by contemporary theories (superheavy magnetic monopole, supersymmetric particles, and so forth), and the problems of astrophysics require the construction of surface, underground, and deep underwater detectors of much greater areas and volumes. For example, on the basis of an idea advanced by M. A. Markov in 1960,[1] in recent years there has been active discussion and study of the possibility of a deep underwater muon and neutrino detector installations of volume $10^7$ m$^3$ or more (the DUMAND project).

In the report we discuss the possibilities of constructing radio detectors of ultralarge size (area about $10^4$ km$^2$, volume about $10^{10}$ m$^3$) which make use of the principle of detecting coherent radiation from extensive air showers and from showers produced by penetrating particles in the Earth, as proposed by G. A. Askar'yan in 1961 and 1965.[2] We discuss the detection of EAS in the energy region above $10^{19}$–$10^{20}$ and in particular we consider the possibilities of searching for inclined EAS from ultrahigh-energy neutrinos which arise in the Earth and develop in the Earth's atmosphere. We have shown the possibility of construction of radio detectors of muons and neutrinos which sense a volume of $10^9$–$10^{11}$ m$^3$ in ice sheets, with a small absorption for radio waves of the decimeter range; it is proposed to use the ice radio detector to study the flux of cosmic electron antineutrinos in the energy region of the W-boson resonance $E \approx 6\cdot 10^{15}$ eV (the reaction $\tilde{\nu}_e + e^- \to W^- \to$hadrons). We also discuss the detection of muons and neutrinos in a volume of water $\gtrsim 10^5$ m$^3$ with use of a system of dielectric waveguides.

*2) Search for EAS with $E > 10^{20}$ eV.* The questions as to whether there is an upper limit to the mass of elementary particles and what is the upper limit of the energy spectrum of elementary particles in cosmic rays have fundamental interest. If stable elementary particles of ultralarge mass ($M \sim 10^{23}$–$10^{28}$ eV) actually exist, then in their interactions hadrons and leptons (including neutrinos) with energies up to $10^{28}$ eV can be produced.[3] Detection of the radio radiation of extensive air showers and cascades in natural dielectric media is the most suitable method of detection of particles of superhigh energies.

Detection of the direct radio radiation of extensive air showers at $E > 10^{20}$ eV requires a large number of antennas of large area, since radio radiation has a sharp directivity (the diameter of the radio spot on the Earth is of the order of hundreds of meters), and the statistics are poor [$F(>E) \sim (E/10^{19}\text{ eV})^{-2}$ km$^{-2}$yr$^{-1}$sr$^{-1}$]. Therefore Gusev *et al.*[4] proposed to search for EAS with energy $\gtrsim 10^{20}$ eV by detecting radio radiation of EAS scattered in reflection from the Earth, and then from the *F*-layer of the ionosphere. In this case the area of the radio spot on the Earth may be $10^4$–$10^5$ km$^2$ and the distance between antennas can be chosen to be rather large, which permits a substantial reduction in the total number of antennas.

*3) Radio detector of neutrinos in the atmosphere.* Studies of extensive air showers in the energy region $10^{19}$–$10^{20}$ eV and above not only can assist in answering the question whether there is a cutoff of the spectrum of cosmic-ray protons by relict photons, but also will make it possible to search for inclined EAS from neutrinos coming out of the Earth. The point is that the length of the cascades from electrons or positrons produced by electron neutrinos or antineutrinos in the rocks or water of the Earth at $E \gtrsim 10^{19}$ eV is more than several hundred meters,[6] as a consequence of the Landau-Pomeranchuk-Migdal effect. Therefore in Ref. 5 we have proposed the possibility of detection of cascades which might be produced by neutrinos with $E \gtrsim 10^{19}$ eV near the surface of the Earth in the rocks or water, and development of which would continue in the atmosphere. The antennas, in particular, can be placed on the slope of a mountain, and the effective volume of such a detector can be as large as $\sim 10^{10}$ m$^3$ of rock or water.

The detection of $p\gamma$ neutrinos ($E \sim 10^{19}$ eV) on the basis of the optical radiation of the cascades traveling upward has been discussed by Linsley.[7]

*4) Radio detection of neutrinos in ice.* The possibilities of constructing a radio detector of cascades from muons and neutrinos, of volume $10^9$–$10^{11}$ m$^3$ of glacial or polar ice (in the antarctic, in Greenland, and so forth), with a relatively small number of antennas located on the surface of the ice were considered in Ref. 8. The possibility of ice as an appropriate medium for detection of radio radiation from cascades was first noted by G. A. Askar'yan in 1965.[2] Our suggestion is based on the fact that the absorption of radio waves in ice in the frequency range $10^8$–$3\cdot 10^9$ Hz is extremely small at low temperatures (at $-50$ °C at frequencies 0.5–1 GHz it amounts to $(4$–$12)\cdot 10^{-3}$ dB/m), which permits reception of weak radio signals from distance of the order of 1 km, and on the basis of the shape and size of the region of reception of Cherenkov radio radiation coming from the lower hemisphere from neutrino and muon cascades (the intersection of the Cherenkov cone with the surface of the ice) it is possible to determine the direction and energy of the cascade. In detection of cascades from depths 0.1–1 km the threshold energies of the cascades can be estimated as $10^{14}$–$10^{15}$ eV. By means of the proposed radio detector it will be possible to search for high-energy neutrinos of galactic and extragalactic origin, to investigate the absorption of neutrinos in the Earth and the generation of direct neutrinos, to study muons from horizontal EAS, to search for supersymmetric particles of high energies (photinos), and so forth. A neutrino radio detector can be used in geophysical experiments in which the Earth is illuminated by neutrino beams from accelerators.

Particular interest is presented by study of the reaction $\tilde{\nu}_e + e^- \to W^- \to$hadrons in the region of the W-boson resonance. The recently discovered W boson has a mass $\sim 80$ GeV and consequently a resonance energy $E_{\rm res} = M_W^2/2m_e \approx 6\cdot 10^6$ GeV. The resonance cross section is well known. Therefore a radio detector in ice of volume $\sim 10^{11}$ m$^3$ provides the possibility of determining the flux of electron antineutrinos in the energy region $6\cdot 10^6$ GeV from the atmosphere and from space.

*5) Underwater detection of radio radiation of cascades by means of waveguides.* If an electron-photon or hadron cascade in water passes through a system of dielectric waveguides, then it will be possible on the basis of the radio radiation in the waveguides to determine the direction and energy of the cascade. There is no atmospheric noise in the decimeter range under water. Therefore it is appropriate to consider the possibility of an underwater detector of cascades from muon and neutrinos of volume, for example, $10^5$ m$^3$ with waveguides of foil-covered polyethylene.

In conclusion we emphasize that the proposed radio detectors for EAS, muons, and neutrinos will permit increase of the area and volume of detection by several orders of magnitude in comparison with the parameters of existing installations, which will provide new possibilities for solution of the problems of high-energy physics and astrophysics.

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