Giant radio detectors of high-energy penetrating particles: thick ice with radio modules; movement of modules through ice by intense microwave beams

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The possibility of constructing giant detectors of high-energy particles in a simple way in thick ice, through the insertion and movement of receiving stations by remote control by means of intense microwave beams, is discussed. This new type of motion—beam ice melting—could be used in research in physics and geophysics.

The development of giant detectors of rare, high-energy penetrating particles (muons, neutrinos, etc.) in large volumes of natural media would be extremely desirable for the development of elementary particle physics, astrophysics, nuclear physics, and the theory of relativity.

A method for detecting such particles based on the radio emission from the cascades which they generate was proposed in Refs. 1 and 2. A moving net negative charge in the cascades was discovered.[1] This net charge results from an excess of electrons due to the Compton effect, δ-electrons, and in-flight positron annihilation. The excess of particles of one sign leads to a coherent amplification of Cerenkov or transition radio emission.

Such natural media as ice, rock, dry sand, etc., which have a low radio-wave absorption, have been proposed[1,2] as suitable layers of large-volume working media.

The high radio transparency of ice at low temperatures has been recognized since the late 1940s. Lamb[3] measured the loss tangent $\tan\delta = 10^{-4} - 10^{-5}$ at temperatures $T < -50°$ C, even at frequencies of 10^{10} Hz. Since the absorption length is given by $L_\alpha \approx \lambda'/\tan\delta$, a volume of up to a cubic kilometer could be monitored by a single module. Conditions of this sort are characteristic of both Antarctic and certain Arctic regions.[4]

Since the particles of greatest interest are those which are moving in directions which are nearly vertical, and the Cerenkov angles are not small, $\sin\theta = \sqrt{\varepsilon\beta^2 - 1/(\varepsilon\beta^2)} \approx \sqrt{\varepsilon - 1/(\varepsilon)} \approx 0.84$ (since the dielectric constant of ice is $\varepsilon \approx 3$), it would be desirable to have receiving and transmitting modules not only at the surface of the ice layer but also in its interior.

Let us examine the possibility of moving a module in deep ice in the beam of an intense microwave transmitter.

Motion of an object in ice in intense microwave beams. If a microwave source with an average power $P \approx 100$ kW, a radiating zone of size $D \approx 10$ m, and a radiation wavelength λ is at the surface of the layer, it would be possible to produce at a depth L

a focused beam with a spot size $a_F \simeq L\lambda/D \approx 30$ cm with the values $L \approx 3 \times 10^2$ m and $\lambda \approx 1$ cm. In this focus the power density would be $I \simeq P/\pi a_f^2 \approx 10^2$ W/cm^2.

If part of the lateral surface of the module had plates which absorbed microwave radiation, they would be heated, and they would melt the ice beside themselves. For example, a plate on top in thermal contact with the bottom could melt the ice above and below the module. This melting would result in a layer-by-layer displacement of liquid and a descent of the module (if the average density of the module were higher than the density of ice) or an ascent of the module (if its density were lower than the density of ice). The velocity of this vertical motion, v, can be estimated under the assumption $I \approx \rho\Lambda v$, where ρ is the density of the ice, and Λ is the latent heat of fusion of the ice. With $\Lambda \approx 100$ cal/g, for example, we would find $v \approx 3$ mm/s $\approx 3 \times 10^2$ m/day. Horizontal motion could be achieved with the help of sloping wings which would be deployed by a coded signal or by an asymmetric stimulus.

There is a simple way to insulate the internal receiving and transmitting apparatus from the intense radiation: by using cutoff waveguides (which do not allow the intense radiation to enter) or resonant absorbers, which absorb only at the frequency of the intense source.

There could also be motions associated with an asymmetric heating or with a heating which creates a pressure which is related not only to the pressure of the ice but also the boiling up of water and the formation of vapor, particularly during the application of periodic pulses.

It seems to us that this method might also simplify and promote the development of giant detectors, particularly in view of the severe conditions during operation at low temperatures.

Objects could also be moved through the interior of ice in microwave beams in geophysics experiments, to obtain samples of ancient ice and bottom soil, to collect meteors from the interior of ice, etc.

Incidentally, Zhelesnykh and his colleagues (see, for example, Ref. 5 and the bibliography there) have recently published papers concerning the detection of muons and neutrinos on the basis of the radio bursts from cascades. In those papers it was asserted that we have suggested the detection of showers, rather than of the particles which caused them. It was also asserted that ice was first proposed as a working medium in Ref. 5 (on page 569). Actually, we have proposed the detection of penetrating particles (Ref. 1, on Russian page 617), and we have called attention to specifically ice as a working medium (Ref. 2, on Russian page 990). The radio transparency of ice at low temperatures had been recognized long before this.

[1] G. A. Askar'yan, Zh. Eksp. Teor. Fiz. **41**, 616 (1961) [Sov. Phys. JETP **14**, 441 (1961)].
[2] G. A. Askar'yan, Zh. Eksp. Teor. Fiz. **48**, 988 (1965) [Sov. Phys. JETP **21**, 658 (1965)].
[3] J. Lamb, Trans. Faraday Soc. 42 A, Dielectrics, 238 (1946).
[4] V. V. Bogorodskiĭ *et al.*, Radioglaciology, Gidrometeoizdat, Leningrad, 1983.
[5] I. M. Zhelesnykh *et al.* in *Proceedings of Eleventh International Conference on Neutrino Physics and Astrophysics*, June 1984, Dortmund (ed. K. Kleinknecht), p. 568.

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