UPPER LIMIT FOR RELATIVISTIC DIRAC MONOPOLE FLUX AT MOUNTAIN HEIGHTS

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The flux of relativistic Dirac monopoles of various energies is estimated by means of above-ground and underground calorimeters at the Tyan'-Shan' high-altitude scientific station of the Lebedev Physics Institute. The monopole flux is $I \leq 2.5 \times 10^{-12}$ cm^{-2} sec^{-1} sr^{-1} at energies $E \geq 10^{13}$ eV and $I \leq 7 \times 10^{-13}$ cm^{-2} sec^{-1} sr^{-1} at $E \geq 3 \times 10^{13}$ eV.

THE negative results of the searches for Dirac's magnetic monopoles thermalized in the atmosphere[1,2], in rocks[3], or in meteorites[4] do not exclude the possible existence of monopoles of very high energy, the thermalization of which is possible only after they pass through an appreciable thickness of matter. Calculations by Goto[5] have shown that monopoles accelerated by galactic magnetic fields can have a relatively narrow energy distribution with an average energy 10^{20} eV. The searches for such monopoles can be carried out not only by extracting them from ferromagnetic minerals taken from great depths,[6] but also with large-transmission apparatus with good spatial resolution and with a system of pulse-height analysis. Burchuladze et al.[7] obtained an upper limit for the flux of monopoles at sea level, $I \lesssim 10^{-10}$ cm^{-2} sec^{-1} sr^{-1}. It can be deduced from the Raynes neutrino experiments (see[8] that the flux of monopoles at the depth $\sim 9 \times 10^5$ m w. e. is $I \lesssim 10^{-14}$ cm^{-2} sec^{-1} sr^{-1}.

As a byproduct of the work of the above-ground and underground calorimeters used in the comprehensive setup for the investigation of extensive air showers in the Tyan'-Shan' high-mountain Scientific Station of the Physics Institute of the USSR Academy of Sciences[9], it is also possible to obtain estimates for the flux of relativistic Dirac monopoles of various energies[1)].

A relativistic Dirac monopole passing through a calorimeter, being a particle having an increased ionizing ability, should cause the appearance of very characteristic events, namely the formation of large ionization bursts with amplitude $\sim 5 \times 10^3$ relativistic particles in all the rows of the chambers through which it has passed. This ionization should be separated in each row in not more than one or two chambers, being concentrated along the monopole trajectory. The monopoles that can be registered in underground calorimeters have higher energies than those that can be registered with above-ground calorimeters, since they must pass through 11 meters of ground to reach the underground laboratory.

In estimates of the flux of monopoles of lower energy, we used data obtained with an above-ground calorimeter, and for higher-energy monopoles we used the data of both calorimeters. We started here from the condition that the monopoles could be reliably separated from the "background" of the cascades observed in the calorimeters, and were identified under the condition that they cross not less than 15 rows of chambers in the above-ground calorimeter and not less than 8 rows in the underground calorimeter. The minimum energy of monopoles with a charge $\sim 3.3 \times 10^{-8}$ cgs emu, needed to traverse the atmosphere (~ 700 g/cm^2) and 15 rows of the above-ground calorimeter (~ 450 g/cm^2) amounts to 10^{13} eV; the minimum energy needed to traverse 8 rows of the underground calorimeter is 3×10^{13} eV. The transmission of the above-ground calorimeter under the indicated condition is 2.27×10^5 cm^{2}sr for an isotropic angular distribution of the monopoles, and the transmission of the underground calorimeter is 3.59×10^5 cm^{2}sr. The effective operating times of the above-ground and underground calorimeters (corrected for the dead time) were 495 and 822 hours, respectively.

The condition for the operation of the registration system was the appearance, in the chambers of the above-ground calorimeter, of ionization corresponding to the passage of more than 3000 relativistic particles through the chambers. In the underground calorimeter, the operating threshold for 514 hours of operation was ~ 600—700 relativistic particles and for 308 hours of operation about 5000 relativistic particles. During the operating time of the underground calorimeter, not a single case of ionization in eight or more rows of chambers was found. We also registered in the above-ground calorimeter events in which the ionization appeared in all 19 rows of chamber, but not a single event was observed in which the amplitude of the ionization bursts exceeded 5×10^3 relativistic particles in 15 rows in sequence. As a rule, a large energy release was observed in 4—6 rows of chambers, and in the remaining chambers the amplitudes of the bursts fluctuated between several dozen and several hundreds of particles, the ionization being usually distributed among a large number of chambers. Such properties are characteristic of purely nuclear cascades or of cases when cores of extensive air showers are incident on the calorimeter, and cannot be interpreted either as the appearance of a single monopole or as a monopole with shower accompaniment.

Starting from this, we can conclude that the flux of monopoles is $I(E \gtrsim 10^{13}$ eV$) \lesssim 2.5 \times 10^{-12}$ cm^{-2} sec^{-1} sr^{-1} and $I(E \gtrsim 3 \times 10^{13}$ eV$) \lesssim 7 \times 10^{-13}$ cm^{-2} sec^{-1} sr^{-1}.

From the results of the operation of the underground calorimeter we can set an upper limit of $\sim 1.1 \times 10^{-12}$ cm^{-2} sec^{-1} sr^{-1} for the flux of monopoles, even if their charge is $\sim 1/3$ that of the Dirac monopole (see[6]).

[1)]This possibility was pointed out to us by A. E. Chudakov.

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