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SEARCH FOR FRACTIONALLY CHARGED PARTICLES IN COSMIC RADIATION

(Proposal)

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An experiment recently performed at the CERN PS has given negative evidence for particles of charge $^1/_3\,e$ and $^2/_3\,e$ (quarks). A lower limit for their mass of about 2.5 GeV has been established and it is likely that more elaborate experiments along the same lines, will not improve this value to any appreciable extent.

Since the hypothesis which has given rise to this search has very many attractive features, and since, up until now, nothing appears to prevent "quarks" from having masses much larger than the available energy of the CERN PS, it seems interesting to investigate the feasibility of alternative ways of looking for quark production by particles of much higher energy. Cosmic rays offer the only available source of particles in the 1,000 GeV region.

The production of quarks by cosmic radiation has already given rise to some discussion at CERN and in particular two sources of information have already been considered:

a) The Millikan experiment gives a limit to the maximum number of quarks accumulated during the lifetime of the earth. The original experiment of Millikan was performed on 25 droplets of size, going from 23.4×10^{-5} to 12.2×10^{-5} cm radius. Assuming that no anomalous charge was observed*), the quark's density in the oil should be, at a 90% confidence level, less than 2×10^8 quarks/cm^3. Assuming 1 km of earth's crust, bombarded for 10^9 years, as the source of quarks that could have contaminated the oil, the experiment indicates a quark's production rate of less than about 1.5×10^{-3} quarks cm^{-2} sec^{-1}. This figure does not exclude appreciable production rates of massive quarks by the high-energy tail of the cosmic radiation. The primary cosmic-ray flux of energies greater than, say, 300 GeV is about 3×10^{-4} cm^{-2} sec^{-1} too small to give a detectable result in the Millikan experiment, unless quarks were produced in high-energy interactions with extraordinarily large multiplicities. Furthermore, it may be stressed that there is a considerable amount of uncertainty in evaluating the thickness of the earth's crust over which the quarks' mixing has occurred over a period of billions of years, and the possibility of non-uniform concentration throughout this volume**). This estimate has to be considered as giving only the order of magnitude of the expected effect.

b) Anomalous specific ionization of cosmic-ray particles. As is well known, a relativistic particle of charge $\frac{1}{3}$e or $\frac{2}{3}$e should ionize, respectively, $\frac{1}{9}$ and $\frac{4}{9}$ of a relativistic particle of unitary charge. A large abundance of such particles should not have escaped detection.

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*) It may be amusing to report the following statement, found in the Physics Textbook of Grimsehl (p. 47, Vol. 3): "Ehrenhaft thought he had found small particles (sub electrons) carrying charges smaller than the elementary charge. These results however appear to be incorrect, and to be explainable by the difficulty of determining the radius and specific gravity of these small particles satisfactorily."

**) The combination of quarks of opposite signs seems quite unlikely. In fact the negative ones would probably bind to a nucleus, in a sort of mesic atom; the positive ones could not approach the negative ones at thermal velocities, due to the repulsive force of the Coulomb field of the nucleus.

It appears that an accurate search for non-ionizing particles amongst the secondaries of the very high-energy cosmic-ray jets (mainly in emulsions) could provide a sensitive test of the validity of the quark idea. We do not know the conditions of study of these jets to appreciate the limits so obtained, and it is clearly worth while to re-examine the existing data from a new viewpoint *).

We suggest a simple experiment intended to search for non-ionizing cosmic-ray particles. After testing at sea level (CERN) we could bring the apparatus to high altitudes for the final data taking run.

Scintillator counters are used to detect particles of fractional charge by their reduced ionizing power. A helium discharge chamber is used to give the necessary redundant signature. The counting of the number of discharge columns will give the confirmation that the detected particle is less ionizing than the minimum.

The work done with these chambers has shown:

That in helium the number of discharge columns is of the order of 2.5/cm and is distributed according to a Gaussian law. A 40 cm chamber will allow a clear distinction between minimum ionizing particles (100 columns) and less ionizing particles. The primary ionization in helium at atmospheric pressure is 6/cm, as shown by cloud chamber experiments. Under these conditionsthe maximum number of columns expected from a charge $\frac{1}{3}$ particle is 26 (against 100) thus giving a good margin of safety. The chambers are used only to give additional evidence, the quantitive evidence coming from the counters. The experiment is planned as follows (Fig. 1).

Counters of 60×40 cm and 2.5 cm thick are used to measure the energy loss of the particles. With two 5 inch tubes on each side we expect

*) There are by now several hundred examples of jets of energies well above 10^3 GeV.

a full width at half height, less than 30%. To trigger our system, we accept particles with an energy loss below minimum by two standard deviations, i.e. at 0.7 of the average energy. We will thus trigger in 5% of the cases for each counter. The coincidence between four counters biased in the same conditions will lower the rate to about 10^5 of the total cosmic-ray flux (i.e. 1/hour).

The pulses from each counter go to an oscilliscope and a picture is taken giving the pulse height in each counter. Even with the resolution of 30% and for a particle of charge $^2/_3$, the probability that all four counters having been traversed by a minimum ionizing particle, giving rise to pulses compatible with 0.45 of the average height, is less than $(2 \times 10^{-4})^4 \sim 10^{-15}$. This shows that the triggering of the counters, if it exists, will be due to true physical effects probably connected with the low-energy γ rays and electrons present in the cosmic-ray flux.

For this reason a visual system is necessary to give additional information about the cause of the triggering. The discharge chambers giving quantitative and independent information about the ionization, seem to be suited to the experiment. Two extra thin-plate spark chambers of gaps larger than usual (3 cm) will serve the additional purpose of giving confirmation on the spatial position of the cosmic ray.

PARAMETERS OF THE APPARATUS

$\Omega \geq 1$ sterad.

Surface $\approx 60 \times 40 = 2400$ cm^2.

Total acceptance = > 2.4×10^3 cm^2 sterad.

Primary cosmic-ray flux at $E \geq 10^3$ GeV $\sim 10^{-5} \times$ cm^{-2} sterad^{-1} sec^{-1}

" " " " " $E \geq 10^4$ GeV $\sim 2 \times 10^{-7}$ cm^{-2} sterad^{-1} sec^{-1}

" " " " " $E \geq 10^5$ GeV (?) $\sim 5 \times 10^{-9}$ cm^{-2} sterad^{-1} sec^{-1}.

Total acceptance $\times$ cosmic-ray flux equals

$$2.4 \times 10^3 \times 10^{-5} \times 8 \times 10^4 = 1.9 \times 10^3 \text{ day}^{-1} \quad (E \geq 10^3 \text{ GeV})$$

$$2.4 \times 10^3 \times 2 \times 10^{-7} \times 8 \times 10^4 = 38.5 \text{ day}^{-1} \quad (E \geq 10^4 \text{ GeV})$$

$$2.4 \times 10^3 \times 5 \times 10^{-9} \times 8 \times 10^4 = 1 \text{ day}^{-1} \quad (E \geq 10^5 \text{ GeV}).$$

The effect is reduced primarily by two factors:

1) Attenuation of quarks through the atmosphere. Quarks are generally very energetic particles (if produced in very high-energy collisions) and it is likely they can undergo several 'nuclear' collisions before coming to rest. Assuming (pessimistically!) the same attenuation mean free path as protons in the atmosphere, one obtains attenuations of ~ 10 of the flux at 460 g/cm^2 atmospheric depth.

2) The quarks are travelling in the core of the jet and the ionization lost in the scintillators is masked by the accompanying "ordinary" particles. This effect is probably quite small for quarks produced in the upper atmosphere. We would like to assume a loss factor of two for such an effect.

A run of 20 days would then detect a quark's production rate of about

$$\frac{2}{2.4 \times 10^3 \times 8 \times 10^4} = 5 \times 10^{-9} \ \mathrm{cm}^{-2} \ \mathrm{sec}^{-1} .$$

which is several orders of magnitude better than the test provided by the Millikan experiment ($\sim 10^{-3}$ sec^{-1} cm^{-2}).

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