ABSORPTION PATH OF NUCLEAR-ACTIVE COSMIC-RAY PARTICLES

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Submitted to JETP editor May 17, 1966

J. Exptl. Theoret. Phys. (U.S.S.R.) 51, 1613—1616 (December, 1966)

The absorption path for the nuclear-active component of cosmic rays with energies up to 2×10^{12} eV was measured in aluminum and lead. The results of the measurements were used to determine the value of the exponent in the formula for the dependence of the nuclear interaction cross section on the atomic weight. The exponent is found to remain constant at 2/3 up to 10^{12} eV.

THEORETICAL investigations[1] predict changes in the transparency of the nucleon at high energies. This can lead to an energy dependence of the cross section for inelastic interaction between nucleons and nuclei.

Measurements with accelerators show that up to 30 BeV the cross section for inelastic interaction of protons does not vary with energy, and according to data obtained from cosmic rays the interaction path in air depends on the energy and decreases by 30% as the energy increases from 10^{11} to 10^{13} eV[2]. Other cosmic-ray investigations show that the inelastic-interaction path of nucleons with energy 10^{11}—10^{12} eV coincides with the path at 10^{10} eV.

The absorption path of nuclear active particles is connected with the interaction path and also with the inelasticity coefficient[3], and consequently measurements of its value in different substances and at different energies of interacting particles give information on the dependence of the interaction cross section on the energy and on the atomic weight of the substance.

We constructed, at an altitude 2000 meters above sea level (Nor-Amberd) an array (Fig. 1) containing an ionization calorimeter, two spark chambers (100 × 60 × 12 cm) placed over the calorimeter, and a hodoscopic system of Geiger-Muller counters[4]. The ionization calorimeter makes it possible to establish the operating threshold of the recording system and determine the energy spectrum of the nuclear-active component. The spark chambers together with the hodoscopic counters are intended to determine the character of the shower accompanying the high energy nuclear-active particle. The chambers are also intended for the study of nuclear interactions in the matter between them, but this study has so far been made difficult by the shower accompaniment.

Rows I and II of the Geiger counters are connected for coincidence with the ionization calorimeter. The event-registration system is triggered when a charged particle (particles) passes through these rows and produces in the calorimeter a local shower with a particle number higher than the threshold value.

The absorption path of the nuclear-active cosmic-radiation component was determined from the change in the number of operations of the ionization calorimeter on which was placed lead (178.0 g/cm^2) or aluminum (89.7 g/cm^2) alternately (with a regular period of approximately two days),

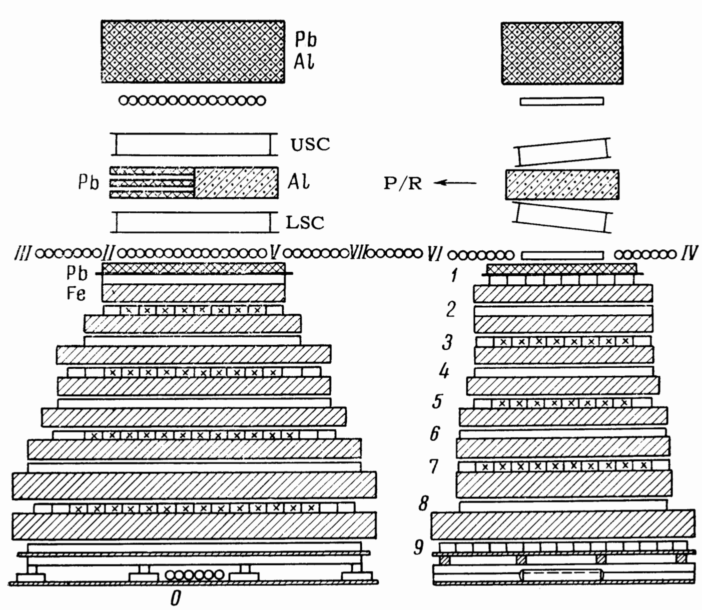

FIG. 1. Schematic diagram of the array in two projections: USC and LSC — upper and lower spark chambers, I — VII and 0 — rows of Geiger-Muller counters, 1 — 9 — rows of ionization chambers of the calorimeter, where the crosses denote chambers connected for coincidence, P/R — spark-chamber photorecorder.

Threshold (particle no.)	Counting rate for different absorbers			Path L, g/cm²		α
	N_{air}	N_{Al}	N_{Pb}	Al	Pb	
1500	3.66±0.12	3.02±0.09	3.03±0.09	388±84	780±146	0.66±0.14
3000	1.69±0.07	1.40±0.06	1.39±0.06	425±120	811±212	0.68±0.19
6000	0.67±0.02	0.56±0.03	0.55±0.02	431±128	798±208	0.70±0.19

thus eliminating errors connected with time-dependent factors. In this case the absorption path is $L = X_{mat}/\ln(N_{air}/N_{mat})$, where X_{mat} is the thickness of absorber above the array, N_{mat} is the counting rate in the presence of the given absorber, and N_{air} the counting rate in its absence.

The absorbers placed over the array had an area 112 × 82 cm and subtended completely the solid angle defined by the counter rows I and II (occupying an area 100 × 55 cm each) and by the calorimeter with average area (of the ionization chambers connected for coincidence) 140 × 100 cm. In spite of this, the shower accompaniment could give rise to cases when high-energy nuclear-active particles passing through the absorber over the array were registered. The contribution of the "imperfect" geometry was taken into account under the assumption that the angular distribution of the emitted particles is of the form $R(\theta) = R(0)\cos^6\theta$ [5], with account taken of the efficiency of oblique-particle registration.

The measurement results obtained after 4900 hours of operation are listed in the table, where thresholds of 1500, 3000, and 6000 particles correspond to the energies 4×10^{11}, 8×10^{11}, and 1.6×10^{12} eV, if we assume for the energy spectrum of registered particles the formula $N(E)dE = cE^{-3.0}dE$.

What is striking is the excessively large path values listed in the table. They cannot be attributed to measurement errors. A difficult-to-account-for error source is the imperfect geometry of the experiment, but an analysis has shown that their maximum value is smaller by several times than statistical errors listed in the tables, and these cannot lead to the observed excessively high absorption path.

The electron-photon component cannot lead to an increase in the absorption range and, to the contrary, is more likely to lead to a decrease. It must be noted, however, that in order for a discernible burst to be produced in the calorimeter, the electron-photon component must traverse not less than 25 t-units. As is well known, this much matter is sufficient to absorb practically all the electron-photon components. Consequently, its contribution to the registered bursts is negligible and cannot change the results.

The bursts produced by the high-energy muons can increase the absorption path. At the present time there are no reliable data on the fraction of bursts due to muons at 2000 meter altitude. Assuming that they amount to 10% of all the bursts registered by the installation[6], we find that the resultant overestimate of the absorption path is not more than 10% and cannot influence noticeably the results.

A more probable cause of the increase in the absorption path is the incidence of more than one high-energy nuclear-active particle on the array simultaneously. Assuming that their mean number is n, we obtained the dependence of the absorption range $L = \varphi(n)$. Figure 2 shows a plot of the experimentally obtained ratio N_{Al}/N_{air}, at a threshold of 3,000 particles. Knowing the average numbers of particles simultaneously incident on the array, we can determine with the aid of this plot the true value of the absorption path of the nuclear-active particles.

The obtained experimental values of the absorption path in lead and in aluminum were used to determine the dependence of the cross section of nuclear interaction on the atomic weight of the substance. The last column of the table shows the values of the exponent of this dependence, the form of which is

$$\sigma_{NA} = \mathrm{const}\cdot A^{\alpha}. \quad (1)$$

It was assumed here that the measured values of the path differ by a constant factor from the interaction path given by formula $L_{int} = A/N_A = \sigma_{NA}$ (N_A is Avogadro's number, σ_{NA} is the cross section for the nucleon-nucleus interaction).

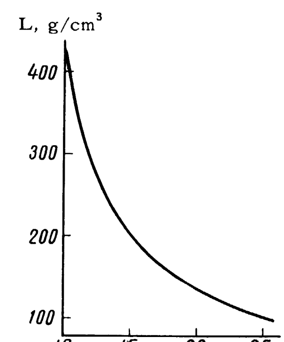

FIG. 2. Plot of absorption path L against the number of particles n simultaneously incident on the array.

The fact that this assumption is not very rigorous cannot introduce a noticeable error in the value of α, since the latter is determined by the ratio of the path in lead to the path in aluminum. For the same reason, the contribution of the muon bursts and lack of allowance for the imperfect experimental geometry are not significant in the determination of α, it is merely necessary that the lead and the aluminum absorbers have equivalent thicknesses and a similar geometrical arrangement. As already noted, this was effected, and the small difference was allowed for in the calculations.

Starting from the foregoing experimental data, we can state that with increasing energy the exponent in expression (1) does not increase noticeably, and remains equal to 2/3 up to $\sim 10^{12}$ eV. It must simultaneously be noted that for a final solution of the problem of the dependence of the cross section of the energy of the interacting particles, it is necessary to determine, besides the absorption path of the nuclear-active component at different energies, also the average number of high-energy nuclear-active particles incident simultaneously on the array.

The authors thank A. I. Alikhanyan for continuous interest in the work.

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Translated by J. G. Adashko
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