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Abstract

Full Text

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Dependence of the Emission Frequency of Shower Particles on the Atomic Number of the Disintegrating Nucleus

(Presented by Academician D. V. Skobeltsyn, January 16, 1957)

The method of submerged threads (^{1}) makes it possible to clarify the question of the frequency of appearance of shower particles as a function of the atomic number of the nucleus disintegrated by cosmic-ray particles in the stratosphere. Multilayer photographic plates, between whose emulsions aluminum and tungsten threads were clamped, were raised into the stratosphere on balloon sondes. For several hours such stacks of photographic plates with threads were exposed at an altitude above 28 km. Table 1 gives the distribution of stars according to the number of thin tracks ($7 > n_s \geq 1$) of secondary shower particles as a function of the total number of dense tracks N_h.

Table 1

Distribution of stars formed in tungsten and aluminum according to the number of thin (n_s) and dense (N_h) $= N_g + N_b$ tracks, from measurements in the stratosphere

		$N_h =$																							
Material	n_s	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18	20	21	23	24	25	28	34	37
Tungsten	0	1	1	4	8	11	7	7	1	1	1	1	1	1										1	
Tungsten	1						1	1		1	2			1											
Tungsten	2								1	1		1	1												
Tungsten	3								1			1				1	1								
Tungsten	4									1			1			1			1		1				
Tungsten	5														1		1					1	1		
Tungsten	6																	1							1
Tungsten	Total	1	1	4	8	11	8	8	3	4	4	3	3	1	1	2	2	1	1		1	1	1	1	1

Total: 71 stars

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		$N_h =$										
Material	n_s	2	3	4	5	6	7	8	9	10	11	12
Aluminum	0	1	6	9	17	7	8	2	2	1	0	0
Aluminum	1			1	1	2	2	1	2	1	1	1
Aluminum	2					1	1			1		
Aluminum	3											
Aluminum	4										1	
Aluminum	5							1				
Aluminum	6											1
Aluminum	Total	1	6	10	18	10	11	5	4	3	2	1

Total: 72 stars

From the data in the table it follows that shower particles appear much more often in stars formed in tungsten than in aluminum. In the case of tungsten, for one collision of an incident particle with a nucleus there are 1.13 ± 0.12 shower particles, whereas in aluminum there are only 0.48 ± 0.08. In other words, the probability of formation of shower particles is more than twice as large in the collision of cosmic-ray particles with a tungsten atomic nucleus as with an aluminum atomic nucleus.

It is usually assumed (^{2}) that the number of shower particles is equal to the number of generated π-mesons. Consequently, considerably more π-mesons are produced in each collision in tungsten nuclei than in aluminum nuclei. This means that π-mesons are generated not only in a single collision of the incident particle with a nucleon of the nucleus, but also in subsequent collisions.

In (^{3}) it was shown that the probability of production of slow (stopping in the photoemulsion) π-mesons in lead nuclei is approximately

but 5–7 times greater than the probability of their production in carbon nuclei. Comparison of the results of work (^{3}) with the data of the present work leads to the conclusion that fast π-mesons are also generated in tungsten nuclei with greater probability than in aluminum; however, the probabilities of their generation in these elements differ only by a factor of 2. It follows from this that the probability of generation of slow π-mesons depends much more strongly on the atomic number of the splitting nucleus than does the probability of generation of shower particles.

From these data it follows that the mechanism of production of slow π-mesons, as well as of π-mesons identified as shower particles in stars with $n_s < 6$, should be explained on the basis of the multiple-production theory.

If the energy of shower-producing particles is estimated from the number of thin and gray tracks according to the empirical data of work (^{4}), then $E_{\text{min}} \approx 10$ Bev when $n_s = 6$. Hence we conclude that at least up to an energy of 10 Bev the probability of formation of π-mesons in tungsten is greater than in aluminum.

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According to data obtained at the cosmotron and bevatron in the energy region $1 \div 6$ Bev, the mean multiplicity is almost independent of the atomic number of the target nucleus. It is possible that, with increasing energy of the incident particle, an ever larger number of nucleons of the target nucleus will take part in meson generation, which will lead to some (apparently not very strong) dependence of the number of emitted mesons on the atomic number of the nucleus. However, the energy region in which Fermi' s statistical theory (^{5}) is applicable to the case of collision of a nucleon with a group of nucleons has not yet been clarified.

In the region of higher energies, all nucleons that lie in the path of the incident particle take part in meson generation, and only in this case is the picture (^{6}) of a collision of a particle with a "tube" of nucleons of the target nucleus valid. It follows from these considerations that comparison of the data presented with the theory of the multiple process of meson production is not possible at present.

If it is assumed that the number of shower particles is proportional to the mean number of collisions of the incident particle with nucleons during its passage through the nucleus, then
$\bar{n}_W/\bar{n}_{\mathrm{Al}} = (A_W/A_{\mathrm{Al}})^{1/3} = 1.9$, which is quite close to the experimentally observed value. If delta-nucleons of the target nucleus also participate in the formation of shower particles, then the indicated ratio should be of the order of (^{7})
$2^{(A_W^{1/3} - A_{\mathrm{Al}}^{1/3})/1.5} = 3.4$. The experimental result cited above, therefore, lies between $(A_W/A_{\mathrm{Al}})^{1/3}$ and
$2^{(A_W^{1/3} - A_{\mathrm{Al}}^{1/3})/2}$. In other words,
$(A_W/A_{\mathrm{Al}})^{1/3} \leq (n_W/n_{\mathrm{Al}})_{\mathrm{exp}} < 2^{(A_W^{1/3} - A_{\mathrm{Al}}^{1/3})/1.5}$, i.e., delta-nucleons of the target nucleus may also participate, in small numbers, in the formation of shower particles in stars with $n_s < 6$.

We hope that the further investigation, continuing in our laboratory, of the interaction of cosmic-ray particles with atomic nuclei of heavy (W) and light (Al) elements may provide important information on the mechanism of production of fast π-mesons (shower particles) as a function of the atomic number of the splitting nucleus. In this work we used the above-mentioned method of submerged threads, the advantage of which is obvious, especially for the investigation of nuclear disintegrations with a small number of shower particles. It has an advantage over the emulsion-chamber method in the case of studying wide showers, since with the latter the majority of shower-particle tracks will be missed during scanning and, consequently, will escape the attention of the investigator. This is connected with the fact that in an emulsion chamber the showers themselves are located along streams of thin tracks, while the tracks of particles going at a large angle to the stream axis are recorded with great difficulty. In addition, many details of the nuclear disintegration remain unclear (the number of black and gray tracks and their composition, etc.).

Along with determining the frequency of the appearance of shower particles as a

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Fig. 1

Figure 1: Fig. 1

function of the atomic number of the nucleus, we also investigated a number of other problems that provide important information on the mechanism of nuclear disintegrations by cosmic-ray particles.

For example, the investigation showed that the energy spectrum of recoil nucleons emitted in the disintegration of tungsten nuclei differs substantially from the energy spectrum of recoil nucleons emitted in nuclear disintegrations of aluminum.

Fig. 1. **I** –mean number of gray tracks (protons with $E = 30 \div 500$ MeV) per star $\bar{N}_g$ as a function of the number of dense tracks $\bar{N}_h$: *a* –tungsten; *b* –aluminum; *v* –emulsion. **II** –mean number of gray tracks $\bar{N}_g$ per star, corresponding to separate intervals of the number of dense tracks N_h. For clarity, the stars are divided into groups depending on N_h: $3 \div 10$; $3 \div 13$; $10 \div 30$; $14 \div 37$: *a*–tungsten, stratosphere; *b*–tungsten, mountain altitude; *v*–aluminum, stratosphere.

It turned out that in the first case low-energy recoil protons (below 100 MeV) predominate; in the second case there are more high-energy protons (above 100 MeV) than in the first case, and the result obtained remains valid in the region of very large energy releases. It should be pointed out that such a result is explained better and more naturally if one assumes individual and independent interactions of the incident nucleon with the nucleons of the target nucleus.

Comparing the experimental data (the number of stars formed in wires of various elements) obtained from mountain experiments (near Alma-Ata) and from flights into the stratosphere at the latitude of Moscow, one can conclude that the "transparency" (in the sense of the formation of stars with $N_h \gg 3$) with respect to the tungsten nucleus, the nuclei of aluminum and copper atoms, decreases as the mean energy of the star-forming particles increases from 600 to 3000 MeV (the mean energies of the star-forming particles at mountain altitude and in the stratosphere, respectively), and in the region of 3000 MeV the nuclei are "opaque." Such a result does not contradict the data obtained in the laboratory (8) when various elements were irradiated with protons accelerated up to an energy of 1400 MeV.

Analysis of the distribution (by rays) of stars formed in various elements at mountain altitudes (4000–4400 m) and of the distribution of stars formed in these same elements in the stratosphere leads to the conclusion that the number of fast protons emitted in this process, with energies from 30 to 500 MeV, will increase with increasing atomic number of the disintegrated nucleus, and also with increasing energy of the star-forming particles. In other words, the number of gray tracks per star grows with increasing energy of the star-forming particles more strongly in stars formed in tungsten than in stars formed in aluminum

(Fig. 1). This experimental fact is in better agreement with the picture of the development of cascade collisions of nucleons inside the nucleus.

In conclusion, we note that the data of the present work cannot be compared directly with the data of other works, since the method used here had not previously been applied to clarifying the question of the dependence of the yield of shower particles on the atomic number of the target nucleus.

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