Momentum Spectrum of the Cosmic Radiation and the Positive Excess in the (0.1–2.5) x 10^9 ev/c Range at an Altitude of 3250 m

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The spectrum of the hard component and the spectrum of unfiltered cosmic radiation have been measured at an altitude of 3.25 km with the aid of magnetic analysis. The spectral distribution of the positive excess was obtained and the contributions of the proton and meson components to the magnitude of the excess have been evaluated.

IN recent years the spectrum of the charged part of the cosmic radiation at mountain altitudes has been studied in a number of works[1-4]. In the present article, momentum spectra of the cosmic radiation which were measured during 1949-52 in the small magnetic spectrograph of the Alagez Cosmic Ray Laboratory are considered. A detailed description of the apparatus and of other similar spectrographs has already been given briefly elsewhere[5,6], so that we can limit ourselves to a schematic diagram showing the arrangement of the counters in the telescope and of the absorbers (Fig. 1).

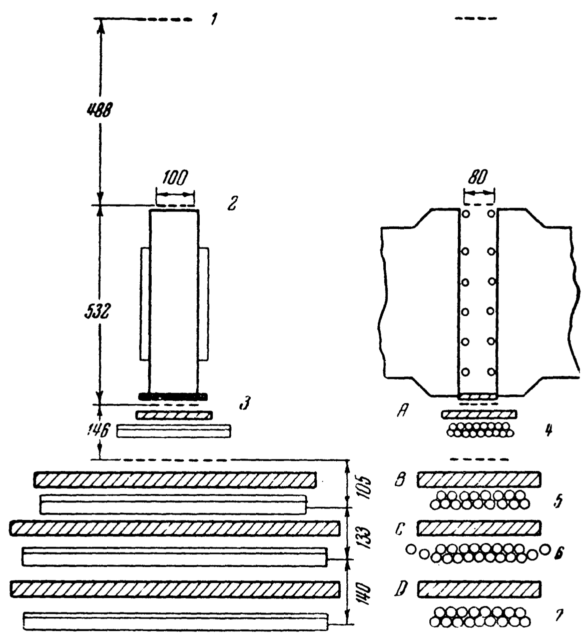

FIG. 1. Scheme of the apparatus 1–7–rows of counters: A, B, C, D– absorbers, measured in millimeters.

In our apparatus the total error in a momentum measurement due to the geometrical dimensions of the counters of groups 1, 2 and 3 (indicated by dashed lines in Fig. 1) and scattering in their walls is such that momenta in the range (0.1–0.2) x 10^9 ev/c is measured with a relative error of about 25%.

In what follows we shall consider spectra of the unfiltered rays, consisting of electrons, mesons and protons, and spectra of the hard component, from which electrons are excluded.

1. SPECTRA OF THE UNFILTERED RAYS

The spectra of the unfiltered rays were obtained in experiments where no special absorbers were used over the magnetic spectrograph or between the counter trays of its telescope.

Let us consider the spectra of the unfiltered rays (Table 1 gives the distribution of particles according to intervals of deviation in the magnetic field. The deviation distance δ (cm) for a momentum pc (ev) is obtained from the formula $\delta = 1.7 \times 10^9/pc$, where 1.7×10^9 ev-cm is a constant of the apparatus.

TABLE I

Deviation interval δ in cm	Average momentum in 10^8 ev/c	Correction for the "aperture ratio"	Spectrum of the infiltered rays		Spectrum of the hard component	
			N_+	N_-	N_+	N_-
$\delta < 0,5$			949		2273	
0,5— 1,0	22,7	1,00	669	409	1569	999
1,0— 1,5	13,6	1,02	500	301	188	747
1,5— 2,0	9,7	1,03	367	207	785	508
2,0— 2,5	7,6	1,05	303	152	538	313
2,5— 3,0	6,2	1,06	218	121	321	246
3,0— 3,5	5,2	1,09	163	89	256	197
3,5— 4,0	4,5	1,11	133	58	140	134
4,0— 5,0	3,8	1,17	165	101	216	166
5,0— 6,0	3,1	1,25	120	69	94	82
6,0— 8,0	2,4	1,46	121	99	89	64
8,0—10,0	1,9	1,85	70	77	14	7
10,0—12,0	1,5	2,44	52	49	4	4
12,0—14,0	1,3	3,40	30	31	5	2
14,0—15,0	1,2	4;60	7	9	2	0
$\delta > 15,0$			12	16	0	2

The third column of the table gives the correction for the "aperture ratio" of the apparatus. The momentum spectrum obtained after the momentum interval is shown in Fig. 2.

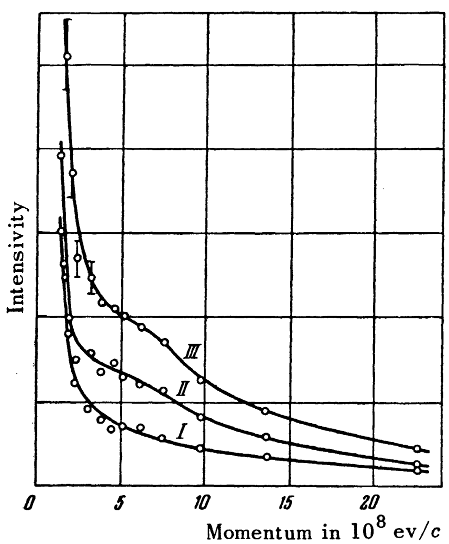

FIG. 2. Momentum spectra:
I—negatively charged
II—positively charged,
III—sum of both spectra.

From the spectra shown it is clearly evident that the spectrum of the negatively charged particles has two components, an electron component, which decreases rapidly with increasing momentum, and a meson component extending to the end of the spectrum, while the spectrum of the positively charged particles differs sharply from it by the presence of a bulge in the momentum region $(3–10) \times 10^8$ ev/c which occurs because of the presence of a third component. It is natural to suppose that this component consists of protons. The difference just described in the spectra of the positively and negatively charged particles was noted also in Ref. 2, where the work was carried out at an altitude of 3.4 km.

The difference between the two spectra can be described in terms of the magnitude of the positive excess $k = N_{\pm}/N_-$ in the various regions of the spectrum. In order to obtain the magnitude of k with sufficient statistical accuracy, it was determined for eight rather large intervals of momentum. The distribution of the positive excess through the spectrum is shown in Fig. 3 (curve A). From a consideration of this curve we may make the following conclusions:

1. For momenta of less than 2×10^8 ev/c the positive excess, to with the limits of the statistical accuracy of the observations, does not occur. That is, $k \approx 1$. Just such a value of k

would, in fact, be expected for the electron-positron part of the spectrum.

2. The positive excess arises in the neighborhood of a momentum of 2×10^8 ev/c and increases rapidly, reaching a maximum value, approximately $k = 2$, near a momentum value of 5×10^8 ev/c. An approximate result was obtained in Ref. 1, where the positive excess in the momentum region $(0.3-0.7) \times 10^9$ ev/c was found to be equal to 2.50 ± 0.14 at an altitude of 3.4 km. We note that the emergence and rapid growth of the positive excess begins in the neighborhood of the minimum momentum of the protons stopped by the apparatus (the total thickness of the walls of the counters, equal to 0.2 mm of Cu, corresponds to a proton momentum of $2.4 \times$ 2.4×10^8 ev/c). This indicates that in the region of small momenta the positive excess arises as soon as protons begin to appear among the particles counted.

3. With a further increase in momentum ($p > 5 \times 10^8$ ev/c) the positive excess decreases slowly, approaching a constant value of about 1.5–1.6. This is in agreement with the date of Ref. 1 and 2, where, under conditions analogous to ours, it is found that $k = 1.50 \pm 0.05$ and $k = 1.68 \pm 0.06$, respectively.

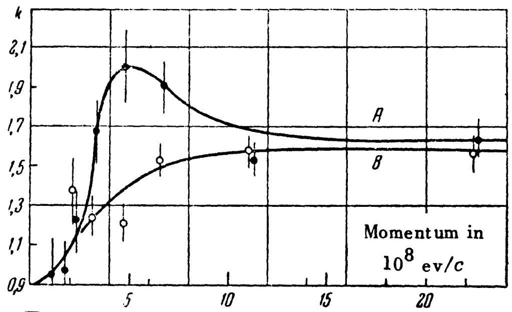

FIG. 3. Distribution of the positive component
A–unfiltered radiation
B–hard component.

2. ABSORPTION OF THE POSITIVE EXCESS

A series of measurements was made in an attempt to determine whether all of the positive excess observed in the spectrum could be explained in terms of the presence of protons. The experiments carried out consisted of the measurement of the magnitude of the positive excess when lead and graphite absorbers which should have cut off a significant part of the proton component (experiments 3, 4 and 5, see Table 2) were placed over the entire apparatus. In experiment 3, a 10 cm layer of lead was placed over the apparatus, in experiment 4, a 20 cm layer of lead was used, and in experiment 5, a 40 cm layer

TABLE II. Absorption of the positive excess

1	Scheme of the experiment	**1** **2** **3** **4** **5**	**1** **2** 0,8 cм Pb **3** 1,1 cм Pb **4** **5**	10 cм Pb **1** **2** 0,8 cм Pb **3** 1,1 cм Pb **4** **5**	20 cм Pb **1** **2** 0,8 cм Pb **3** 1,1 cм Pb **4** **5**	40 cм C **1** **2** 2,4 cм Pb **3** 3,0 cм Pb **4** **5**
2	Number of the Experiment	1	2	3	4	5
3	P_{min} (10^8 eV/c)	—	—	8,3	10,8	8,5
4	N_+	1870	11914	3260	1295	1673
5	N_-	1288	8411	2350	948	1256
6	$k = N_+/N_-$	$1{,}45 \pm 0{,}05$	$1{,}42 \pm 0{,}02$	$1{,}39 \pm 0{,}03$	$1{,}37 \pm 0{,}06$	$1{,}33 \pm 0{,}05$

Note. The boldface numbers indicate the rows of counters in the apparatus. The horizontal bars signify absorbers placed over the counters. The first column gives the number of the line in the table.

or graphite was used. In order to pass through these absorbers, the protons must possess minimum momenta of 8.3, 10.8 and 8.5 × 10^8 ev/c, respectively. Hence the protons having smaller momenta before their entrance into the absorber must disappear from the spectrum. As for the protons with larger momenta, nuclear interactions in the upper filters must lead to a significant weakening in their intensity. Hence if the entire positive excess is composed of protons, then one would expect it to decrease strongly in experiments 3, 4 and 5.

For an inspection of the results of the experiments, let us turn to Table 2, which gives the scheme of the experiments and its number (lines 1 and 2), the minimum momentum of a proton passing through the upper filter (line 3), the number of positively and negatively charged particles in the complete spectrum which pass through the apparatus without multiplication (lines 4 and 5), and the magnitude of the positive excess (line 6).

Consideration of the data of Table 2 allows us to make the following conclusions:

1. The positive excess has much greater value in the spectrum of the filtered rays (k = 1.45 ± 0.05).
2. As the layer of material above the apparatus is the magnitude of the absorption of the positive component decreases correspondingly from the value k = 1.42 ± 0.02, when there is no material above the apparatus, to a minimum value 1.33 ± 0.05, when a 40 cm layer of graphite is placed over the apparatus.

The results obtained serve as an argument to show that the observed positive excess cannot be explained by protons alone, and that the positive excess occurs also in the meson part of the spectrum. The measurement of the spectrum of the hard component has allowed the separation of the mesonic and protonic parts of the positive excess.

3. SPECTRUM OF THE HARD COMPONENT

In the measurement of the spectrum of the hard component, measures were taken, as carefully as possible, to get rid of electrons. The arrangement of the absorbers in this experiment is shown in Fig. 4. The hard component consists of particles which have passed without multiplaction (recorded by rows of counters 3 and 4) through absorbers A, B, C, and D, the total thickness of which is equivalent to 8.6 cm of lead. The number of electrons among such particles must be very small: the probability of cascade multiplication is near unity, but the electrons which have not undergone multiplication will be absorbed in the layers A, B, C and D and will not enter into the hard component. The measured spectrum of the hard component is shown in Table 1 and Fig. 4. A comparison of this spectrum with the spectrum of the unfiltered radiation (Fig. 2) shows that the electron component, the principal part of which belongs to the momentum region below (3–4) (3–4) × 10^8 ev/c, is actually missing from it.

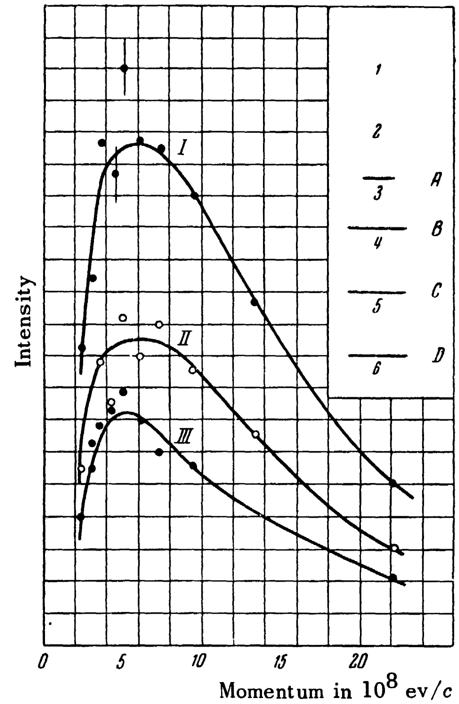

FIG. 4. Spectra of the hard component. I–total radiation, II–positively charged particles, III–negatively charged particles. A = 1.5 cm Pb, B = 5.1 cm Pb, C = 4 cm C, D = 4 cm C.

Considering the spectrum from the point of view of the presence of protons, it should be kept in mind that protons whose path lenghts are less than 8.6 cm of lead, (i.e., protons with momenta less than 7.7 × 10^8ev/c) are absent from it. In connection with this, it is of interest to consider the positive excess for this spectrum, and to compare it with the positive excess for the spectrum of the unfiltered radiation. The positive excess in the spectrum of the hard component is shown in Fig. 3 (curve B). A comparison of curves A and B shows clearly that a significant part of the positive excess in the spectrum of the unfiltered radiation in the momentum region (2.4–7.7) × 10^8 ev/c is connected with protons. Since protons in the momentum interval (2.4 × 10^8 ev/c are not present in the spectrum of the hard component (R > 8.6 cm Pb), then the positive excess in this momentum interval is composed only of mesons. The magnitude of the purely mesonic part of the positive excess can be determined. 1105 positively charged particles and 883 negatively charged particles were counted in the interval $(2.4-7.7 \times 10^8$ ev$/c$. This corresponds to a positive excess $k_\mu = 1105/883 = 1.25 \pm 0.06$.

4. INTENSITY OF THE PROTON COMPONENT

A knowledge of the positive excess inherent in the meson part of the spectrum allows one to make a rather accurate estimate of the intensity of the proton component. For this purpose one must take as a measure of the number of protons the difference between the first and second spectra, the ordinates of which are increased by the magnitude of the positive excess at any given point of the spectrum where the meson spectrum is present. In order to make such an estimate it is necessary to know the magnitude of k_μ. The average value of k_μ in the momentum interval $(2.4-7.7) \times 10^8$ ev$/c$ was determined above to be equal to 1.25 ± 0.06. Although the dependence of k_μ on the momentum is unknown, the value obtained and the totality of the known experimental results on the positive excess in the meson component indicate that for the momentum interval in question the magnitude of k_μ changes very little, being within the limits 1.2 to 1.3 and close to 1.25. We shall determine the number of protons in the spectrum of the unfiltered radiation, starting from this magnitude of the mesonic positive excess. We will concern ourselves with protons the momentum of which is greater than 3.4×10^8 ev$/c$, that is, protons which are deviated less than 5 cm in the magnetic field. The number of such protons is given by the formula

$$N_p = \sum_i N_+^i - k_\mu N_-^i,$$

where the summation is taken over all deviations less than 5 cm (Table 1). Values of N_p calculated for k_μ assumed equal to 1.00, 1.25 and 1.30, respectively, are given below in percent of the total intensity registered by the apparatus.

k_μ	N_p
1,00	22 ± 1
1,25	14 ± 1
1,30	11 ± 1

We see that the intensity of the proton component lies within the limits of 11–14% of the total intensity. In order to obtain the intensity of the protons in the hard component it is necessary to increase these numbers by 18%. Thus the proton intensity lies within the limits of 13–17% of the intensity of the hard component. This result is very close to that obtained in Ref. 1–4.

CONCLUSIONS

1. From the form of the spectra of the unfiltered radiation, it follows that, besides the electron and meson components, a notable amount of proton component is also present at an altitude of 3250 m. The existence of an intense proton component manifests itself in the measured spectra first of all in the fact that the positive excess for the total radiation is equal to 1.50 ± 0.02, while at sea level, where the intensity of the proton component if less by an order of magnitude, the positive excess lies within the limits 1.2–1.3.

2. In the region of momenta greater than 8×10^8 ev$/c$, where the main portion of the particles counted by the apparatus are located, the positive excess changes very little with momentum, and its magnitude is close to 1.5. The positive excess is close to unity in the region of small momenta in the spectrum of the unfiltered rays. This is explained by the fact that the overwhelming majority of particles in this region of the spectrum are electrons and positrons.

3. In the intermediate region of momenta, from 2 to 8×10^8 ev$/c$, the positive excess increases rapidly, reaching a maximum of about 2 at $k \sim 5 \times 10^8$ ev$/c$, and then decreases to 1.5. The large value of the positive excess in this region is explained by the presence of a significant number of protons.

4. The influence of the protons on the magnitude of the positive excess is clearly manifested in the spectrum of the hard component from which all protons with momenta $(2.4-7.7) \times 10^8$ ev$/c$ have been removed. Thus it has been possible to determine the purely mesonic positive excess in this region of the spectrum. It turns out to be equal to 1.25 ± 0.06.

5. Knowing the positive excess of the meson component, we may estimate the number of protons in the momentum interval $(3.4-25) \times 10^8$ ev$/c$, which we are investigating. It lies within the limits of 13–17% of the total intensity of the hard component.

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Energy and Angular Distribution of Neutrons Emitted in the Be^9 (d, n) B^{10} Reaction

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The energy spectra and angular distributions of neutrons from the Be^9 (d,n) B^{10} reaction have been investigated at deuteron energies of 0.5, 0.8, 1.0, 1.2, 1.4 and 1.6 Mev. The excitation curve for this reaction indicates a resonance at 1 Mev in the compound nucleus, B^{11}. The angular distribution corresponding to an excited state in B^{10} with excitation energy $E_x = 3.62$ Mev points to the existence of a stripping mechanism. The angular distributions of reactions involving the formation of compound nuclei are appreciably distorted on passage through a resonance.

1. INTRODUCTION

THE experimental study of spectra and of angular distributions of neutrons emitted when light nuclei are bombarded by charged particles, for instance by deuterons, yields useful information on the excited states of the residual nucleus and on the mechanism of the nuclear transmutation. In this work*, the reaction Be^9 (d, n) B^{10} was investigated. Lately a number of authors[1-3] have published results on the investigation of this reaction for deuteron energies less than 1 Mev. Five energetic neutron groups were observed. The angular distributions indicate a stripping mechanism only for the fourth excited state of B^{10}, for the other states a substantial contribution from the formation of the compound nucleus is presented.

This work is believed to be more detailed investigation of the energy spectra and the angular distributions of the neutrons from the reaction Be^9 (d, n) B^{10} as a function of the incident deuterons in the range of 9.5 to 1.6 Mev.

*This work was carried out in 1950-1952

2. EXPERIMENTAL SET-UP

A beam of fast deuterons, obtained from the tube of an electrostatic generator, hit a thin metallic beryllium foil after magnetic analysis. The energy of the incident deuterons had values of 0.5, 0.8, 1.0, 1.2, 1.4 and 1.6 Mev. The voltage of the electrostatic generator was determined with the help of a generating voltmeter, calibrated with the reaction F^{19} $(p\,\alpha\gamma)$ O^{16}. The voltage stabilization was carried out with the help of a corona triode for which the signal was the beam passing through the magnetic analyzer.

The focussed deuteron beam falling on the target had a diameter of about 5 mm. The neutrons from the reaction were detected by means of proton recoil tracks in photoemulsions. The surface of the photoemulsions was placed parallel to the direction of the incoming neutrons coming out of the target. The NIKFI photographic plates with 200 μ thick emulsions were placed at various angles to the direction of the incident deuteron beam in a ring-like hermetically closable duraluminum chamber (Fig. 1). The inside diameter of the chamber was 140 mm, the outside diameter was 170 mm. The