MEASUREMENTS OF THE PRIMARY COSMIC RAY SPECTRA IN THE $10^{10}-10^{14}$ eV ENERGY RANGE FROM PROTON-1, 2, 3 SATELLITES

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This paper presents the results of measurements of the spectrum of the primary cosmic ray protons in the 10^{10}—10^{13} eV energy range and the spectrum of all particles of the primary cosmic rays in the 10^{11}—10^{14} eV energy range carried out on Proton-1, 2, 3 satellites. The approximating function which describes the proton spectrum is presented. It has been shown that the spectrum of all particles can be represented by superposing the obtained proton spectrum and power spectrum of nuclei with $Z \geq 2$.

The measurements of the spectra were carried out on Proton-1, 2, 3 satellites using the SEZ-14 instrument consisting of two identical halves each of which included a charge detector (double proportional counter), scintillation detector of interactions, ionization calorimeter (energy detector), and lower scintillation counter intended for limiting the angular aperture of the instrument. Changeable graphite and polyethylene targets were placed between the proportional counter and interaction detector. The SEZ-14 instrument is described in detail in [1].

The instrument installed on Proton-3 was supplemented with two large Čerenkov counters placed above the proportional counters. Čerenkov detectors selected only those cases for detection when a primary particle entered the instrument from the proportional counter end of the instrument, i.e. they were used as the detectors which determine the direction of the entry of primary particles; thus we called them "direction detectors" (DD). Detection of protons in the 1st half of the SEZ-14 took place only when the direction detector was in operation whereas in the 2nd half the measurements were carried out both with and without DD, i.e. the measurement programme was similar to that on Proton-1, 2. The processed data showed that in time intervals, when the total solid angle of SEZ-14 device was shaded by the Earth, the counting rate of protons was zero. This suggests that the SEZ-14 device with a direction detector records only those protons which enter the device from the proportional counter end.

Measurement results

1. *The spectrum of primary cosmic ray protons*

Previously the spectrum of primary cosmic ray protons was considered to be the spectrum of $Z_1 N_1 E_{C_i}$ type events, corresponding to the detection of one singly charged particle in both proportional counters (Z_1) and interaction detector (N_1) energy release in the calorimeter exceeding the i-th threshold (E_i), and the operation

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of the lower scintillation counter limiting the solid angle of the instrument (index "C"). A change in the spectrum exponent from $\gamma \simeq 1.7$ at $E < 10^{12}$ eV to $\gamma \simeq 2.5$ in the $2 \cdot 10^{12} - 10^{13}$ eV energy range was observed in the spectra of such events obtained from Proton-1, 2 satellites [2].

The Proton-3 measurements confirmed this character of the $Z_1 N_1 E_{C_i}$ events. As we have shown before, according to our estimate [3] the observed changes in the spectrum exponent cannot be explained by the secondary particles entering the interaction detector from the ionization calorimeter.

To give an experimental confirmation of this we considered the dependence of the event sum intensity $Z_1 N_1 E_{C_i} + Z_1 N_2 E_{C_i}$ (without the direction detector) and also $Z_1 N_1 DDE_{C_i} + Z_1 N_2 DDE_{C_i}$ (with the direction detector) on energy E. In this sum of events there are no limits to the number of particles in the interaction detector. ($Z_1 N_2 E_{C_i}$ events differ from $Z_1 N_1 E_{C_i}$ events only in the number of particles $N \geq 2$ in the interaction detector.) Therefore their intensity will not depend on the presence or absence of the inverse particle flow from the ionization calorimeter into the interaction detector.

To decrease the possibility of the secondary particles entering the proportional counters, measurements with targets have been considered for the event sum $Z_1 N_1 E_{C_i} + Z_1 N_2 E_{C_i}$. In this case there was more than 30 g $\cdot$ cm^{-2} of light material between the proportional counters and the ionization calorimeter.

The results of measurements are presented in Fig. 1. Along the abscissa axis the energy of the proton is given. Along the ordinate axis, to the right, the counting rate of event sum $Z_1 N_1 E_{C_i} + Z_1 N_2 E_{C_i}$ is given from Proton-2 [1, 2] and Proton-3 satellite measurements. The counting rate of the event sum $Z_1 N_1 DDE_{C_i} + + Z_1 N_2 DDE_{C_i}$ measured by SEZ-14 with the direction detector on "Proton-3" [4] satellite was normalized to the counting rate $Z_1 N_1 E_{C_i} + Z_1 N_2 E_{C_i}$ in one point at $E = 10^{11}$ eV. The normalization factor 3 is connected with the additional counting effect (see [3, 4]).

From Fig. 1 we see that

1. The intensities of the event sum $Z_1 N_1 E_C + Z_1 N_2 E_{C_i}$ according to three measurement series are in good agreement.

2. Measurements either without or with the direction detector give the same form of the proton spectrum and confirm the previous result concerning the slope spectrum change at $E \approx 10^{12}$ eV.

The left ordinate axis scale presents the absolute proton flux intensity. It is obtained from counting rate measurements of events $Z_1 N_1 DDE_{C_i} + Z_1 N_2 DDE_{C_i}$, as in measurements with the direction detector the additional counting is essentially smaller than that without it (for details see [4]).

The proton spectrum obtained can be approximated by the function

$$I_p = 3 \cdot 10^{-4} \left(\frac{100}{E}\right)^{1.62} \cdot \frac{1}{\left[1 + \left(\frac{E}{1500}\right)^2\right]^{0.35}} \text{ cm}^{-2}\,\text{sec}^{-1}\,\text{sr}^{-1}$$

shown in Fig. 1 with a solid line. The energy was measured in GeV.

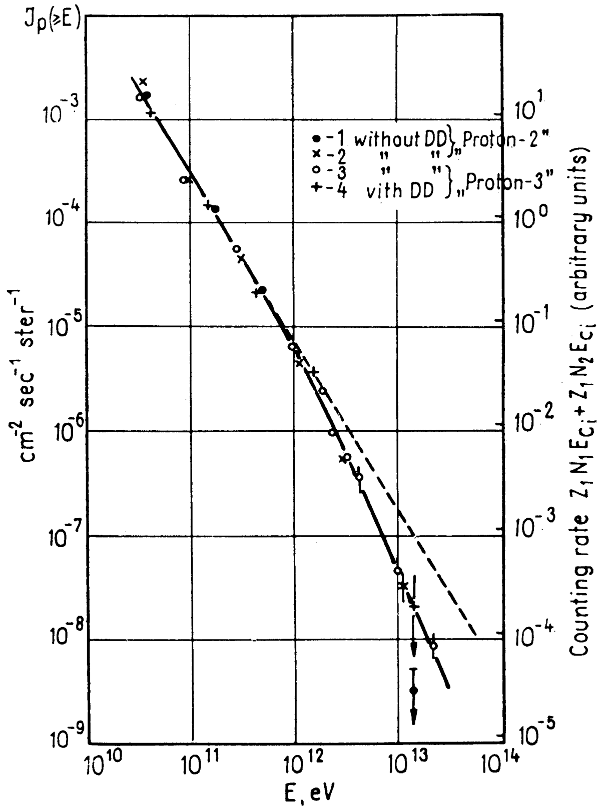

Fig. 1. Energy spectrum of the primary cosmic ray protons (for symbols see text)

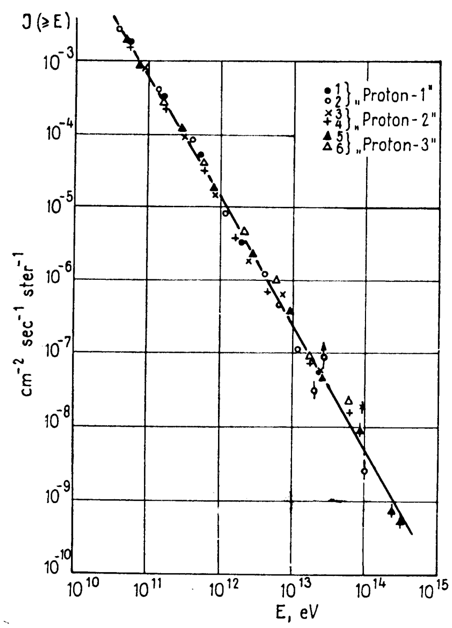

Fig. 2. Energy spectrum of all particles of primary cosmic rays. Solid line represents the expected form of spectrum (see text)

2. *The spectrum of all particles of primary cosmic rays*

The integral spectrum of ionization bursts in the calorimeter caused by all cosmic ray particles irrespective of their nature and point of entering the calorimeter was considered as the spectrum of all particles.

The results of all measurement series carried out on Proton-1, 2, 3 are shown in Fig. 2.

The energy thresholds of all instruments were adjusted according to the latitude effect in the cosmic ray protons. This problem was considered in detail in [3, 4].

If one assumes that the spectrum of particles with charges $Z \geq 2$ is of the form:

$$I_Z (\geq E) = B \left(\frac{100}{E} \right)^{1.62}$$

the observed spectrum $I(\geq E)$ will be the sum of

$$I_p (\geq E) \quad \text{and} \quad I_Z (\geq E).$$

It can be seen from the ratio of the value of absolute fluxes of protons and all particles at energies of 10^{11} eV that $B = 3 \cdot 10^{-4}$. Thus, the summary spectrum of all particles is of the form:

$$I = I_p + I_Z = 3 \cdot 10^{-4} \left(\frac{100}{E\,(\text{GeV})} \right)^{1.62} \left[1 + \frac{1}{\left[1 + \left(\frac{E}{1500} \right)^2 \right]^{0.35}} \right] \text{cm}^{-2}\ \text{sec}^{-1}\ \text{sr}^{-1}.$$

This function is shown in Fig. 2 by the solid curve. It can be seen that it agrees sufficiently well with experimental data.

References

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