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ON IRREGULARITY IN THE PRIMARY COSMIC RAY SPECTRUM IN THE 10^{12} eV ENERGY RANGE

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ABSTRACT: Analysis of the integral spectrum of all primary cosmic ray particles obtained in the Proton-1,2,3 experiments shows that the approximation of this spectrum by power law with a single spectrum exponent of 1.7 in the whole studied energy range is not the best one. The power dependence with an exponent of 1.6 and irregularity of the form of a "step" in the 10^{12} eV range agrees much better with the experimental data. This irregularity may be connected with the steepening of proton spectrum in this energy range obtained in the Proton-1,2,3 experiments. Such approximation also agrees well to the data on the spectrum of all particles obtained from Proton-4 satellite.

The Proton-1,2,3 satellites measured primary cosmic ray spectra in the 10^{10}–10^{14} eV energy range. The equipment of the satellites is described in detail in /1/.

The measurements have made it possible to obtain the proton spectrum in the 10^{10}–10^{13} eV range and the spectrum of all particles in the 6×10^{10} – 10^{14} eV range. A characteristic feature of the proton spectrum was an abrupt increase in the spectrum exponent at an energy of 10^{12} eV/2/. Various methodical effects were analyzed capable of causing such distortion in the measurement results/3/. Some of the effects could not be estimated within sufficient reliability. They include, in particular, the events of "back current" into the charge detectors and non-local showers. The former consists in that the particles from a cascade developing in the calorimeter may scatter back and enter the charge detector (proportional counter). This will result in an additional ionization in the proportional counter which will lead to the appearance of an amplitude exceeding the maximum admissible for proton value. This effect should increase with increasing of particle number in the cascade and, therefore, the portion of protons which failed to be detected due to the "back current" particles entering the charge detector should increase with increasing the proton energy which may result in a steeper form of the spectrum recorded in the high-energy range. The latter effect consists in the fact that when a high-energy particle interacts with the matter surrounding the calorimeter a shower of particles is produced which enter the corresponding detectors of the instrument and may imitate detection of a high-energy proton with the instrument. In principle, this effect may be energy dependent and distort the recorded proton spectrum.

The presence of the above mentioned factors invokes one to seek for a confirmation of the steepening of the proton spectrum in the information which is not affected by these effects. Such information is provided by the spectrum of all particles obtained in the Proton experiments which was recorded without any limitation imposed on the particle charge, the location of particle entrance to the calorimeter, and the direction of particle movement.

The protons amount to about a half of all particles of primary cosmic rays of given energy at 10^{10} - 10^{11} eV and therefore an irregularity in the form of a step should be observed in the all particle spectrum. All data on the intensities of all primary cosmic rays particles with energies exceeding the given values E_i obtained from Proton-1,2,3 were used in the analysis. The analyzed aggregate data included the results of independent measurements from six instruments carried on the three Proton satellites.

The mean values of the function

$$A(E,\gamma) = \lg\left[J(\geq E) \times \left(\frac{E}{10^{11}}\right)^{\gamma}\right] \quad {}^{*)}$$

have been found in the intervals of $\lg\left(\frac{E}{10^{11}}\right)$ $-0.3 \div 0$; $0 \div 0,3$; $0.3 \div 0.6$; $0.6 \div 0.9$; $0.9 \div 1,2$; $1.2 \div 1.5$; $1.5 \div 1.8$; $1.8 \div 2.1$; $2.1 \div 2.4$ for various values of γ . The values

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*) $J(\geq E)$ is expressed in arbitrary units, E-in eV

of A (E, γ) obtained for $\gamma = 1.6$ are shown with circles in Fig. 1. It can be seen from the figure that an irregularity is possible in the 10^{12} eV range. To determine the validity of this irregularity the function A (E, γ) was approximated for each value of γ by the functions of two forms: A_I = const = C_0 which corresponds to the spectrum with a single exponent in the whole energy range and

$$A_2 = \begin{cases} C_1 \text{ at } & -0{,}3 < lg \frac{E}{10^{11}} < 0{,}9 \\ C_2 \text{ at } & 1{,}2 < lg \frac{E}{10^{11}} < 2{,}4 \end{cases}$$

corresponding to the spectrum with exponent γ at energies lower than 8×10^{11} eV and higher than 1.6×10^{12} eV and having a step-like irregularity in the 10^{12} eV range. The functions A_I and A_2 for $\gamma = 1.6$ are shown with the dotted and solid streight lines in Fig. I. The value χ^2 was determined for each approximation. The obtained dependences of χ^2 on γ for the functions of the forms A_1 and A_2 are presented in Figs. 2a and 2b respectively. It can be seen from these figures that the value of χ^2 for the A_I function reaches its minimum at $\gamma = 1.72$ being equal to 68 at eight degrees of freedom. The minimum of χ^2 for the A_2 function corresponds to $\gamma = 1.60$ and is 4.5 at six degrees of freedom. The obtained minimum values of χ^2 indicate that the representation of the all particle spectrum in the studied energy range by a power function with a single spectrum exponent is not the best approximation. The function having an irregularity in the range of $E = 10^{12}$ eV and the exponent $\gamma = 1.6$ before and after the irregularity agrees much better with the experimental data. Shown with the crosses in Fig. 3 are the values of A ($\dot{E}$, $\gamma = 1.60$) obtained from the information on the all particle spectrum as measured on the Proton-4 satellite with an instrument which differed considerably from the Proton-1,2,3 equipment/5/.

The Proton-1,2,3 data are shown with the points in Fig. 3. It can be seen that the data of Fig. 3 agree well with each other.

The obtained result indicates a rapid disappearance of 35% of the primary cosmic rays particles at $\sim 10^{12}$ eV which may be associated with the steepening of proton spectrum in this energy range obtained in the Proton-1,2,3 experiments and hence with the change in the chemical composition of primary cosmic rays.

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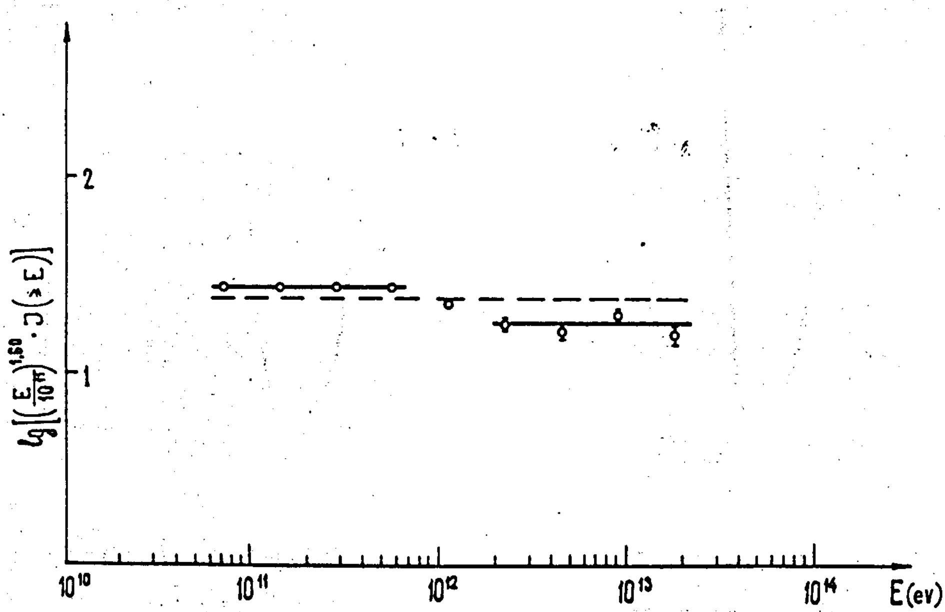

Fig. 1 Energy dependence of $lg\left[\left(\frac{E}{10^{11}}\right)^{1.60} J(\geq E)\right]$ according to the Proton-1,2,3 data.
The dotted straight line is the approximation by the function $A_I = C_o$. The solid lines are the approximation by the function

$$A_2 = \begin{cases} C_1 \text{ at } -0{,}3 < lg\frac{E}{10^{11}} < 0{,}9 \\ C_2 \text{ at } 1{,}2 < lg\frac{E}{10^{11}} < 2{,}4 \end{cases}$$

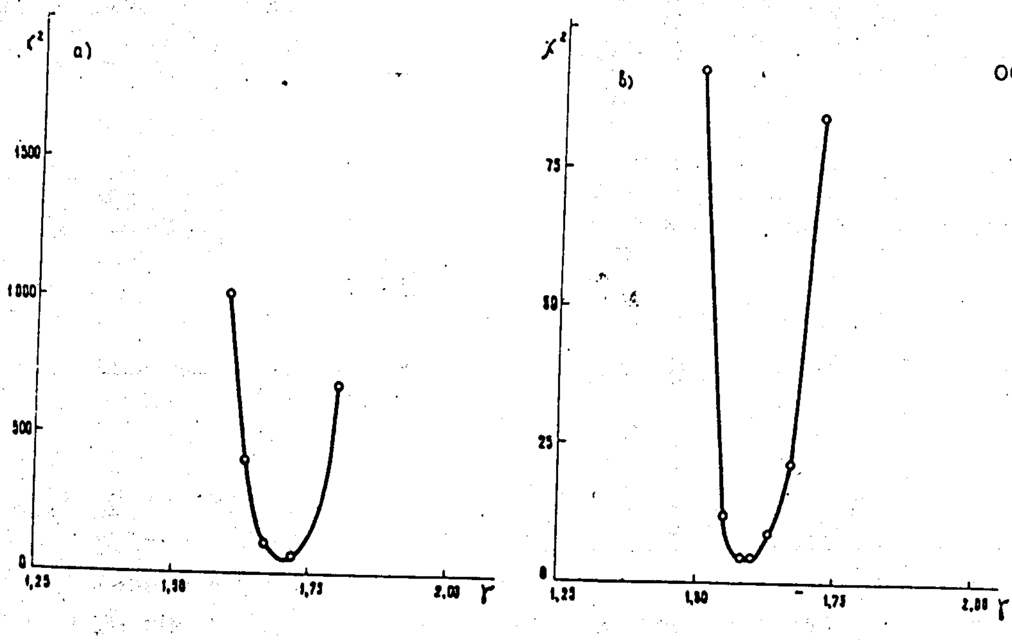

Fig. 2 Dependence of χ^2 on the value of γ :

(a) for the approximation corresponding to a single spectrum exponent over the whole energy range;

(b) for the approximation corresponding to the presence of irregularity in the 10^{12} eV range.

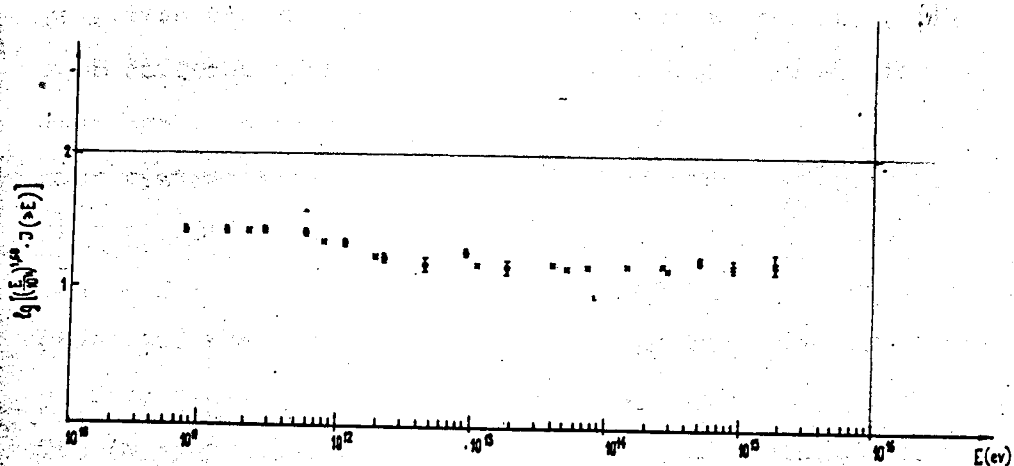

Fig. 3 Energy dependence of $lg\left[\left(\frac{E}{10^{11}}\right)^{1.60} J(\geq E)\right]$

• according to the Proton-1,2,3 data;

x according to the Proton-4 data [4].