Armenian Journal of Physics, 2024, vol. 17, issue 4, pp. 90-93

Dependence of the Linear Intensity Coefficient of Cosmic Rays Hard Component on the Path Length Through Earth's Atmosphere

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(Received: January 22, 2025; Revised: February 10, 2025; Accepted: February 25, 2025)

Abstract. The work examines the dynamics of changes in the intensity of the hard components of cosmic radiation per unit path length, depending on the length of the atmospheric air layer.

Keywords: Cosmic rays, intensity of radiative flow, hard component investigation

DOI: 10.54503/18291171-2024.17.4-90

1. Introduction

The primary cosmic radiation (CR) is constant in time and isotropic in space. It consists of protons (about 90%), alpha particles (about 7%) and other atomic nuclei (up to the heaviest nuclei), as well as a small number of electrons, positrons, and neutrinos.

High-energy protons entering the Earth's atmosphere collide with atoms in the atmosphere, destruction of nuclei and nuclear conversions occur, resulting in the formation of high-energy secondary cosmic radiation: electrons, γ-quanta, π and μ-mesons, protons, neutrons. The soft component includes gamma quanta, positrons, and electrons, which are strongly absorbed by lead [2]. Meanwhile, the hard component of cosmic rays, consisting of particles like neutrons and muons, penetrates lead layers with thicknesses of 16 cm or more.

Only a small fraction of CR reach Earth's surface, but this fraction still influences biological and chemical processes on our planet. A proton with initial 10^{14} energy in electron-volts generates a cascade of secondary particles 10^6- 10^9 such as protons, neutrons, pions, muons, electrons, positrons, and photons [4]. Among these secondary particles, muons, characterized by high energy and relatively long lifespans, can reach the Earth's surface and penetrate its depths.

The hard component of cosmic rays is primarily muons, which, compared to electrons, expend 40,000 times less energy passing through the nuclear fields of atmospheric atoms.

2. Results and Discussions

The study focuses on the behavior of the hard component of CR as it passes through atmospheric air layers of varying thickness (under different zenith angles) above Earth's surface. Specifically, it examines the dynamics of changes in the linear intensity coefficient per unit length. For this purpose, data from a previous study [1] was used, where soft components of CR were screened with an 18 cm thick lead layer, allowing only the hard components to be studied. The data from [1] is presented in Table 1 (columns 2 and 4). Additional calculations were performed for the linear enhancement coefficient, and the corresponding columns in Table 1 were updated.

The linear enhancement coefficient of the hard component of CR per unit length $a\left(km^{-1}\right)$ To graphically represent the dynamics of numerical value changes of the linear enhancement coefficient, it is advisable to evaluate the particle counts of the hard component of CR in two adjacent atmospheric layers. A characteristic feature is the dependence of their differences on the averaged lengths of the atmospheric layers $\bar{L}$ which can be calculated as follows.

Table 1. Changes in the Number of Hard Component Particles of Cosmic Rays (CR).

θ	$L(km)$	$\bar{L}(km)$	N_{aver}	ΔN	$\overline{\Delta L}(km)$	$a \cdot 10^3 \left(km^{-1}\right)$
0^0	15	17	74,4	17,1	4	$\frac{17{,}1}{4} = 4{,}27$
15^0	19	21,7	57,3	17	5,4	$\frac{17}{5{,}4} = 3{,}15$
30^0	24,4	29,2	40,3	11,7	9,6	$\frac{11{,}7}{9{,}6} = 1{,}22$
45^0	34	47	28,6	13,0	26	$\frac{13}{26} = 0{,}50$
60^0	60	77	15,6	6,1	34	$\frac{6{,}1}{34} = 0{,}18$
75^0	94	125,5	9,5	1,5	63	$\frac{1{,}5}{63} = 0{,}024$
90^0	157		8,0			

For example, $\theta = 0^o$ and $\theta = 15^o$. For the given values, the lengths of the atmospheric air layers reaching the recording device, the cosmic telescope, are respectively equal to 15 km and 19 km, respectively. The average value of these two adjacent layers will be 17 km, as recorded in the first row of the third column in Table 1.

Whereas, for $\theta = 15^o$ and $\theta = 30^o$. In the case of the values, the lengths of the atmospheric layers are 19 km and 24,4 km, with the average value being 21,7 km. This value is also entered in the second row of the third column in Table 1, and similarly, the remaining rows of the third column in Table 1 are filled accordingly. According to the data from Table 1, the linear enhancement coefficient of the rigid component of CRs $a\left(km^{-1}\right)$ per unit path length will vary across different lengths of atmospheric layers as follows:

$$a = \frac{\Delta N_{21}}{\Delta L_{21}} = \frac{N_2 - N_1}{L_2 - L_1} \tag{1}$$

where N_1 and N_2 are the numbers of particles recorded per unit of time in atmospheric layers with lengths L_1 and L_2, respectively. The values for these particle counts are provided in the fourth column of Table 1.

Using formula (1), $\theta = 0^o$ and $\theta = 15^o$ for the values ΔL. The difference of values, $\Delta L = 4$ (in km) is presented in the fifth column of Table 1, and the corresponding values for the solid component particles of the CRs recorded per unit time are 74,4 and 57,3**,** respectively, with their difference, equal to 17,1, presented in the fourth column of Table 1. For the enhancement coefficient, we obtain:

$$a = \frac{\Delta N_{21}}{\Delta L_{21}} = \frac{N_2 - N_1}{L_2 - L_1} = \frac{74{,}4 - 57{,}3}{19 - 15} = \frac{17{,}1}{4} = 4{,}27\,\mathrm{km}^{-1} \tag{2}$$

For the remaining cases of the enhancement coefficient, the corresponding rows in the seventh column of Table 1 are completed using the calculations based on formula (2). Using the completed data in Table 1, a graph is constructed a the dependence of the enhancement coefficient on the third column of Table 1. $\overline{L}(km)$ from the average lengths of adjacent atmospheric layers. The enhancement coefficient's dependence on between the values of a and $\overline{L}(km)$, that is, the third and the graph of the dependence, based on the data from the third and seventh columns, has the appearance shown in Fig.1.

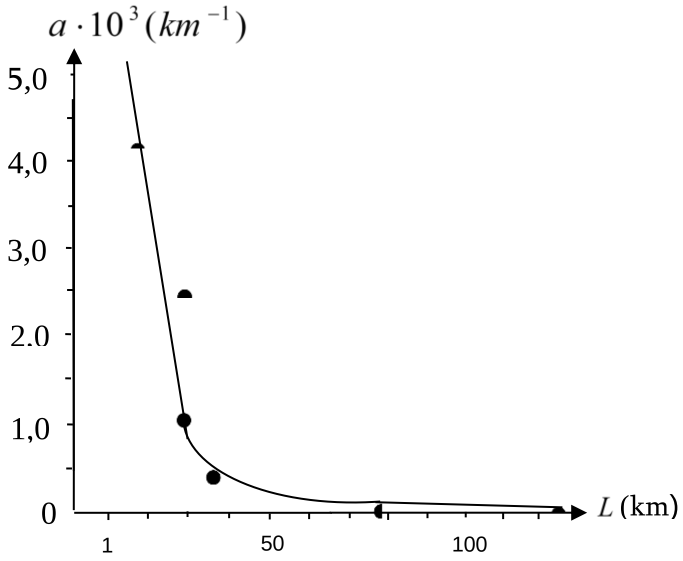

Fig. 1. The variation of the strengthening coefficient of the solid component of TC per unit $a(km)^{-1}$ length as a function of the average lengths of different layers of $\overline{L}(km)$ atmospheric air.

The graph of the variation a in the amplification coefficient per unit length shows that it increases sharply above 20-30 km from sea level and starts intensifying around 17 km in altitude. The amplification coefficient grows by nearly two orders of magnitude, indicating a significant increase in the intensity of these atmospheric layers. Fortunately, these particles are not radioactive. The graph also reveals that the amplification coefficient a continues to rise below 17 km and does not exhibit any signs of decrease.

3. Conclusions

From this analysis, it follows that the amplification coefficient exhibits a growth pattern, suggesting that specific rigid components of cosmic rays reach the Earth's surface. This result holds significant scientific and economic interest, especially considering ongoing efforts to utilize the rigid components of cosmic rays in customs services [5] for scanning cargo. This method is more effective than X-ray scanning, as the attenuation of X-rays is substantial even with a few millimeters of material. From the above, it follows that the amplification coefficient exhibits a growth pattern, suggesting that specific rigid components of cosmic rays reach the Earth's surface. This result is of great scientific and economic interest and is important because experiments are being conducted to use the rigid components of cosmic rays in customs services [5] for scanning cargo. This method is more efficient than X-ray scanning since a few millimeters of lead are sufficient for the attenuation of X-rays, while the absorption of cosmic ray rigid component particles is negligible even through lead layers tens of centimeters thick.

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