pina, Igonin, Lazareva, and Lepestkin, JETP **44**, 1787 (1963), Soviet Phys. JETP **17**, 1200 (1963).

[2] Balashov, Shevchenko, and Yudin, JETP **41**, 1929 (1961), Soviet Phys. JETP **14**, 1371 (1962).

V. V. Balashov, Nucl. Phys. **40**, 93 (1963).

Translated by C. S. Robinson
278

INVESTIGATION OF THE COMPOSITION OF PRIMARY COSMIC RADIATION BY OBSERVATION OF CERENKOV RADIATION FLUCTUATIONS IN EXTENSIVE AIR SHOWERS

N. M. NESTEROVA and S. I. NIKOL'SKIĬ

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor November 31, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **46**, 1908-1910 (May, 1964)

THE study of the composition of the primary cosmic radiation in the energy region above 10^{14} eV has previously been carried out either by analysis of the structure of the cores of extensive air showers (EAS)[1] or by comparison of the relative intensities of the electron and μ-meson components of showers[2-4].

In the present work we have analyzed the composition of the primary radiation by study of the burst of Cerenkov radiation accompanying the passage of an extensive shower through the atmosphere, and the total number of particles at the level of observation. We compute the fluctuations in the ratio of the intensity of the Cerenkov radiation burst (Q) to the number of particles in the shower (N). The results of calculations made with different assumptions about the primary composition are compared with the fluctuation in Q/N obtained from experiments[5,6] carried out in the Pamirs (elevation 3860 m above sea level).

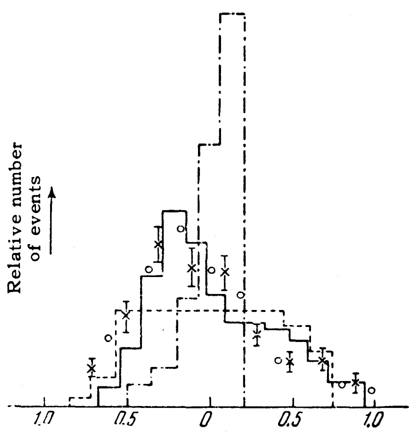
In the calculations the dependence of Q/N on the energy E_0^n of the primary nucleus of mass number A, which produced the shower, was assumed to be

$$Q/N \sim (E_0^n/A)^{\beta-\alpha},$$

where α and β are the exponents in the relations: $N \sim E_0^{\alpha}$ and $Q \sim E_0^{\beta}$. The experimental data of Chudakov et al.[5] on the Cerenkov radiation for showers with a number of particles $N = 10^5 - 10^7$ at the elevation of the Pamirs yield a value $\beta - \alpha = 0.2 \pm 0.05$.

Using the relation $Q/N = f(E_0^n, A)$, we have computed the distributions of Q/N for two different primary compositions, on the basis of the analogous distribution of showers formed by protons (see the figure). The latter distributions were obtained with the assumption that proton showers develop according to the scheme assumed by Nikol'skiĭ and Pomanskiĭ[7].

In the calculations we took into account the fact that the difference in the development of showers produced by protons and by heavier particles causes the charge distribution of the primary particles to differ from the corresponding distribution of showers at the level of observation. We have introduced a correction coefficient $K = A^{\kappa-\gamma}$, where κ and γ are the respective exponents of the shower particle-number spectrum and of the primary energy spectrum. In addition we took into account the increase in



Distribution of relative number of Cerenkov bursts in EAS at an elevation of 3860 m above sea level. The abscissa is the quantity $(Q_i/N_i)/(Q/N) - 1$. Calculated distributions: dash-dot line – for the case when all showers are generated by protons, solid line – Assumption I, dotted line – Assumption II. Experimental data: (circles) 1955 experiments[6], (crosses) 1957 experiments[5].

	Composition of primary radiation (in %)		Corresponding distribution of EAS at mountain altitude (in %)	
	Assumption I	Assumption II	Assumption I	Assumption II
p ($\bar{A}=1$)	27	8	46	13
α ($\bar{A}=4$)	27	11	24	15
M ($\bar{A}=14$)	14	21	11	20
H ($\bar{A}=31$)	19	32	12	27
VH ($\bar{A}=51$)	13	28	7	25

counting efficiency for showers formed by primary protons, due to fluctuation in the shower development [8].

The first composition assumed (I) corresponded to the direct experimental data on the primary composition at the edge of the atmosphere in the energy interval $10^{10}-10^{12}$ eV [8,9]. In the second set of calculations (II) we assumed a primary composition enriched in heavy particles, corresponding to an increase in the exponent γ of the integral energy spectrum by an amount $\Delta\gamma = 0.5$ in the energy interval $10^{11}-10^{15}$ eV. Here the energy interval of the change would be shifted towards the high energy region in proportion to the charge of the primary particle. The composition of the primary radiation and the corresponding relative number of EAS observed at mountain altitude for these two assumptions are listed in the table.

The calculated distributions of the ratio of the intensity of Cerenkov bursts Q to the number of particles N in an EAS are shown in the figure, where it can be seen that the distributions depend appreciably on the primary composition. The same figure shows experimental data for showers with $N \cong 10^6$ at the elevation of the Pamirs ($E_0 \cong 10^{15}$ eV), obtained by Chudakov and others in a series of experiments [5,6] in 1955 and 1957. Distributions are shown of the deviation of Q_i/N_i for the showers recorded from the mean value $\overline{Q/N}$ at a definite distance from the axis. The agreement between experiment and the calculation based on the composition of the primary radiation at an energy of $10^{10}-10^{12}$ eV is evident at a glance.

We must keep in mind that the fluctuations observed in the experiment include measurement errors characterized by an average deviation of 0.25. If, after calculating the spread due to measurement errors, we evaluate the consistency of theoretical and experimental data by means of Pearson's χ^2 distribution, then we obtain, for assumption I, $p(\chi^2) = 0.12$ for the 1955 measurements and $p(\chi^2) = 0.16$ for the 1957 measurements. According to this criterion, the distribution for assumption II, corresponding to a primary composition enriched in heavy nuclei, does not agree with experiment: $p(\chi^2) \leq 0.001$ for the 1955 measurements and $p(\chi^2) = 0.025$ for the 1957 measurements.

It must be noted, however, that the accuracy of the presently available experimental data and the scarcity of information on the elementary interactions of particles with energies of 10^{15} eV do not yet permit us to draw a final conclusion on the identity of the primary composition at high energy ($\sim 10^{15}$ eV) with the composition at low energies ($10^{10}-10^{12}$ eV).

[1] Murthy, Peters, Ramanamurthy, and Sreekantan, Trudy mezhdunarodnoĭ konferentsii po kosmicheskim lucham (Proceedings, International Cosmic Ray Conference) July 1959, **3**, AN SSSR, 1960, page 166.

[2] Fukui, Hasegawa, Matano, Miura, Oda, Suga, Tanahashi, and Tanaka, Progr. Theor. Phys. (Kyoto), Suppl. **16**, 1 (1960).

[3] Vernov, Solov'eva, Khrenov, and Khristiansen, Report at the Yakutsk Cosmic Ray Meeting, 1962.

[4] J. Linsley and L. Scarsi, Phys. Rev. Letters **9**, 123 (1962).

[5] Chudakov, Nesterova, Zatsepin, and Tukish, op. cit. [1] **2**, AN SSSR, 1960, page 47.

[6] N. M. Nesterova, Dissertation, Moscow State University, 1961.

[7] S. I. Nikol'skiĭ and A. A. Pomanskiĭ, JETP **39**, 1339 (1960), Soviet Phys. JETP **12**, 934 (1961).

[8] L. G. Dedenko, JETP **40**, 630 (1961), Soviet Phys. JETP **13**, 439 (1961).

[9] V. L. Ginzburg and S. I. Syrovat-skiĭ, UFN **71**, 411 (1960), Soviet Phys. Uspekhi 4, 504 (1961).

[10] M. Shapiro, Discovery, March, 1963.

Translated by C. S. Robinson
279