ENERGY SPECTRUM AND COMPOSITION OF COSMIC RAYS OF GALACTIC AND METAGALACTIC ORIGIN[1)]

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We present the energy spectrum and the composition of the primary cosmic radiation of galactic and metagalactic origin, calculated on the basis of the diffusion model of propagation of cosmic rays, assuming a definite energy dependence of the coefficient of diffusion of the cosmic rays. The results of the calculation are compared with the experimental particle-number spectrum of extensive air showers and with the muon-number distribution in a shower with a specified number of particles. The results of this comparison lead to the deduction that cosmic rays of metagalactic origin assume a major role in the energy region $E > 10^{17}$ eV.

1. INTRODUCTION

THE presently available experimental material on the investigation of extensive air showers (EAS) [1,2] makes it possible to obtain new information on the energy spectrum and composition of the primary cosmic radiation at ultrahigh energies. At the present time a detailed study was made of the spectrum of EAS with respect to the number of particles N in the region $N = 10^4-10^8$ at sea level, and of the distribution with respect to the number N_μ of muons in showers with a specified number of particles N in the range $N = 10^5-10^7$. It was established in many investigations that the particle number spectrum of EAS experiences an abrupt change in form in the vicinity $N \sim 10^5-10^6$, where the spectrum exponent κ increases by 0.5 over the extent of one order in N. Unlike the particle-number spectrum of the EAS, the experimental distribution with respect to the number of muons in the shower with specified number of particles N is more sensitive to the composition of the primary radiation [3]. According to [2], these distributions are found to be almost the same both for $N \sim 10^5$ and for $N \sim 10^7$.

Recently some of these facts have been interpreted in connection with the energy spectrum and composition of primary cosmic radiation of ultrahigh energy [3,4] [2)]. It is shown in I that to explain the experimentally observed change in the EAS particle-number spectrum exponent in the range $N \sim 10^5-10^6$ it is sufficient to assume the existence of a fast variation of the form of the primary cosmic-radiation energy spectrum. This assumption is connected in turn with the specific dependence of the coefficient of diffusion of cosmic rays on their energy. The energy spectrum and the composition of the cosmic rays (CR) were obtained in I under these assumptions.

The energy spectrum of the primary cosmic radiation was subsequently calculated in greater detail in II for the diffusion model of CR propagation in the galaxy, with account of the fragmentation of the nuclei during the diffusion process. The primary energy spectrum of the CR and the composition of the primary cosmic radiation were obtained in II for different energies and for the case when the CR diffusion coefficient D remains constant up to a certain critical energy $\epsilon_{cr} \sim 10^{15}$ eV per nucleon, and varies like $D \sim \epsilon^\alpha$ for $\epsilon > \epsilon_{cr}$ ($\alpha = 0.5$ and $\alpha = 0.7$).

In the present paper we calculate the energy spectrum and composition of CR of both galactic and metagalactic origin, starting from the diffusion model of CR propagation, and using more general assumptions concerning the $D(\epsilon)$ dependence. In addition, a more detailed comparison is made between the results of the calculation and the experimental data.

[1)]By cosmic rays of metagalactic origin are meant here cosmic rays which enter into our galaxy from the metagalactic space, into which they in turn enter as a result of leaving other galaxies.

[2)]References[3] and[4] are henceforth cited as I and II, respectively.

2. COSMIC RAYS OF GALACTIC ORIGIN

Without contradicting the experimental data on the anisotropy and composition of the primary cosmic radiation, we can assume that the diffusion coefficient D is energy-dependent also in the region $\epsilon < \epsilon_{cr}$, but this dependence is weaker than when $\epsilon > \epsilon_{cr}$. It is further assumed in the calculation that

$$D = D_0 \varepsilon^{0,2} \quad \text{for } 1 < \varepsilon < \varepsilon_{cr},$$
$$D = D_0 \varepsilon^{0,5 \ln(\varepsilon/\varepsilon_{cr}) + 0,2} \quad \text{for. } \varepsilon_{cr} < \varepsilon < \varepsilon'_{cr},$$
$$D = D_0 \varepsilon^{0,7} \quad \text{for } \varepsilon > \varepsilon_{cr}',$$

where ϵ—energy per nucleon in BeV, and ϵ_{cr}—critical energy, assumed equal to $\epsilon_{cr} = 2.5 \times 10^{15}$ eV for nuclei with $Z > 1$, and $\epsilon_{cr} = 5 \times 10^{15}$ eV for protons. The remaining assumptions concerning the lateral distribution of the sources and the dependence of their intensity on the energy and on the atomic number of the nuclei contained in the CR are the same as in II. Just as in II, we assume a continuous stationary generation of CR by the sources.

The partial energy spectra of the primary cosmic radiation obtained under these assumptions, corresponding to nuclei of different groups, are shown in Fig. 1, which shows also the summary spectrum. The summary energy spectrum has an exponent $\gamma = 1.7$ up to $E \approx 5 \times 10^{15}$ eV, and then changes rather abruptly to $\gamma = 2.2$ in the energy range $5 \times 10^{15} - 5 \times 10^{16}$ eV.

The calculated composition of the primary cosmic radiation at different energies E per particle is shown in Table I and in Fig. 2a. As is seen from Table I, at $\sim 10^{15}$ eV the number of protons per particle in the composition of cosmic radiation on earth decreases to almost one half, and the number of heavy nuclei increases accordingly over the value observed at $E \sim 10^9$ eV. At energies $E > 10^{15}$ eV, the fraction of the protons decreases greatly, as in II.

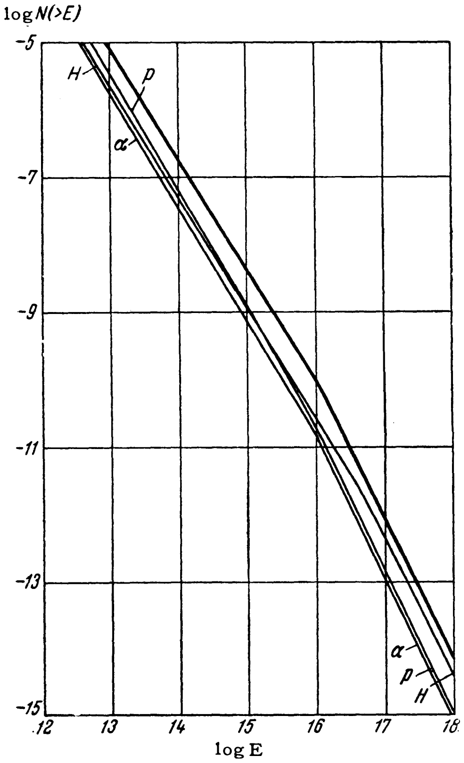

FIG. 1. Integral energy spectrum of the primary cosmic radiation of galactic origin and partial spectra of: p – protons, α – α particles, H – heavy nuclei of group H (see Table I).

It is of interest to compare the results of the present calculations in II with the direct experimental data, namely the spectrum with respect to the number of particles N, and with the distribution with respect to the number of muons N_μ. For this comparison it is necessary to assume a definite model of the development of the EAS. We choose for this purpose the model of Zatsepin and Dedenko [5]. According to [5], the particle-number spectrum of the showers can be expressed by

$$C(> z) = \int_{y_{min}}^{\infty} B e^{-\gamma k y} \psi(> z / y)\, k dy.$$

where $z = \log N$, $y = \log E$, and $\psi(z/y)$ are the

Table I. Composition (per cent) of primary cosmic radiation of galactic origin*

Nuclear group	E, eV								
	10^{10}	10^{11}	10^{12}	10^{13}	10^{14}	10^{15}	10^{16}	10^{17}	10^{18}
p	49.5	42	38	35,7	33,3	32,4	26	13	11,5
α	24	22,2	21	19,5	18,4	17,2	17,7	9.8	8,2
L	2	2,3	2	1,7	1,4	1,1	0,9	0,6	0,2
M	11.5	15	17	17,6	18,5	18,8	20,8	23,4	21,9
H	13	18,5	22	25,5	28,8	30,5	34,6	53,2	58,2

*All nuclei contained in the cosmic radiation are broken up into the following groups: 1) H($Z \geq 10$), 2) M($9 \geq Z > 6$), 3) L($5 \geq Z \geq 3$), 4) α($Z = 2$), and 5) p($Z = 1$).

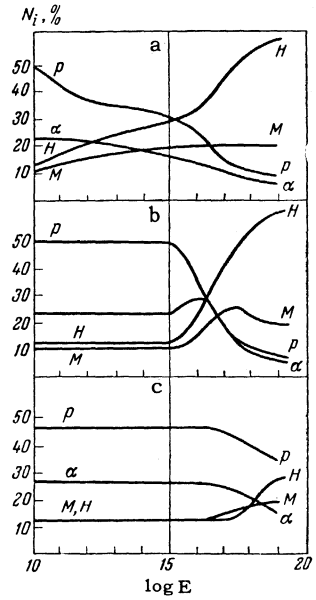

FIG. 2. Composition of primary cosmic radiation on the top of the atmosphere, calculated: a — assuming $D \sim \epsilon^{0.2}$ for $\epsilon < \epsilon_{cr}$ and $D \sim \epsilon^{0.7}$ for $\epsilon > \epsilon_{cr}$; b — in I; c — for metagalactic cosmic radiation.

probability distribution functions of the logarithm of the number of particles for a given value of the logarithm of primary energy, k = 1/log e = 2.3, and γ—exponent of the integral energy spectrum of the primary cosmic radiation. Using the value of the function from the paper of Dedenko and Zatsepin [5], we have constructed the partial particle-number spectrum of EAS generated by protons. The values of γ were chosen for the different energy intervals from the partial primary energy spectrum of the protons, which was calculated above.

The particle-number spectra of showers generated by nuclei with atomic weight A were calculated under the assumption that the nucleus with energy E generates upon collision with the air atom a shower which is equivalent to A showers due to nucleons with energy E/A. Then on the basis of the central limit theorem of probability theory, the number of particles in the shower due to the primary nucleus A with energy E has a normal distribution with mean value $\overline{N}_A = A\overline{N}$ and a variant $D_A = AD$, where $\overline{N}$ and D are the mean value and the variance of the distribution ψ(z/log [E/A]) (see [6]). An analogous calculation of the shower particle-number spectrum was made for mountain levels (640 g/cm^2), with the values of the function ψ taken from the paper of Dedenko [6].

The partial spectra obtained at sea level and at mountain level were added with corresponding weights, in accordance with Table I. The resultant summary particle-number spectra of the showers, for two different altitudes (x = 1033 g/cm^2 and x = 640 g/cm^2) are shown in Fig. 3,

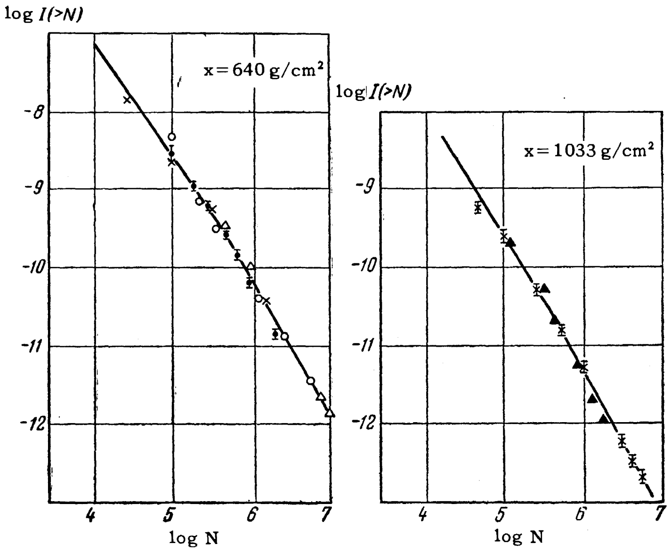

FIG. 3. Comparison of particle-number spectra at sea level (x = 1033 g/cm^2) and at mountain altitudes (x = 640 g/cm^2) with the experimental data: o —[9], △ —[10], × —[11], ● —[1], ▲ —[12], × barred —[2].

which shows also the experimental data obtained by different authors. Thus, as can be seen from Fig. 3, calculation shows that under the assumptions made concerning the primary radiation it is possible to obtain the variation of the exponent of the integral particle-number spectrum of the showers with $\gamma = 1.5$ to $\gamma = 2.0$ in the region $N \sim 10^5$—10^6, and this variation of the exponent occurs within the limits of the same range of values of M, both at sea level and at mountain altitudes, in full agreement with the experimental data.

From the calculated partial particle-number spectra we can obtain the contribution of the different groups of nuclei to the production of a shower with a specified number of particles at sea level and at mountain altitudes (see Table II). The fact that the change in the particle-number

Table II. Contribution of different nuclear groups (per cent) to the production of a shower with specified N.

N	p	α	M	H
10^5	77	13.5	5.5	4.0
10^6	70	15	8.5	6.5
10^7	41	13.8	19.6	25.6

spectrum index of the showers occurs at different altitudes in the atmosphere and approximately the same value of N is obviously connected with the large role played by the fluctuations in the development of the proton-induced shower. According to Table II, the main contribution to the total number of showers at sea level is made by proton showers, at least for $N < 10^6$.

We now proceed to calculate the distribution with respect to the muon number N_μ at a fixed total number of particles N. Dedenko [7] calculated for different groups of nuclei the energy spectra of the particles generating at the observation level a shower with a specified N. By adding these spectra with weights corresponding to the contributions of the different groups of nuclei to the number of showers with specified N, it is possible to obtain the energy distribution of all the particles which produce a given number of particles at the observation level. According to [7] $N_\mu \sim E^{0.85}$, so that it is possible to change over from a distribution by the primary energies to a distribution by the number of muons in a shower with specified N. In this manner, the distributions $f(N_\mu/\bar{N}_\mu)$ were constructed ($\bar{N}_\mu$—average number of muons in a shower with given N) for two values of N, 10^5 and 10^7 (Figs. 4 and 5).

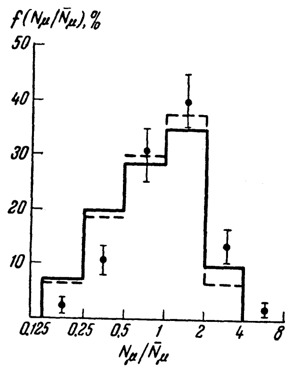

FIG. 4

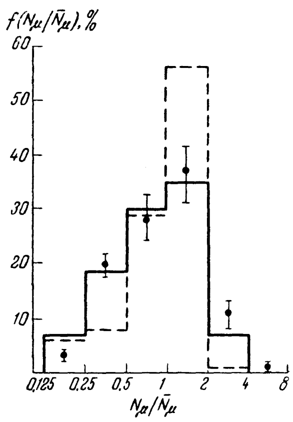

FIG. 5

FIG. 4. Distribution $f(N_\mu/\bar{N}_\mu)$ for $N = 10^5$. Continuous line – calculated distribution under the assumption that $D \sim \epsilon^{0.2}$ for $\epsilon < \epsilon_{cr}$, dashed – D = const for $\epsilon < \epsilon_{cr}$, point – experimental data[2].

FIG. 5. Distribution $f(N_\mu/\bar{N}_\mu)$ for $N = 10^7$. Continuous line – calculated distribution for metagalactic composition of CR, dashed – under the assumption that $D \sim \epsilon^{0.7}$ for $\epsilon < \epsilon_{cr}$, point – experimental data.

We have calculated $f(N_\mu/\bar{N}_\mu)$ for the energy spectrum and the composition in accordance with Table II, and in accordance with II. As can be seen from Figs. 4 and 5, the distributions $f(N_\mu/\bar{N}_\mu)$ differ greatly from each other. This difference is due to the sensitivity of the distribution to the composition of the primary cosmic radiation. It is seen from Table I that in the region of energies $E \sim 10^{15}$–10^{17} eV the composition experiences an appreciable change: the number of protons decreases and the number of heavy nuclei increases, and this is consequently reflected in the form of the distribution $f(N_\mu/\bar{N}_\mu)$. As can be seen from Figs. 4 and 5, the experiment does not confirm a similar change in the form of the distribution $f(N_\mu/\bar{N}_\mu)$. At $N \sim 10^5$ a good agreement exists between the calculations and experiment. To reconcile the calculations with experiment in the region of primary energies responsible for the production of showers with $N = 10^7$ particles it is apparently necessary to assume a much larger number of protons and a smaller number of heavy nuclei than is obtained from the diffusion model of propagation of cosmic rays of galactic origin. In this connection, we have considered the question of cosmic rays of metagalactic origin.

3. COSMIC RAYS OF METAGALACTIC ORIGIN

In considering this question we have assumed that all the cosmic rays in the metagalaxy come only from galaxies. All the galaxies are assumed to be equivalent with respect to the absolute intensity, energy spectrum, and composition of the cosmic rays produced in them, and also with respect to their structure. It is further assumed that the galaxies fill uniformly the entire volume of a sphere of radius R, from which the CR can reach our galaxy.

As shown by Ginzburg and Syrovat-skiĭ [8], the radius R is determined by comparing the rate of diffusion of the CR in the metagalactic space and the rate of divergence of the galaxies during the expansion of the metagalaxy. The rate at which the galaxies diverge at a distance r from the observer is $(dr/dt)_g = hr$, where h is the Hubble constant, and is connected with the characteristic evolution time of the metagalaxy T_{mg} by the relation $h = T_{mg}^{-1}$, where $T_{mg} = 3 \times 10^{17}$ sec. On the other hand, the rate of CR diffusion in the metagalaxy is $(dr/dt)_{dif} = D_{mg}/r$, where D_{mg} is the coefficient of diffusion of the CR in metagalactic space. The unknown radius R is determined from the equality $(dr/dt)_g = (dr/dt)_{dif}$. Hence $R = (D_{mg}T_{mg})^{1/2}$. The diffusion coefficient is assumed to be $D_{mg} \sim 10^{33}$ cm²/sec [8]. If it is assumed also that the density of matter in the intergalactic space does not exceed 10^{-29} g/cm³ (see [8]), then the quantity of matter, in g/cm^2, traversed by the cosmic rays diffusing from a distance R does not exceed $\rho cR^2/2D \lesssim 10^{-1}$ g/cm^2, which is much less than the interaction range of nuclei with $A \sim 50$. Therefore, when considering the diffusion of CR in the metagalaxy we can neglect the interaction of the CR with the matter, and the problem of determining the concentration of metagalactic CR reduces to a solution of the diffusion equation in the presence of uniformly distributed forces (galaxies) in a sphere of radius R, drawn about the point of space at which the concentration is considered.

As is well known, the solution of the diffusion equation in infinite space takes the form

$$N(r) = I/4\pi r D_{\mathrm{mg}}$$

where I—intensity of the source, which in our case obviously is equal to $I = D_g(\mathrm{grad}\, N_g)_{r_g} 4\pi r_g^2$. Here D_g—coefficient of diffusion of CR in the galaxies, r_g—radius of the galaxies, assumed equal to 5×10^{22} cm, and $(\mathrm{grad}\, N_g)_{r_g}$—gradient of the CR concentration on the boundary of the galaxies (all these quantities are assumed the same for all galaxies and equal to the values of the corresponding quantities for our own galaxy). The CR concentration in the metagalactic space is therefore given by the following expression:

$$\mathfrak{N}_{\mathrm{mg}} = \int_0^R nN(r)\, 4\pi r^2 dr = \frac{nI}{D_{\mathrm{mg}}} \frac{R^2}{2} = \frac{nIT_{\mathrm{mg}}}{2}. \qquad (1)$$

Here $n \sim 5 \times 10^{-75}$—concentration of the galaxies in metagalactic space (in units of cm^{-3}) (see [8]). We see that the result does not depend on the value D_{mg} of the coefficient of diffusion on the CR in the metagalaxies.

It is obvious that this formula gives a minimum value of the concentration $\mathfrak{N}_{mg}$, since it does not take into account the contribution of those galaxies which had generated CR at an earlier stage of evolution of the metagalaxy, and then moved outside the limits of the sphere of radius R. However, an account of this contribution presupposes already the knowledge of a definite model of the metagalactic evolution. Thus, as can be seen from the presented formula, the form of the energy spectrum and the composition of the cosmic rays in metagalactic space are determined by the quantity

$$I_i = D_{i\mathrm{g}}(\varepsilon)\, [\mathrm{grad}\, N_{i\mathrm{g}}(\varepsilon)]_{r_{\mathrm{g}}}\, 4\pi r_{\mathrm{g}}^2, \qquad (2)$$

where the diffusion coefficient D_{ig} and the concentration N_{ig} pertain to galactic space and depend on the energy ϵ and on the species of nuclei i.

To determine the gradient of the concentration of the CR on the boundary of the galaxy, we used the same method of calculation as in II. In the case when CR leave the galaxy freely (see [8]), the gradient of concentration of nuclei of species i is determined by the expression

$$\mathrm{grad}\, N_i = \varepsilon^{-(\gamma+1)} \sum_{k=1}^{i} \frac{r_{\mathrm{g}}}{2\pi r_{\mathrm{g}}^2 D \sqrt{DT_k}} \{\exp(r_{\mathrm{g}}/\sqrt{DT_k}) - \exp(-r_{\mathrm{g}}/\sqrt{DT_k})\}^{-1} \sum_{l=1}^{k} a_{ikl}\, q_l, \qquad (3)$$

where r_g—distance from the center of the galaxy to its boundary ($r_g = 5 \times 10^{22}$ cm), T_k—lifetime of the nuclei of species k relative to their absorption, a_{ikl}—some coefficients which depend on the probabilities of fragmentation and mean free paths relative to absorption, and $q_i \epsilon^{-(\gamma+1)}$—intensity of the sources with respect to nuclei of species i per unit interval of energy. The values of a_{ikl}, T_k, and q_i were taken from II. The proton concentration gradient, in accordance with considerations advanced in II, was defined as

$$\mathrm{grad}\, N_p = \frac{q_p \varepsilon^{-(\gamma+1)} r_{\mathrm{g}}}{2\pi r_{\mathrm{g}}^2 D \sqrt{DT_p}} \left\{\exp\left(\frac{r_{\mathrm{g}}}{\sqrt{DT_p}}\right) - \exp\left(-\frac{r_{\mathrm{g}}}{\sqrt{DT_p}}\right)\right\}^{-1} + \sum_{i=1}^{4} \frac{A_i q_i (k\varepsilon)^{-(\gamma+1)}}{4\pi r_{\mathrm{g}}^2 D(k\varepsilon)} - \sum_{i=1}^{4} A_i\, \mathrm{grad}\, N_i(k\varepsilon),$$

where k = 2.

The coefficient of diffusion of CR in the galaxy was assumed: 1) constant up to critical energy $\epsilon_{cr} = 5 \times 10^{15}$ eV for protons and $\epsilon_{cr} = 2.5 \times 10^{15}$ eV for nuclei, and 2) in the form given in Sec. 1. The value of D was assumed equal to 2×10^{29} cm^2/sec for $\epsilon \sim 10^9$ eV. Using the obtained values of the gradient of galactic CR, we can construct the partial energy spectra of the metagalactic CR.

The partial energy spectra and the summary energy spectrum of the metagalactic CR for variant 1) are shown in Fig. 6. In Table III are given the composition of the meta-galactic cosmic radiation for different energy particles, and the exponent of the integral energy spectrum, calculated for variant 1). From Fig. 6 and Table III we see that the energy-spectrum exponent decreases somewhat in the 10^{17}—10^{18} eV region. This decrease can apparently be attributed to the decrease in the role of fragmentation of heavy nuclei in this region of energies.

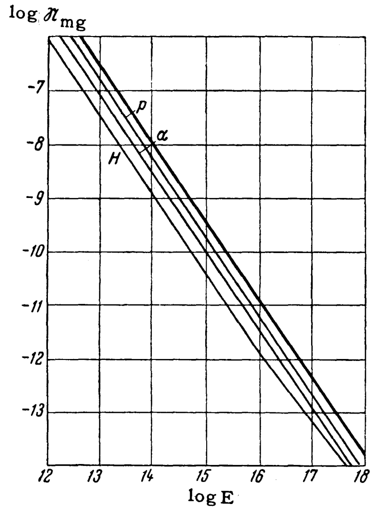

FIG. 6. Integral energy spectrum of primary cosmic radiation of metagalactic origin and partial spectra: p – of protons, α – of α particles, H – of group H nuclei.

Table III. Composition of primary cosmic radiation of metagalactic origin (in percent) for variant 1) and value of the exponent γ of the integral energy spectrum.

E, eV	p	α	L	M	H	γ
10^{12}	49	28.4	3	10.2	9.4	1.50
10^{15}	49	28.4	3	10.2	9.4	1.50
10^{17}	47.3	28	2.7	13	9	1.45
10^{18}	40.3	21.7	1.5	17.5	19	1.40

An analogous calculation made for variant 2) yielded a summary integral spectrum with an exponent which does not differ from the exponents for variant 1) within the limits of computational accuracy (0.05). The metagalactic cosmic-radiation composition obtained for variant 2) is likewise essentially the same as that of variant 1). Figure 7 shows a comparison of the galactic spectrum of CR for variant 1) and of the calculated metagalactic spectrum. Figures 2b and c show a comparison of the composition of the galactic and metagalactic radiations.

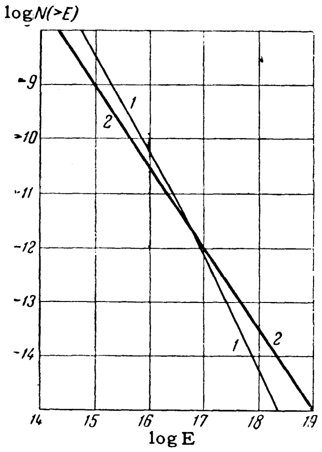

FIG. 7. Comparison of energy spectra of primary cosmic radiation: 1 – galactic and 2 – metagalactic origin.

The results can be illustrated semiquantitatively in the following fashion. From the diffusion model of the propagation of CR in the galaxy it follows that the concentration of CR decreases with increasing diffusion coefficient, owing to the departure of the CR from the galaxy, since

$$N_g \sim (4\pi r D)^{-1} \exp(-r/\sqrt{DT}).$$

It is seen from (1), (2), and (3) that

$$\mathfrak{N}_{mg} \sim \frac{r_g}{\sqrt{DT}} \left[\exp\left(\frac{r_g}{\sqrt{DT}}\right) - \exp\left(-\frac{r_g}{\sqrt{DT}}\right)\right]^{-1}.$$

Hence

$$\mathfrak{N}_{mg}/N_g \sim D_g(1/r - 1/\sqrt{D_g T}),$$

i.e., the contribution of the metagalactic CR increases with increasing diffusion coefficient, and therefore the energy spectrum of the metagalactic CR has a gentler sloping D(E) dependence (see Table III).

As is seen from Table III, the metagalactic radiation turns out to be relatively richer in protons and light nuclei than the galactic radiation of the same energy. The reason for it is that, owing to the large value of T_i, the protons experience hardly any nuclear collisions with the interstellar gas during the diffusion time $R^2/2D(E)$, and therefore go out into metagalactic space without noticeable loss. As to the nuclei, their flux outside the limits of the galaxy is relatively larger, on the one hand, owing to the sharper variation of their concentration with distance from the center of the galaxy, compared with the protons. On the other hand, however, this flux decreases, since the nuclei have a relatively small time of nuclear collision, and they do not go out fully outside the limits of the galaxy into intergalactic space.

It is seen from the table that at low energies the composition of the metagalactic radiation differs relatively weakly from the composition of the galactic radiation; to the contrary, in the region of large nuclei, where D is a function of E, the difference between the composition of the metagalactic and galactic cosmic rays becomes appreciable.

It must be noted that whereas at extremely large energies, 10^{18}–10^{19} eV, the CR of galactic origin are relatively richer in heavy nuclei than the CR near the source (see II), the CR of metagalactic origin, to the contrary, remain richer in protons than the CR near the source, up to the highest energies.

A comparison of the contribution of $\mathfrak{N}_{mg}$ and N_g to cosmic radiation of specified energy is given in Table IV. For $\mathfrak{N}_{mg}$ we used here the minimum estimate [see formula (1)]. This comparison shows that in the region of ultrahigh energies we can expect, generally speaking, an appreciable fraction of cosmic radiation of metagalactic origin within the limits of our galaxy. Special calculations are needed to explain how the energy spectrum and the composition of the metagalactic CR change as they diffuse within the galaxy itself. However, the change in the composition and the energy spectrum on the periphery of the galaxy (where the solar system is situated), will hardly be appreciable. It is therefore meaningful to compare the $f(N_\mu/\overline{N}_\mu)$ distribution shown in Fig. 5 with the theoretical distribution calculated under the assumption of the metagalactic composition for the CR. As can be seen from Fig. 5, good agreement is obtained between the theoretical and experimental distributions, $p(\chi^2) = 0.1$ 3). It must also be noted that the gentler slope of the energy spectrum of the CR, which is predicted on the basis of the foregoing calculations and which is typical of metagalactic CR ($\gamma = 1.5$), does not contradict in any case the existing experimental data in the region $E < 10^{17}-10^{18}$ eV [1].

Table IV. Comparison of contributions of $\mathfrak{N}_{mg}$ and N_g to the cosmic radiation of given energy.

E, eV	$\mathfrak{N}_{mg}/N_g$ (variant 1)	$\mathfrak{N}_{mg}/N_g$ (variant 2)
10^{15}	$3.6\cdot10^{-3}$	$1\cdot10^{-2}$
10^{17}	$1.4\cdot10^{-2}$	$3.1\cdot10^{-2}$
10^{18}	$7.4\cdot10^{-2}$	$6.6\cdot10^{-2}$

3) We note that the Pearson criterion gives a value $p(\chi^2) = 10^{-3}$ for the probability of matching the experimental data and the distribution, with allowance for the galactic composition of the CR (see Fig. 5).

In conclusion, the authors express sincere gratitude to S. I. Syrovat-skiĭ for a discussion of the problem and to L. G. Dedenko for acquainting us with the results of the calculations.

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