Letters to the Editor

Account of Primary α-Particles in the Development of a Nucleon Shower in the Stratosphere

ZH. S. TAKIBAEV AND P. A. USIK
Physico-Technical Institute, Academy of Sciences Kazakh SSR

(Submitted to JETP editor February 24, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 924-925 (April, 1957)

HEAVY NUCLEI ($Z>2$) constitute a considerable part of the primary cosmic radiation. It follows from the data by Bradt and Peters[1], obtained by means of photo-emulsions, that 45% of the nucleons incident upon the top of the atmosphere are protons, 45.3% are α-particles, and 9.7% are heavier nuclei.

Measurements carried out at different geomagnetic latitudes[2] demonstrate that primary protons, α-particles and heavier nuclei possess similar energy-per-nucleon spectra up to 4000 Mc^2. In the account of α-particles we can therefore use the same spectrum exponent as used in the expression for the primary protons.

Haber-Shaim and Yekutiely[3], using the model of a mean nucleus for the atoms of air[4], estimated that in the mean 2.5 nucleons originating in the disintegration of an air nucleus by a high-energy α-particle are star-producing. In our calculations the mean number ν of star-producing nucleons which take their origin in the disintegration of an air nucleus by a primary α-particle is assumed to be equal to 2.5.

In the study of the interaction mean free path of heavy particles, Eisenberg[5] used the value $\lambda = 5\times 10^{-13}$ cm for the mean free path of a nucleon from the primary nucleus in the target nucleus. This value was obtained from experiments on the scattering of nucleons on nuclei at energies attained in accelerators. The resulting satisfactory agreement between theory and experiment makes it plausible to consider the behavior of the nucleons of the primary α-particle in the target nucleus as independent even at the energies involved. We shall therefore regard as fully grounded the use of the model of independent interaction of the incident nucleons with the target nucleus nucleons[6] for the calculation of cascade curves for nucleons in the stratosphere, caused by primary protons.

In our calculations we did not account for mesons, secondary α-particles, and ionization energy losses of charged particles. Assuming that the intensity of primary protons is normalized to unity, we shall use the following expression for the differential spectrum of primary α-particles:

$$S(E_0)\,dE_0 = \begin{cases} 0{,}3\gamma E_c^{\gamma} E_0^{-\gamma-1}\,dE_0 & \text{for } E_0 \geqslant E_c = 740\text{ MeV}, \\ 0 & \text{for } E_0 < E_c, \end{cases}$$

where E_0 and E_c are energies per nucleon and $\lambda = 1.1$ (Ref. 6).

The value of the intensity of α-particles at the top of the atmosphere was obtained (using the above expression for the spectrum) recalculating the data of Bradt and Peters[1] obtained at the geomagnetic latitude of 30° N to the geomagnetic latitude of Moscow, 51° N, for which the proton cut-off energy was assumed to be equal to 2000 Mev. Correspondingly, the cut-off energy for α-particles equals 740 Mev per nucleon.

At an atmospheric depth x (measured in the units of the nucleon interaction mean free path, $\lambda = 75\text{g/cm}^2$), the flux intensity of primary α-particles will be equal to $I = I_0 e^{-x/l}$, where l is the interaction mean free path of α-particles in the air, measured in the units of λ. According to Fermi[7] we used the value of 44.5 g/cm² for the mean free path l.

The flux of nucleons with energy greater than E at a depth θ (in units of λ), produced by primary α-particles in a layer of thickness θ, can be represented as follows:

$$S_\alpha(E_c \geqslant E,\ \theta) = -\frac{\nu\gamma}{2\pi i} \int\limits_{S_0 - i\infty}^{S_0 + i\infty} \int\limits_{I_0}^{I_\theta} \left(\frac{E_c}{E}\right)^s \frac{e^{-f(D\alpha_s)z}}{s(\gamma - s)}\, dI\, ds,$$

where z is the atmospheric depth from the layer dx, in which the number of α-particles which interacted with air nuclei equals $-dI = (I_0/l)e^{-x/l}dx$, where $\theta = x + z$, $z = \theta - x$;

$$\alpha_s = 1 - 240 / (s+2)(s+3)(s+4)(s+5).$$

We have then

$$S_\alpha(E_c, \geqslant E, \theta) = -\frac{\gamma\nu I_0}{2\pi i l}\int_{s_0-i\infty}^{s_0+i\infty}\left(\frac{E_c}{E}\right)^s\int_0^\theta \frac{\exp\{-f(D\alpha_s)(\theta-x)\}\,e^{-x/l}}{s(\gamma-s)}\,dx\,ds$$

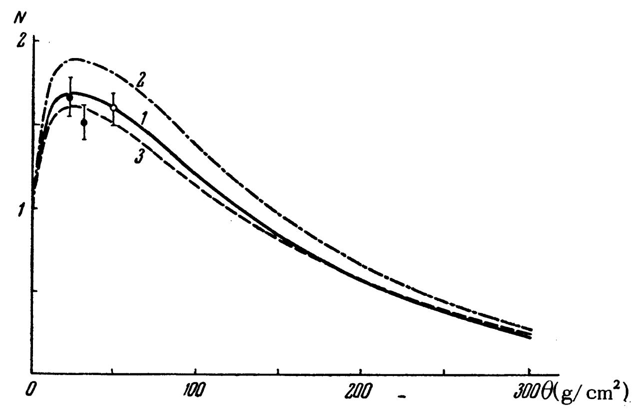
$$= \frac{\gamma\nu I_0}{2\pi i l}\int_{s_0-i\infty}^{s_0+i\infty}\int_0^\theta\left(\frac{E_c}{E}\right)^s \frac{\exp\{-f(D\alpha_s)\theta + f(D\alpha_s)x - x/l\}}{s(\gamma-s)[f(D\alpha_s)-1/l]}\,d[-f(D\alpha_s)\theta$$

$$+ f(D\alpha_s)x - x/l]\,ds = \frac{\gamma\nu I_0}{2\pi i l}\int_{s_0-i\infty}^{s_0+i\infty}\left(\frac{E_c}{E}\right)^s \frac{e^{-f(D\alpha_s)\theta} - e^{-\theta/l}}{s(\gamma-s)[1/l - f(D\alpha_s)]}\,ds.$$

Therefore

$$S_\alpha(E_c, \geqslant E, \theta) = \frac{\gamma\nu I_0}{2\pi i l}\int_{s_0-i\infty}^{s_0+i\infty}\left(\frac{E_c}{E}\right)^s \frac{e^{-f(D\alpha_s)\theta} - e^{-\theta/l}}{s(\gamma-s)[1/l - f(D\alpha_s)]}\,ds.$$

The value $S_\alpha = (E_c, > E, \theta)$ was estimated by the saddle point method.



Altitude dependence of the number of stars and the flux of star-producing particles: 1- stars with account of primary α-particles, 2- flux of star-producing particles with account of primary α-particles, 3- stars without account of α-particles, ●- experimental data obtained in laboratory, O- point of normalization of the experimental data. All curves are normalized to unity.

We calculated the curves for the star-producing particles with energy larger than E = 100 Mev for for various atmospheric depths. The calculations were carried out with and without account of the primary α-particles. Results are given in the figure.

[1] H. L. Bradt and B. Peters, Phys. Rev. 77, 54 (1950).

[2] B. Peters, Progress in Cosmic Ray Physics 1, 4 (Amsterdam, 1952).

[3] U. Haber-Shaim and G. Yekutieli, Nuovo cimento 11, 2, 172 (1954).

[4] U. Haber-Shaim, Phys. Rev. 84, 1199 (1951).

[5] Y. Eisenberg, Phys. Rev. 96, 1378 (1954).

[6] H. Messel, Progress in Cosmic Ray Physics 2, 4 (Amsterdam, 1954).

[7] E. Fermi, Progr. Theor. Phys. 5, 570 (1950).

Ponderomotive Forces in a Localized Plasma in the Electromagnetic Field of a Plane Wave

V. V. IANKOV
P. N. Lebedev Physical Institute, Academy of Sciences, USSR
(Submitted to JETP editor December 6, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 926-927 (April, 1957)

WHEN THE FIELD of a plane wave is impressed on a localized plasma, there arise both a radiation pressure in the direction of the wave motion and ponderomotive forces tending to produce a deformation of the plasma. The present article is devoted to the explanation of the nature of these forces in the special case where the wavelength is much larger than the linear dimensions of the region of localization A quasi-neutral plasma may be described phenomenologically as a medium having dielectric constant ε, conductivity σ and magnetic permeability $\mu = 1$.

A sphere of ionized gas with a uniform density of ionization may be considered as a rough model of a localized plasma. The electromagnetic field inside and outside such a plasma sphere is in accordance with the theory of the diffraction of a plane wave by a homogeneous dielectric sphere