When $\omega > \omega_{cr}$, a sufficient condition for the propagation of s.w. is $M < 0$, where $M = (\Gamma + P_1 + 1)(\Gamma - P_2 - 1)$. When $\omega < \omega_{cr}$, the sufficient condition is $M > 0$. Equation (5) applies to the direct wave; for the reverse wave the sign of Γ must be reversed, giving different conditions for propagation of the two different waves.

4. Analogous conflicting properties are characteristic of a channel 3 ($0 < x < d$; $\epsilon = \epsilon_0$; $\mu = \mu_0$) between two gyrotropic media 1 ($x < 0$; $\mu = \mu_{ik}$) and 2 ($x > d$; $\mu = \tilde{\mu}_{ik}$). With $\mu_\perp < 0$ and $\tilde{\mu}_\perp < 0$, the gyrotropic plates 1 and 2 insulate channel 3 from the surrounding medium like the walls of a metal waveguide. The characteristic equation which corresponds to (4) is

$$h^2\Gamma\tilde{\Gamma} + h(\gamma_1\tilde{\Gamma} - \gamma_2\Gamma) - \gamma_1\gamma_2 - \gamma_3^2 Q\tilde{Q}$$

$$= \gamma_3 [h(\Gamma\tilde{Q} - \tilde{\Gamma}Q) + \gamma_2 Q + \gamma_1\tilde{Q}] \coth\gamma_3 d, \qquad (6)$$

where $Q = \mu_\perp/\mu_0$; $\tilde{Q} = \tilde{\mu}_\perp/\mu_0$. The critical frequency is

$$\omega_{cr} = \frac{c}{d}\left(\frac{\tilde{Q}}{\tilde{\Gamma} - \beta} - \frac{Q}{\Gamma + \alpha}\right),$$

$$\alpha = \left(1 - \frac{\varepsilon\mu_\perp}{\varepsilon_0\mu_0}\right)^{1/2}, \quad \beta = \left(1 - \frac{\tilde{\varepsilon}\tilde{\mu}_\perp}{\varepsilon_0\mu_0}\right)^{1/2}.$$

Sufficient conditions for the propagation of the direct s.w. are $N < 0$ for $\omega > \omega_{cr}$ and $N > 0$ for $\omega < \omega_{cr}$, where $N = (\Gamma + Q + 1)(\tilde{\Gamma} - \tilde{Q} - 1)$. By interchanging the signs of Γ and $\tilde{\Gamma}$ we obtain the conditions for the propagation of the reverse wave.

Waves of the waveguide type (by which we mean waves for which $\gamma_3^2 < 0$) can also propagate in this channel. In such waves the energy maximum is not at the walls as in s.w. but in the middle of the channel, so that we can expect smaller loss.

5. The boundary of a gyrotropic medium and the plate and channel discussed in Secs. 3 and 4 are of considerable interest as retarding systems. Their advantages are the possibility of modifying (and specifically, modulating) the retardation coefficient in time (by changing H_0) and in space, and the absence of distortions.

---

[1] L. D. Landau and E. M. Lifshitz, Электродинамика сплошных сред (The Electrodynamics of Continuous Media), GTTI, 1957, p. 364.

[2] M. A. Gintsburg, Izv. Akad. Nauk SSSR, Ser. Fiz., 18, 444 (1954).

Translated by I. Emin
319

ENERGY SPECTRUM OF NUCLEAR-ACTIVE PARTICLES IN EXTENSIVE AIR SHOWERS

O. I. DOVZHENKO, O. A. KOZHEVNIKOV,
S. I. NIKOL' SKII, and I. V. RAKOBOL' SKAIA

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

Submitted to JETP editor February 26, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1637-1638 (June, 1958)

As a continuation of our earlier work,[1] we studied the energy spectrum of nuclear-active particles in extensive air showers (EAS) of cosmic radiation at 3860 m above sea level. Nuclear-active particles of the shower were identified by production of electron-nuclear showers in lead plates of a large rectangular cloud chamber.* Total thickness of the lead plates amounted to ~ 100 g/cm^2. As a criterion of the nature of secondary showers we used the presence of penetrating or heavily ionizing particles in electron-nuclear showers, which corresponds to that used in reference 3.

The experiment was carried out in two variants, one with no absorber above the chamber, and another with an absorber of ~ 100 g/cm^2 Al. A diagram of the arrangement is shown in Fig. 1.

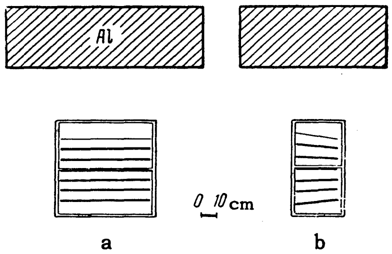

FIG. 1. Diagram of the array, a – front view, b – side view.

EAS with total number of particles N between 10^4 to 10^6 were recorded. The average shower size was $N \sim 10^5$ in the first variant of the experiment, $N \sim 2 \times 10^5$ in the second. A hodoscope consisting of a large number of self-quenching counters made it possible to select EAS, the axes of which fell within 9 m from the cloud chamber, and to determine the total number of particles in a shower.[4] The error in the axis location amounted to ~ 1 m. The energy of nuclear-active particles was determined from the energy of the electron-photon component produced by these particles.[3]

Integral energy spectra of nuclear-active particles for the energy region 2 to 50 Bev at dis-

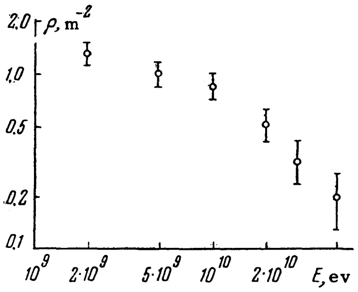

FIG. 2. Integral energy spectrum of nuclear-active particles in the energy region 2 to 50 Bev. The x axis represents the energy of nuclear-active particles in ev, and the y axis the absolute flux density of nuclear-active particles.

tances 0 to 9 m from the shower axis were constructed from 52 nuclear interaction events. Since the spectra obtained in the two variants of the experiments were identical, we averaged the results of both series of measurements.

The observed integral energy spectrum of nuclear-active particles in the 10 to 50 Bev energy region can be approximated by a power law E^{-k}, where $k = 0.95 \pm 0.25$ (cf. Fig. 2). This result is not surprising, since a spectrum of this shape can be expected from the integral energy spectrum of μ mesons in EAS, measured at the same altitude.[5] Furthermore, the same value of the spectrum exponent has been obtained for 10^{11} to 10^{12} ev nuclear-active particles.[1]

We estimated the fraction of nuclear-active particles of > 2 Bev, at a distance of 0 to 9 m from the axis, by comparing the observed number of nuclear-active particles with the electron flux density in showers detected by our array. We have obtained a value (1.3 ± 0.3)% which, within the limits of experimental error, is in a good agreement with the value (1 ± 0.1)% obtained earlier[6] by means of a hodoscope. It should be noted that the fraction of nuclear-active particles measured in the present experiment may be underestimated, in view of the difficulties in identifying nuclear-active particles when the number of electrons in the shower produced in the chamber is large.

---

*For details of the cloud chamber, cf. reference 2.

---

[1] Zatsepin, Krugovykh, Murzina, and Nikol' skii, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 298 (1958), Soviet Phys. JETP **7**, 207 (1958).

[2] Danilova, Dovzhenko, Nikol'skii, and Rakobol'skaia, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 541 (1958), Soviet Phys. JETP **7**, 374 (1958).

[3] Ivanovskaia, Sarycheva, and Chikin, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 45 (1958), Soviet Phys. JETP **7**, 30 (1958).

[4] Dovzhenko, Zatsepin, Murzina, Nikol' skii, Rakobol' skaia, and Tukish, Dokl. Akad. Nauk SSSR **118**, 5 (1958).

[5] Dovzhenko, Nelepo, and Nikol' skii, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 463 (1957), Soviet Phys. JETP **5**, 391 (1957).

[6] Nikol' skii, Vavilov, and Batov, Dokl. Akad. Nauk SSSR **111**, 71 (1956), Soviet Phys. "Doklady" **1**, 625 (1956).

Translated by H. Kasha
320

CALCULATION OF THE LIFETIMES OF EXCITED STATES OF Hf^{178} *AND* Hf^{180}

V. V. ANISOVICH

Leningrad Physico-Technical Institute

Submitted to JETP editor February 6, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1639-1641 (June, 1958)

THE nuclides Hf^{178} and Hf^{180} have excited states from which transitions occur to a level of the rotational band with total angular momentum $I = 8$, with emission of E1 radiation. The γ-ray energies are 88.8 and 56.6 kev, respectively. The lifetimes of these long-lived states are 3 seconds and 5.5 hours.[1,2] The standard theoretical estimates of the lifetimes of these excited states according to the independent particle model (examples of which can be found in reference 3) give values approximately 10^{16} times smaller. However, in highly deformed nuclei (such as Hf^{178} and Hf^{180}) a new quantum number K appears — the magnitude of the projection of the total angular momentum on the symmetry axis of the nucleus. For γ transitions in such nuclei there is therefore a new selection rule on K: $\Delta K \leq L$, where L is the angular momentum of the emitted radiation. The selection rule on K is not strict, since the rotational motion of the nucleus somewhat perturbs the nucleon configuration and distorts its shape. Transitions with $\Delta K > L$ are said to be K-forbidden, and their degree of forbiddenness is characterized by the number $\nu = \Delta K - L$. The occurrence of K-forbiddenness can explain the long lifetimes of the Hf nuclides.

The possibility of K-forbiddenness has been treated by A. Bohr in the uniform nuclear model which he proposed.[4] For a numerical estimate of