[5] A. V. Voronel', Yu. R. Chashkin, V. A. Popov, and V. G. Simkin, Zh. Eksp. Teor. Fiz. 45, 828 (1963) [Sov. Phys.-JETP 18, 568 (1964)].
[6] A. V. Voronel, Doctoral Dissertation, Moscow, 1966.

DEPENDENCE OF THE ENERGY OF AN ELECTRON-PHOTON CASCADE, PRODUCED BY COLLISION OF A NUCLEAR-ACTIVE COSMIC-RAY PARTICLE WITH A LEAD NUCLEUS, ON THE ENERGY OF THE INTERACTING PARTICLE

R. A. Nam, S. I. Nikol'skii, V. P. Pavlichenko, V. I. Sokolovskii, and V. I. Yakovlev
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 29 January 1969
ZhETF Pis. Red. 9, No. 6, 338-340 (20 March 1969)

An ionization calorimeter [1] was used to investigate the development of nuclear-cascade avalanches produced in the calorimeter when cosmic-ray particles interact with lead nuclei. In the present paper we present the preliminary results of the reduction of some of the available experimental data concerning the fraction of the energy of the interacting particle transferred to the electron-photon cascade in one inelastic collision. The energy of the particles producing the investigated avalanches was 5×10^{11} - 2×10^{13} eV. The selection of the events and the determination of the nuclear-cascade energy released in the calorimeter material were performed with the aid of a computer. The final analysis included the uniquely separated nuclear cascades whose initiation was not distorted by an accompanying electron-photon avalanche from the atmosphere, and in which the length of the avalanche trajectory in the calorimeter following the first interaction exceeds 540 g/cm^2 (>12 trays of the calorimeter).

The fraction of the nuclear-active-particle energy transferred in the first collision to the electron-photon cascade ($K_{\pi 0}$) was determined from the depth distribution of the ionization in the calorimeter, it being the ratio of the energy of the first electron-photon cascade to the total energy of the nuclear-cascade avalanche. Contributing to the separation of the electron-photon avalanches from the series of consecutive interactions in the lead was the large value of the ratio of the range of the nuclear interaction to the radiation-unit length (~30). In the conversion from the energy released by the nuclear-active particle in the calorimeter to the total energy (E_0), account was taken of the energy transported by the nucleon and by the pion avalanche to the outside of the calorimeter, and also of the energy not registered by the ionization chamber (the binding energy of the nuclei, slow neutrinos). The energy transported by the nucleon was calculated from the observed $K_{\pi 0}$ distribution. Its average value, introduced as a correction, is $0.14E_0$. The energy carried to the outside of the calorimeter by the pion avalanche was determined for each individual event from the ionization in the last trays of the calorimeter. In agreement with [2], it was noted that the energy carried away to the outside of the calorimeter increases with increasing energy of the interacting particles.

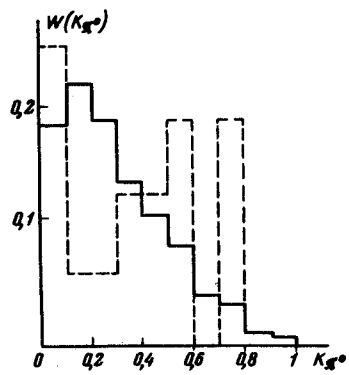

Fig. 1

The analyzed material was grouped in the energy intervals 5×10^{11} - 10^{12} eV, 10^{12} - 2×10^{12} eV, 2×10^{12} - 3×10^{12} eV, 3×10^{12} - 5×10^{12} eV, 5×10^{12} - 10^{13} eV, and $\geq 10^{13}$ eV. The

number of events in the indicated intervals, used for the analysis, was 86, 224, 94, 51, 23, and 16.

The $K_{\pi 0}$ distributions for all the energy groups except $E_0 \geq 10^{13}$ eV agree with each other and are shown in averaged form in Fig. 1 by a solid line. The $K_{\pi 0}$ distribution for 16 events with energy higher than 10^{13} eV is shown dashed.

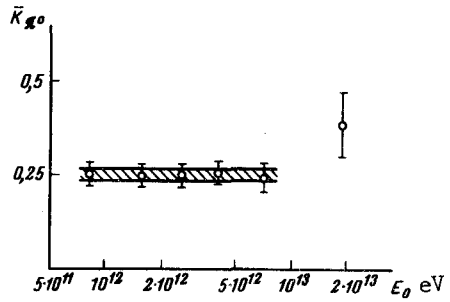

Fig. 2.

The average values $\bar{K}_{\pi 0}$ for the indicated energy intervals are shown in Fig. 2. The errors of the mean values $\bar{K}_{\pi 0}$ include, besides the statistical errors, also methodological uncertainties in the values of the energy carried away by the nucleon, uncertainties in the superposition of cascades from several interactions, and also an inaccuracy in the determination of the location of the first interaction. Their magnitudes therefore depend little on the statistics of the events when the number of cases exceeds 50. At $E_0 = 1.8 \times 10^{13}$ eV, the statistical error in $\bar{K}_{\pi 0}$ amounts to ~2/3 of the error shown in Fig. 2. The mean value $\bar{K}_{\pi 0}$ for $E_0 \geq 10^{13}$ eV is given without allowance for the energy transported by the nucleon to the outside of the calorimeter, corresponding to an increasing value of $\bar{K}_{\pi 0}$. Introduction of this correction decreases $\bar{K}_{\pi 0}$ to 0.34, a fact for which allowance is made in the error of the mean value. In the determination of $\bar{K}_{\pi 0}$ for all the events, account was taken of the experimentally observed fact that the energy removed by the pion avalanche from the calorimeter increases with increasing E_0. However, the assumption that the range for absorption of the pion avalanche is independent of E_0 and equals 1, 2, or 3 interaction ranges does not cause $\bar{K}_{\pi 0}$ to deviate by more than the errors indicated in Fig. 2. Finally, it is possible for $\bar{K}_{\pi 0}$ to be underestimated as a result of superposition of avalanches from two nuclear-active particles passing through the calorimeter at a distance that cannot be resolved with the aid of the ionization chamber. Such events are more probable at high energies and, if the maximum in the distribution at $\bar{K}_{\pi 0} \leq 0.1$, for avalanches with energy $E_0 \geq 10^{13}$ eV (Fig. 1), is attributed to such a superposition and is eliminated during the course of the averaging, then the mean value of $\bar{K}_{\pi 0}$ increases to the upper limit of the error.

Thus, we have obtained experimentally a reliable result indicating that $\bar{K}_{\pi 0}$ is constant in interactions between nucleons (or pions) and lead nuclei in the energy interval from 5×10^{11} to 10^{13} eV.

The tendency of the energy transferred in the electron-photon cascade to increase when the energy of the interacting particles exceeds 10^{13} eV can be connected with the change of the composition of the particles incident on the calorimeter or with the hypothesis of the "gammaization" [3], and with the theoretical prediction of direct production of gamma quanta when nucleons of ultrahigh energy collide [4].

[1] A. D. Erlykin, N. M. Nesterova, S. I. Nikol'skii, et al., Proc. Intern. Conf. on Cosmic Rays, London 2, 731 (1965).
[2] E. V. Denisov, V. M. Kim, A. E. Morozov, and S. A. Slavatinskii, Izv. AN SSSR, Ser. fiz. 31, 1468 (1967).

[3] S. I. Nikol'skii, Zh. Eksp. Teor. Fiz. 51, 804 (1966) [Sov. Phys.-JETP 24, 535 (1967)].
[4] E. L. Feinberg, Izv. AN SSSR, Ser. fiz. 26, 622 (1962).

CHEMICAL LASER OPERATING ON BRANCHED CHAIN REACTION OF FLUORINE WITH HYDROGEN

O. M. Batovskii, G. K. Vasil'ev, E. F. Makarov, and V. L. Tal'roze
Branch of Institute of Chemical Physics, USSR Academy of Sciences
Submitted 10 February 1969
ZhETF Pis. Red. 9, No. 6, 341-343 (20 March 1969)

The principal feasibility of developing lasers based on chemical reactions has been examined in detail recently [1,2]; examples of such an analysis are the papers of Tal'roze [3] and Oraevskii [4]. It was reported [5-7] that laser action was realized in vibrationally-excited HC* and HF* in photochemical chain reactions. The rate of population of the "upper" level in such reactions does not exceed $W_0\nu$, where W_0 is the photo-initiation rate and ν is the length of the chain. An analysis of the data of [5-7] shows that in practice a small number of links of the chain is effective in the population of the "upper" level, and the inversion and generation occur only at sufficiently rapid photo-initiation W_0, so that as a result the principal fraction of the total energy loss in the generator is due to the electric energy lost in the flash lamp, and one can speak in this case of a chemical laser only by stretching the point somewhat.

The main difficulties in creating a "truly" chemical laser are connected, in particular, with the fact that the reaction should proceed at a sufficiently rapid rate, i.e., it should have a small activation energy, and at the same time the reacting mixture should be able to fill the volume of the optical resonator before the start of the reaction. These two requirements are apparently best satisfied by branched chain reactions which have ignition limits - curves in coordinates of pressure (P) and temperature (T) (Fig. 1) - which separate the regions of values of P and T in which the reaction does not occur in practice (shown shaded in the figure) from the regions in which the reaction is explosive [8]. One of the characteristic reactions of this type is the reaction of hydrogen with fluorine, for which Semenov and Shilov [9] established the existence of a first (I) and second (II) ignition limit. In addition, it is possible to realize in this reaction also a third (III) chain ignition limit.

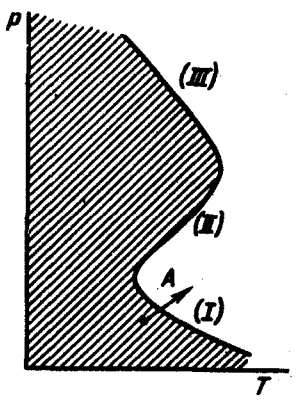

Fig. 1

An investigation of the mechanism of this reaction [10] has shown that the branching occurs in it in reactions of vibrationally-excited hydrogen fluoride. In this case it is to be expected that inside the ignition region the accumulation of products at the upper level will first be proportional to $ae^{t/\tau}$, where a is a quantity that depends on the rate of initiation and τ is the characteristic branching time of the reaction.

The authors investigated a mixture of fluorine with hydrogen of approximately stoichiometric composition near the first ignition limit. The passage through the limit (see arrow A in Fig. 1) is by means of an electric discharge with an energy (Q_E) lower 1.5 - 2 or-