Subtracting from our measured intensities the level of star intensity, given by the exponential absorption law with $L_{\mathrm{Pb}}=320$ g/cm^{-2}, e.g., by the points of George and Jason, we find an additional intensity of mainly few-pronged stars, very similar to the transition curve of photon-produced showers.[6] However, there are some difficulties. From the comparison of the known multiplication of the cascade-component in lead with the peak of our transition maximum of stars, one is led to the conclusion that several percent of the stars in air should be initiated by photons; the cross section would be $\sigma_{\mathrm{air}}\sim 10^{-26}-10^{-27}$ cm^2. This is not consistent with ecently reported results of Kikuchi,[7] showing a cross section $=4\times 10^{-28}$ cm^2 for star production by 300-Mev photons. As far as our experiments go, we can, from an energy point of view, exclude a transition effect of nucleons as responsible for the additional frequency of stars at this altitude.[8] There remains the possibility of an interaction of mesons.

It is difficult, too, to understand the second increase of star frequency beginning at about 15 cm Pb, which is scarcely due to statistical deviations. Together with a point of George and Jason at 28 cm Pb, it suggests a second maximum. One may suppose a connection between this phenomenon and the second maximum of the Rossi curve, recently published by Bothe and Thurn.[9]

Further experiments aiming at a more detailed study of these phenomena are in progress.[10]

* Reported at the conference of Verband Deutscher Physikalischer Gesellschaften, Bad Nauheim, October, 1950.
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[7] S. Kikuchi, Phys. Rev. 80, 492 (1950).
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[10] To be published in Z. Naturforsch.

Secondary Nucleons in Lead

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TRANSITION effects of cosmic-ray stars[1] and of low energy neutrons, observed in lead at 3000 m, suggest some considerations concerning the production of secondary nucleons in lead.

As to stars, there is good reason to believe that most of them at this altitude are produced by secondary nucleons originating in nuclear disintegrations. Thus the formation of the nuclear component is a cascadelike process, which may happen in different ways in absorber material and in air, respectively.

We have observed in our experiments an increase in the number of neutron-produced single tracks of protons, beginning and ending in the photographic emulsion (Kodak NT 4 plates), by a factor of roughly 2.5 with varying thickness of the lead absorber (Fig. 1). This is in agreement with experiments of Tongiorgi.[2]

The particles of the nucleonic component can be divided roughly into three groups. The first, containing particles of relativistic energy, produces mesons and secondary nucleons. For the second group (10^9 ev$>E>10^8$ ev) meson production is negligible. The third group ($E<10^8$ ev), containing mainly neutrons, gives rise to single protons but not to stars.

Assuming the probability of nuclear collisions per gram to be proportional to $A^{-\frac{1}{3}}$ ($A=$mass number) and the number of secondary nucleons starting in a nuclear disintegration to be proportional to $A^{2/3}$, we find the number N of secondaries per gram proportional to $A^{+\frac{1}{3}}$, and the ratio $N_{\mathrm{Pb}}/N_{\mathrm{air}}=2.4$. The energy transferred to these secondary nucleons is due to the energy loss

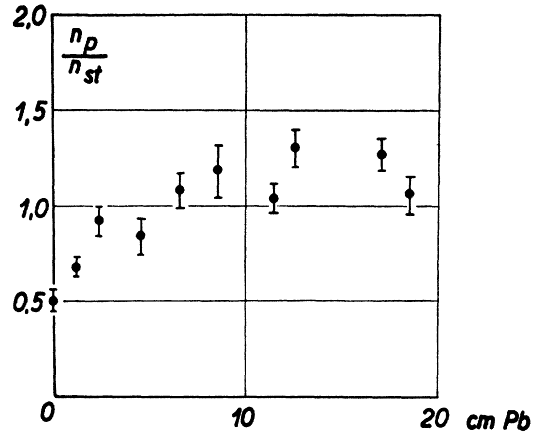

FIG. 1. Intensity of neutron-produced single proton tracks (n_p) under Pb screens, relative to the star intensity of the unscreened plate (n_{st}).

of their primaries, that is, proportional to $A^{-\frac{1}{3}}$. Thus, we have a greater number of secondaries in lead with smaller energy.

Nucleons of the first group being rather rare at 3000 m, the main contribution to star production will be made by nucleons of the second group. From the foregoing considerations their secondaries in lead are not expected to initiate further stars at a sizable rate, since they belong mainly to the third group. It seems, therefore, not probable that the transition effect of stars in lead[1,3] can be attributed to secondary nucleons produced in lead, regardless of the shape of the transition curve itself. This is, however, not conclusive for higher altitudes, where a nucleonic transition effect of star intensity in lead may occur because of the comparatively greater frequency of first-group nucleons.[4]

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A Cloud-Chamber Study of the New Unstable Particles*

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IN a set of pictures taken with a large multiple-plate cloud chamber at 700 g cm^{-2} atmospheric depth, we have observed 10 examples of tracks that deviate suddenly in the gas of the chamber. These are similar to the "V" tracks reported by Rochester and Butler,[1] by Seriff, Leighton, Hsiao, Cowan, and Anderson,[2] and recently by Fretter.[3] Of these 10 events, 4 can be interpreted as neutral-particle decays, 4 as charged-particle decays, while 2 are uncertain as to type.

Of the 4 neutral-particle decays, 2 show one of the decay products ionizing heavily and stopping in a plate. In 2 cases it is possible to say from ionization, range, and scattering that one of the decay products is probably a meson.

In general, we could not ascertain whether the plane of the "V" contained the origin of the event which gave rise to the neutral particle. However, in one case in which many penetrating particles were seen to traverse the chamber vertically, the plane of the "V" was nearly horizontal. In most events of this type reported up to the present, the triggering system was such as to favor events in which the V was vertical.

In all of the 4 cases of charged-particle decay one can see the primary event in which the unstable particle is produced. Two cases show decay of a heavily ionizing parent into a lightly ionizing product which, if an electron, must have an energy >2 Mev because it does not scatter noticeably in the gas. Possibly these are cases of β-decay (B^{12} decays with a mean life of 0.02 second), or they may be cases of $\mu \rightarrow e$ decay. From the production spectrum of π-mesons obtained by Camerini and his collaborators,[4] one can estimate that the probability to see two $\mu \rightarrow e$ decays in our set of pictures is $\sim 10^{-3}$.

One of the charged events (see Fig. 1) can be analyzed in some detail. Several penetrating particles from a nuclear event enter the chamber and one of them produces a nuclear interaction in the third Pb plate. A particle from this interaction penetrates one Al plate, after which its track is deviated suddenly through 90° in the gas. From this point the track, *a*, goes upward and enters the Al plate above. Here it appears to suffer a nuclear scattering with little loss in energy and is deflected again in the downward direction, stopping in the ninth Pb plate. From the observed range, scattering, and ionization, particle *b* must be a meson. In 4 plates, this particle is scattered through an angle greater than twice the average value of the scattering angle calculated under the assumption that the particle is a proton. One proton in 10^4 will be scattered in this way. If the charged-decay product is a meson, it must be a π-meson, since it suffers a nuclear scattering in an Al plate.

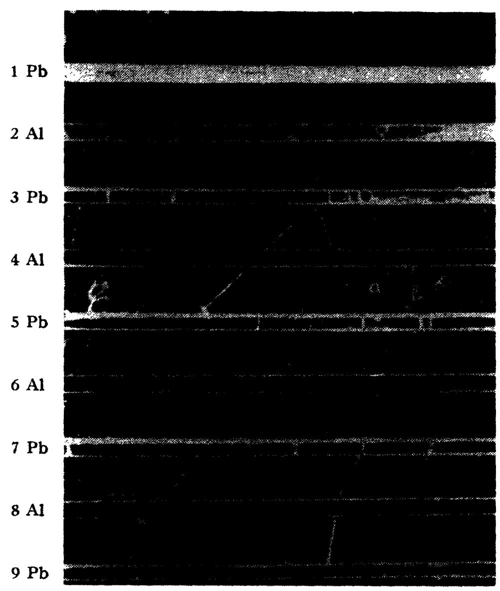

FIG. 1. A particle executing a right-hand turn in the gas of a cloud chamber. Track *a* and track *b* reproject to the same height in plate 3 in both views. Track *c* does not reproject to the same point in the plate and is probably one of the electrons of the pair seen above the plate. Alternate plates are 0.25-inch Pb and 0.31-inch Al.

Assuming the process is a two-body decay, one can calculate the mass, m_1, of the unstable particle assuming different masses, m_0, for the neutral-decay product. Provided m_0 lies between zero and m_π, m_1 is not sensitive to the choice of m_0. Using these limits for the mass of the neutral particle and extreme values for the ionization, we obtain a mass for the parent between 600 and $1200m_e$. This spread is mostly the result of assuming that the estimated specific ionization is uncertain by a factor of 1.7. The choice of m_0 has little effect on the result if m_0 is taken lighter than a π-meson.

We have also observed 7 cases in which a particle enters the chamber from above, slows down, and apparently stops in a plate (Fig. 2). From this plate there emerges a thin track with no other products visible. In one of these pictures (Fig. 2) the secondary particle traverses $\sim$35 g cm^{-2} of Pb with no multiplication. The average scattering angle in 3 plates is 3°. If the secondary particle were an electron, the minimum value of the energy loss due to

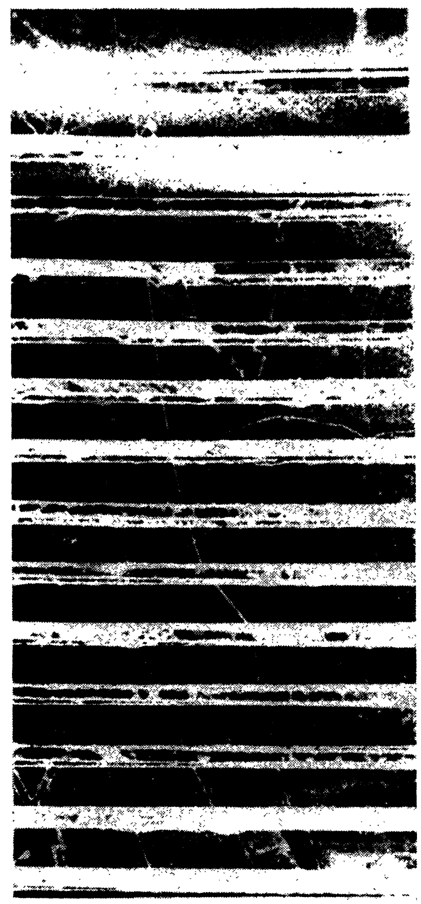

FIG. 2. Particle stopping in a lead plate and giving rise to a lightly ionizing product. All plates are 0.25-inch Pb.

collision processes alone would be 43 Mev, while the average radiation loss would be at least 850 Mev. The particle is thus not an electron from a $\mu \rightarrow e$ decay. We think that at least some of the other cases are not $\mu \rightarrow e$ decays, yet we can think of no process other than a decay which would explain these events.

One can show that the time of flight in the cloud chamber of a particle heavier than $200m_e$ which stops in the chamber after traversing 8 Pb plates is at least 10^{-9} second. The mean life of these stopped particles is thus not much shorter than 10^{-9} seconds, although it might be appreciably longer.

The analysis of these particles is being continued.

We are indebted to Professor R. W. Williams and to Mr. F. B. Harris for aiding us during the experiment, and to Professor B. Rossi for aid in the analysis of the pictures.

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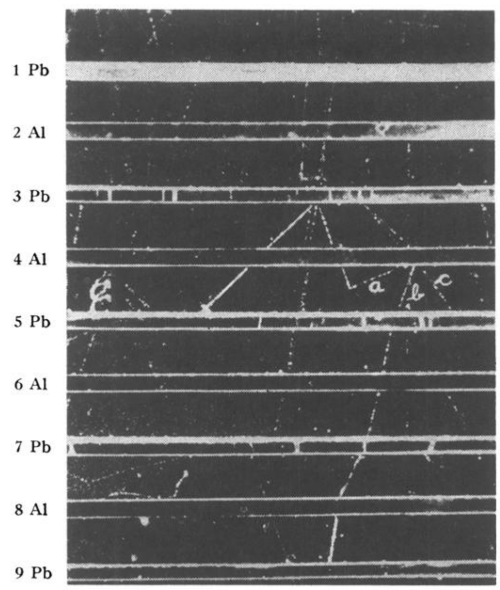

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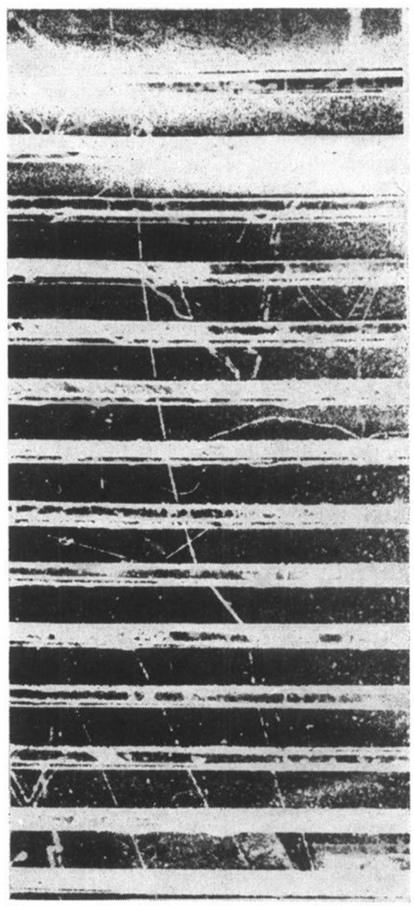

FIG. 2. Particle stopping in a lead plate and giving rise to a lightly ionizing product. All plates are 0.25-inch Pb.