right direction and of the proper order of magnitude to accord with the observed moments. The results are not sensitive to the strength of the interaction provided it is large compared with the core level spacing. It would be of interest to continue the calculations further by taking account of higher order excitation of the $Y_2$ modes as well as other modes which can be excited, but the labor involved appears prohibitive at present.

Before taking the proposed model too seriously, however, one should observe certain of its limitations. First, the model predicts that spin $\frac{1}{2}$ nuclei have magnetic moments coinciding with the Schmidt limits; there are a considerable number of observed exceptions. Secondly, the model predicts (small) deviations in the wrong direction for nuclei with $1=I+\frac{1}{2}$ for $I>5/2$ resulting in additional discrepancies particularly for the compact group of odd proton nuclei with $I=7/2$. To just what extent and in what direction the model must be modified to explain these discrepancies is not clear.

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[3] L. W. Nordheim, Phys. Rev. **75**, 1894 (1949); M. G. Mayer, Phys. Rev. **75**, 1969 (1949); **78**, 16 (1950); Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949); E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949); E. Feenberg, Phys. Rev. **77**, 771 (1950).
[4] In this connection, see J. Rainwater, Phys. Rev. **79**, 432 (1950).

## Cascade Processes Recorded in an Emulsion Chamber Exposed in the Stratosphere

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A LUCITE frame supporting 5 disks of emulsion (5 cm diameter, cast between 1200 and 2400 microns thick) was exposed in the stratosphere at λ 55°N for 6.8 hr. at an average elevation of 90,000 ft. The disks developed uniformly and the tracks of singly charged particles at the minimum of ionization exhibited 23 grains per 100 microns.[1] Intensity measurements on the number of low energy mesons created in one of the 1200 micron disks have been made, a phenomenon particularly suited to the emulsion chamber owing to the greater probability of the ejected particles terminating their range within the thick recording medium. In a volume of 1.5 ml a total of 8 events were observed in which either $\Pi^+$- or $\Pi^-$-mesons were created, the range of the ejected particles residing between 213 and 9150 microns. This corresponds to an observational intensity of 19±7 per cc per day, which is about 8 times greater than that observed in plates of comparable sensitivity coated 300 microns thick.[2]

One of these events exhibiting the termination and decay of a $\Pi^+$-meson (Fig. 1) is of particular interest as this track is the wide angle member of a 17-particle shower initiated by a relativistic alpha-particle. With the exception of track 10, which produces a small star, the remaining shower particles leave the disk after traversing 14 to 20 mm of emulsion[3] without appreciable increase in grain density. The emission of the slow $\Pi^+$ at a large angle with the shower axis provides further evidence for the Bethe mechanism of plural-multiple meson production.[4]

In this preliminary survey no attempt was made to count or identify all the incident heavy primaries, but a large number were observed to stop within the disk either by ionization or nuclear capture processes. An exceptionally heavy track (maximum core diameter 8 microns, total diameter including delta-rays measuring up to 30 microns) came to rest after traversing 15 mm of the disk. On the basis of a thin down length of 700 microns its charge[5] is estimated at 49±3. The track may possibly have been produced by a tin nucleus, as this element has the greatest astrophysical abundance of the elements with atomic numbers[6] between 45 and 55.

A cascade initiated by a heavy primary of charge 18.1±1.3 as estimated by delta-ray counts is described in Fig. 2. At point $C$ the incident particle produces a nuclear disruption constituted of six shower particles $C_1\cdots C_6$, and 15 evaporated nucleons, and a heavy residual fragment emerges co-linear with the primary. This residual fragment has a charge of 10.2±0.7, continues for a distance of 8.9 mm and while still moving at relativistic speed produces a narrow angle shower (tracks $N_1\cdots N_6$) without any associated slow nucleons. In the second shower particles $N_1$ and $N_3$ have a recorded range of 7 mm at the points of emergence from the disk and both show a continuous grain density of 4×minimum, and hence are probably relativistic alpha-particles. Tracks $N_2$, $N_4$, $N_5$, and $N_6$ have minimum ionization grain density and are probably a mixture of fast mesons and protons.

The charge of the incident primary and that of the co-linear heavy fragment indicate that the particles are very probably argon and neon nuclei respectively. While the masses of the particular isotopes are not determinate, $A^{36}$ and $Ne^{20}$ are distinct possibilities. These isotopes have a particularly stable nuclear shell-structure, and if tracks $ZC$ and $CN$ were produced by them, the event suggests that in the interaction of heavy primaries with nuclei in the emulsion a preferential shearing may occur such that units constituted of integral multiples of the helium structure may emerge as sub-units of the interacting nuclei. This implies that the incident argon nucleus also originated from a more complex

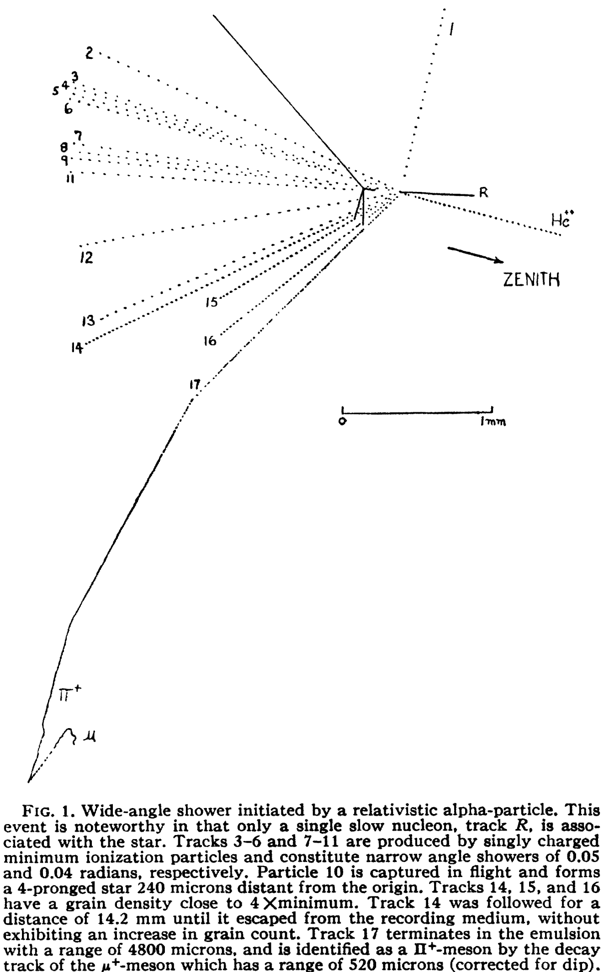


Fig. 1. Wide-angle shower initiated by a relativistic alpha-particle. This event is noteworthy in that only a single slow nucleon, track $R$, is associated with the star. Tracks 3–6 and 7–11 are produced by singly charged minimum ionization particles and constitute narrow angle showers of 0.05 and 0.04 radians, respectively. Particle 10 is captured in flight and forms a 4-pronged star 240 microns distant from the origin. Tracks 14, 15, and 16 have a grain density close to 4×minimum. Track 14 was followed for a distance of 14.2 mm until it escaped from the recording medium, without exhibiting an increase in grain count. Track 17 terminates in the emulsion with a range of 4800 microns, and is identified as a $\Pi^+$-meson by the decay track of the $\mu^+$-meson which has a range of 520 microns (corrected for dip). The center of the shower occurred at a depth of 890 microns and the $\mu^+$-particle terminated 10 microns below the upper surface of the 1200-micron disk.

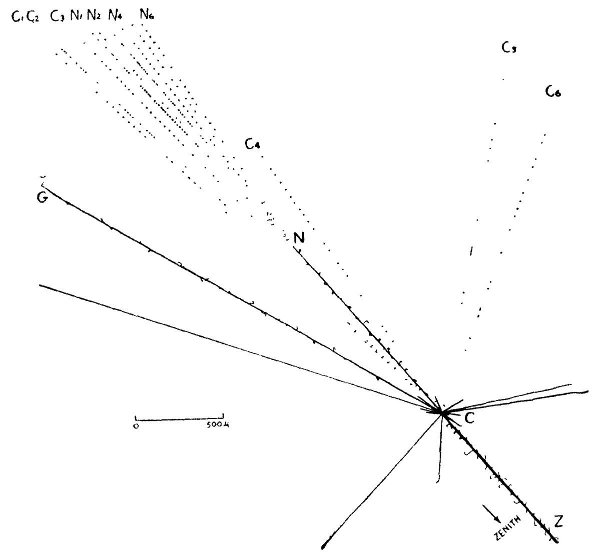


FIG. 2. Cascade processes initiated by a heavy primary. The event extends along a total length of 42.2 mm. In order to reproduce its more important features tracks $ZC$ (23 mm), $CN$ (8.9 mm), and $NN_1$ (10.3 mm) have been greatly shortened in the facsimile drawing. The scale applies only to the evaporated low energy nucleons. Among these, track $G$ (range 2620 microns) is of particular interest because of its high charge $Z=5\pm1$ and the 28 micron electron track originating from its rest point. This corresponds to an energy of about 70 kev, a value consistent with the beta-decay spectrum of $C^{14}$.

structure, a concept not at variance with Spitzer's hypothesis concerning the acceleration and breakdown of interstellar dust particles.[7]

Opportunity is taken to thank the ONR and the aeronautical staff of General Mills for the exposure and recovery of the emulsion chamber.

[1] A brief description of the emulsion casting and development procedures has been presented, H. Yagoda, Phys. Rev. **79**, 207 (1950). Working details will be presented in a manuscript in preparation.
[2] H. Yagoda (to be published).
[3] In assembling the chamber, the upper surface of each disk is infected at two fixed points with a polonium-coated needle. An autoradiograph of these points develops on the lower face of the adjoining disk. It is thus possible to follow dense tracks through the chamber by measuring the coordinates of the tracks with reference to these orientation marks. In order to allow for small differences in shrinkage incurred in the processing, a coordinate net is printed photographically on the surface of each disk prior to development. In this particular event the shower tracks escaped from the chamber owing to the small angle with the plane of the disk. Experiments are now in progress toward increasing the area of the chamber, and one disk measuring 9 cm in diameter and 1500 microns thick has been cast and dried successfully.

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## Are Mesons Complex Particles?

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RECENTLY Fermi and Yang[1] have discussed the possibility that the meson is not an elementary particle, but rather is a complex entity, consisting of a nucleon and an anti-nucleon bound together. A similar suggestion was put forward a few years ago by de Broglie[2] for particles of spin one, in general. De Broglie's theory was developed in a direction different from that of Fermi and Yang. The assumption that the meson is complex in nature seems attractive as it presents a physical picture explaining the integral nature of the spin and the statistics obeyed by the mesons.

As it is now generally admitted that the $\pi$-mesons are responsible for the nuclear forces and have the spin value one while the $\mu$-mesons have the spin value $\frac{1}{2}$, we shall assume that the $\pi$-meson is a complex particle, composed of two $\mu$-mesons, or rather of a charged $\mu$-meson and a neutral anti-$\mu$-meson bound together by strong attractive force. If $\pi^+$, $\pi^-$, and $\pi^0$ refer to the positively and negatively charged and neutral $\pi$-mesons, with similar notations for the $\mu$-mesons, we represent the constituent particles for the $\pi$-mesons as follows:

$$\pi^+=\mu^+ + \text{anti-}\mu^0;\quad \pi^-=\mu^- + \text{anti-}\mu^0;\quad \pi^0=\mu^0+\text{anti-}\mu^0.$$

Since $m_\mu=(212\pm4)m_e$, and $m_\pi=(286\pm6)m_e$, we shall assume that the difference between twice the mass of the $\mu$-meson and the $\pi$-meson is the mass equivalent of the binding energy of the $\pi$-meson. Taking for the binding potential, $V$, the step function:

$$V(r)=0 \text{ for } r>\hbar/m_\mu c,$$
$$V(r)=V_0=\text{constant, for } r<\hbar/m_\mu c,$$

and for the lowest eigenvalue $E=m_\pi c^2$, we have determined the depth $V_0$ of the assumed potential box. We found the following two solutions for $V_0$:

$$V_0=5.87m_\pi c^2=839.4 \text{ Mev}\quad\text{and}\quad V=3.03m_\pi c^2=433.3 \text{ Mev}.$$

The corresponding normalized solutions will be generally similar to those given by Fermi and Yang. The geometrical size of the meson in the present case will be of the order of $\hbar/m_\mu c$; i.e., the Compton wave-length for the $\mu$-meson.

As regards the interpretations of the interactions between mesons and other particles we propose the following schemes:

(1) In collisions involving $\pi^-$-mesons with different nuclei, the charged $\mu^-$-mesons (constituting the $\pi^-$-meson) might be forced to occupy the hole representing the neutral anti-$\mu^0$-meson, and thus the $\pi^-$-meson will be annihilated, giving its energy and charge to the colliding nucleus. This might cause an explosion with the formation of a star.

(2) In certain cases, collisions could cause the disintegration of the $\pi$-meson itself, into its two constitutents. Thus we get:

$$\pi^+\rightarrow\mu^+ + \text{anti-}\mu^0 \text{ (a neutretto)},$$
$$\pi^-\rightarrow\mu^- + \text{anti-}\mu^0 \text{ (a neutretto)}.$$

(3) A free $\mu^0$-meson, when colliding with a $\pi$-meson, could occupy the hole representing the anti-$\mu^0$-meson and thus the charged $\mu$-meson will be set free:

$$\mu^0+\pi^+\rightarrow\mu^+ + \text{two photons}.$$
$$\mu^0+\pi^-\rightarrow\mu^- + \text{two photons}.$$

These high energy gamma-photons will be of the type observed by Moyer, York, and Bjorklund.[3]

These photons could also result from the (self-) annihilation of the $\pi^0$-mesons caused by collisions with other particles.

(4) On the other hand, a free charged $\mu^-$-meson could be annihilated on collision with $\mu^+$ or $\mu^0$, giving rise to:

$$\mu^- + \mu^+ \longrightarrow \text{two photons},$$
$$\mu^- + \mu^0 ---- \text{an electron} + \text{a neutrino}.$$

This last reaction represents the decay of the $\mu$-meson.

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[2] L. de Broglie, *Une Nouvelle Theorie de la Lumiere* (Hermann & Cie, Paris, 1940); *La Theorie du Noyau* (Hermann & Cie, Paris, 1945).
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## On the Probability of Asymmetric and Symmetric Fission

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THIS paper explains the experimental facts that the symmetric fission becomes predominant compared to the asymmetric one, according as the velocity of the incident neutron increases, by the aid of assumptions about the structure of heavy nuclei. In this paper, we use the notation $\sigma(E)$, $T(E)$, and $R(E)$ as the cross section of a nucleon, the probability of free transmission through the nucleus, and the ratio of the symmetric to