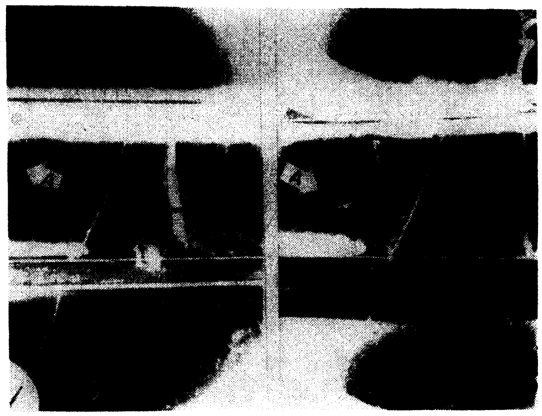

FIG. 1. Pair of stereoscopic photographs of heavily ionizing penetrating track taken at 93,000 feet. Lightly ionizing tracks are barely visible at "A." Because of temperature changes during the flight the cloud chamber is rather foggy, especially near the lead plates. Parts of the right-hand picture are doubly exposed because of failure of the film advance.

passed through the upper 0.63-cm lead plate as well but is not well illuminated above the plate. The track is somewhat old, so that it is not sharp and the bottom section is much distorted, presumably by turbulence.

On the assumption that the tracks marked "A" have minimum ionization, it is estimated that between the two plates the heavily ionizing track has a density of ionization between 10× and 100× minimum ionization. There is no marked change in ionization density on passing through the bottom plate. The ionization density above the top plate cannot be determined. The extent of scattering is unknown since the tracks are certainly distorted by turbulence.

Comparison of these observations with curves for range and energy loss[1] shows that the particle causing the track must be heavier than a proton. A proton with ionization density of 10× minimum or greater would have a range not greater than 2 g/cm^2, whereas the particle actually passes through 16 g/cm^2 in the bottom plate. An alpha-particle with ionization 10× the minimum for a particle of unit charge would, however, have a range of about 28 g/cm^2 of lead and could penetrate our lead plate. A lithium nucleus could also cause such a track, but a particle of charge 4 would cause ionization at least 16× minimum. If the ionization is considered to be as high as 100× minimum, then the particle must have $7 \leqslant Z \leqslant 10$, assuming that its mass is $2Z$. Thus the estimate of ionization between 10× and 100× the minimum for a particle of unit charge implies a charge not less than two nor more than ten, with higher charges resulting from higher estimates of the ionization. In the absence of an accurate determination of the density of ionization of the track, it seems most probable that it was caused by an alpha-particle since alpha-particles have been reported to be much more numerous than heavier nuclei.[2] To cause the observed track an alpha-particle would require energy of the order of 400 Mev; a heavier particle would have to be more energetic. The high energy and approximately vertical incidence make it probable that a primary particle is involved, similar to those found by Freier, Lofgren, Ney, and Oppenheimer.[2]

* Research carried out at Brookhaven National Laboratory under the auspices of the AEC.
** Now at Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.
*** Equipment was flown by General Mills, Inc. Project "Skyhook" balloon from Camp Ripley, Minnesota.

1 B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941).
2 Freier, Lofgren, Ney, and Oppenheimer, Phys. Rev. **74**, 1818 (1948).

The Mass of the Cosmic-Ray Mesotrons*

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January 10, 1949

IN a paper by W. B. Fretter[1] measurements were reported on the range (R) and the momentum ($B\rho$) of 26 mesotrons. There is a unique relation between mass, range, and momentum so that the knowledge of range and momentum enables one to determine the mass of the mesotrons. The 26 mass values observed by Fretter were treated by him as a set of linear measurements, and the mean value ($\bar{m}$) was found by weighting each value (m_i) in inverse proportion to the square of the probable error (Δm_i) assigned to that value, i.e.,

$$\bar{m} = \{\Sigma[m_i/(\Delta m_i)^2]/\Sigma[1/(\Delta m_i)^2]\}.$$

This calculation gave a value, in units of the electrons' mass, for m of 202 with a probable error of ±5. The probable error of the individual measurements was of the order of 15 percent of the mass values.

Since the range of the mesotron was measured by observing the lead plate in which it stopped, the mean value of the range is taken as the distance to the middle of the plate with a probable error in this estimate of one-quarter of the plate thickness. This probable error is independent of the range of the particle. The curvature (C) of the particle in the magnetic field determines its momentum. The scattering of the particle and turbulence in the cloud chamber introduces spurious curvatures which with equal probability increase or decrease the true curvature. The principal cause of error in curvature is the turbulence which introduces an error that is independent of the magnitude of the curvature. In a plot which uses range and curvature to determine the mass of the mesotron, the probable errors in both of the variables are nearly independent of their position in the plot. The choice of the best parameter curve, that is the curve of constant m, for the distribution of observed values of range (R) and curvature (C) is given by the curve for which

$$\Sigma\{[V_R^2/(\Delta R/R)^2]+[V_C^2/(\Delta C/C)^2]\}$$

is a minimum. The residuals V_R and V_C are the difference between the observed coordinates and the coordinates of the corresponding point on the parameter curve.[2] With this more accurate method of treatment of the data given by Fretter the value of the mesotron mass in electron mass units is found to be 212±5.

If the percent probable errors in range and curvature are equal, the observed point will be on the orthogonal to the parameter curve that passes through the corresponding point on the parameter curve. An inspection of the curves of constant m in the range, curvature coordinates shows that the linear measure orthogonal to the parameter curves is closely proportional to log m. The change of the variable from m to log m with appropriate change in weight makes an appreciable change in the mean value of the mass. When each value of log m is weighted inversely as a square of $\Delta m/m$ the value of m corresponding to the mean is found to be 212 in agreement with the more accurate method.

* Assisted by the joint program of the ONR and AEC.

[1] W. B. Fretter, Phys. Rev. **70**, 625 (1946).

[2] A detailed discussion of the adjustment of a parameter curve to two Gaussian variables is given by Demming, *Statistical Adjustment of Data* (John Wiley and Sons, Inc., 1943), pp. 141–144.

Interaction of Mesons with Nucleons and Light Particles

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January 7, 1949

We have been making a phenomenological study of the various experiments which have been done in recent years on the interaction between the various types of particles. In the course of this investigation two interesting points have come to light.

First, we found that if the decay of the μ-mesons and the capture of the μ^--mesons by nuclei are described by the reactions[1]

$$\mu \rightarrow e+\nu+\nu \qquad (e=\text{electron},\ \nu=\text{neutrino})$$
$$\mu^- + P \rightarrow N+\nu \qquad (P=\text{proton},\ N=\text{neutron}),$$

and that the Fermi type interactions are assumed to be responsible for these processes, the coupling constants would have the values

$$g_{\mu e} \sim 3\times 10^{-48}\ \text{erg cm}^3$$

and

$$g_{\mu P} \sim 2\times 10^{-49}\ \text{erg cm}^3,$$

respectively. These values are so determined as to fit the experimental lifetime[2] of the μ-mesons and the capture probability of the μ^--mesons by nuclei.[3] It is remarkable that the three independent experiments: the β-decay of the nucleons and the μ-mesons and the interaction of the nucleons with the μ-mesons lead to coupling constants of the same order of magnitude.

One can perhaps attempt to explain the equality of these interactions in a manner analogous to that used for the Coulomb interactions, i.e. by assuming these interactions to be transmitted through an intermediate field with respect to which all particles have the same "charge." The "quanta" of such a field would have a very short lifetime and would have escaped detection.

Second, if we assume the π-mesons to have integral spin and assume direct couplings for the processes

$$\pi \rightarrow \mu + \text{anti } \nu$$
$$N \rightarrow P + \pi^-$$

with coupling constants determined from the lifetime of the π-mesons[4] and the strength of nuclear forces,[5] the interaction between the μ-mesons and the nucleons can be *quantitatively* explained as a second-order interaction through the virtual creation and annihilation of π-mesons.

After the completion of our work Mr. A. Ore has kindly informed us that similar considerations have been carried out by J. A. Wheeler and J. Tiomno.

[1] The masses of the π- and μ-mesons are taken to be

$$m_\pi = 286 m_e, \qquad m_\mu = 212 m_e.$$

[2] B. Rossi, Rev. Mod. Phys. **20**, 537 (1948).

[3] B. Rossi, Rev. Mod. Phys. **20**, 537 (1948). In the calculation for the capture process the Fermi model for the nucleus is assumed and only single particle excitations are considered. See M. Rosenbluth, Phys. Rev. **75**, 532 (1949).

[4] J. R. Richardson, Phys. Rev. **74**, 1720 (1948).

[5] H. Bethe, Phys. Rev. **57**, 390 (1940).

Some Preliminary Cloud-Chamber Photographs of Artificial Mesons

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January 24, 1949

The 184-inch cyclotron has recently been converted so that it accelerates protons up to an energy of 350 Mev. A cloud chamber has been operated in the neutron beam which is produced when the 350-Mev protons are allowed to strike a two-inch copper target. The first run has yielded several tracks that may be definitely classified as meson tracks though we are not able to distinguish between light and heavy mesons.

The cloud chamber was operated in a magnetic field of 21,700 gauss and contained $1\frac{1}{2}$ atmospheres of argon with water vapor. The neutron beam was six inches in diameter and was allowed to strike the chamber so that it traversed

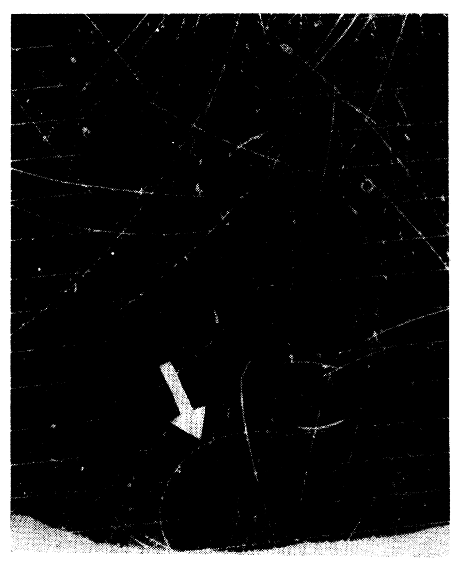

Fig. 1. Meson track produced in a cloud chamber, operated in a beam of neutrons from a copper target bombarded by 350-Mev protons. Its radius of curvature corresponds to a π-meson of 2.3 Mev or a μ-meson of 3.0 Mev.