(see Fig. 1) and the experiment in principle offers the possibility of distinguishing between the two solutions. Granting the validity of an s and p analysis, the question of whether or not the experiment resolves between positive or negative $\delta(s)$ depends on the expected deviation ω in fitting six experimental points in a theory with three free parameters. We have analyzed this statistical problem using the "Monte Carlo" method and find ω expected <5 in 50 percent of the cases. On the order of 15 percent of the cases are expected to have deviations as large as that observed or larger. The experiment, therefore, to a considerable extent favors the repulsive s and attractive p interaction, in agreement with the pseudoscalar theory.

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An Example of Multiple Meson Production Observed with a High Pressure Hydrogen-Filled Cloud Chamber

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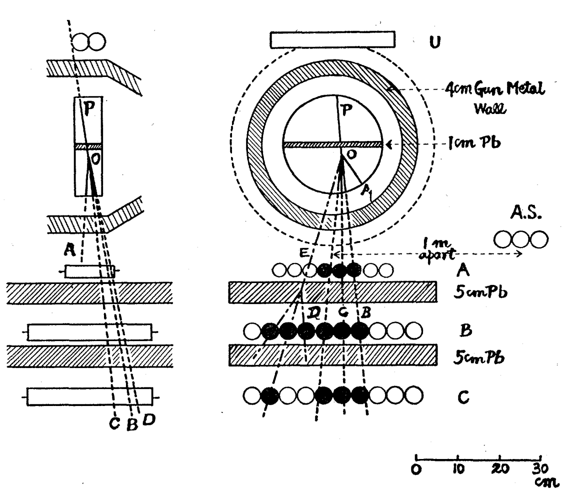
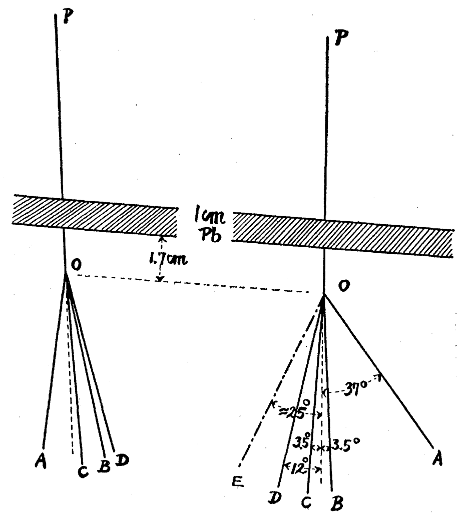
In order to study the hard showers produced in hydrogen by the cosmic-ray particles, a counter-controlled high pressure cloud chamber,[1,2] filled with hydrogen gas to a pressure of 100 atmos, was operated on Mt. Norikura (2740-m altitude) in the summer of 1951. A nuclear event which was most probably due to multiple meson production by a proton-proton collision was observed.

As shown in Fig. 1 (a) and (b), five trays (U, A, B, C, and A.S.) were used, and individual counters of each tray were connected to the hodoscope. A tray consisted of eight counters 3 cm in diameter and 12 cm in effective length. The B, C, U, and A.S. trays consisted of 10, 10, 2, and 3 counters, respectively, of 4-cm diameter and 30-cm effective length. The master pulse was obtained from the coincidence A(≧2)+B(≧3)+C(≧2). The cloud chamber was filled to *ca* 100-atmos pressure with hydrogen gas of 99 percent purity (remainder is nitrogen) and a mixture of isopropyl alcohol (3) and ethyl alcohol (1) as vapor source.



(a) (b)

Fig. 1. Diagram of the apparatus and event. (a) Side view. (b) Front view.



(a) (b)

Fig. 2. Drawing of the hard shower produced in hydrogen. (a) Side view. (b) Front view.

In the course of operation for about 50 days, an event was observed which is described below. Figures 1 and 2 are the drawings of this event, which occurred in the gas space of the cloud chamber. All five tracks, P, A, B, C, and D are at minimum ionization. P is inclined by 7.5° to the zenith and believed to be a primary particle—probably a proton. A, B, C, and D are secondary particles. Particles B, C, D triggered the counters of trays A, B, and C as shown by the dashed lines in the hodoscope scheme. Tracks B, C, and D penetrated the 4-cm gun metal wall and 10 cm of Pb. Thus their kinetic energy is more than 300 Mev if they are π-mesons. The angles between each track and the primary particle are as shown in Fig. 2. The primary and the four secondary particles are almost coplanar within the experimental accuracy. Trays U and A.S. are not fired in this event.

From the fact that the chamber contained 99 percent hydrogen and 1 percent nitrogen and that about 10 percent of the hard shower generated in nitrogen gas appeared in a previous experiment,[3] as stars with no heavily ionizing secondaries, it is believed that this event is a hard shower produced by the collision with a proton, with a probability of 99 percent. The possibility of production of the four charged secondaries by an electromagnetic process may be ruled out. If one assumes that hard showers are produced with geometrical cross section, the expected frequency is consistent with the observation time of this event.

As for the interpretation of this event, it is possible that the 4 particles A, B, C, and D are all π-mesons, or that 3 are π-mesons and one is a proton, or that 2 are π-mesons and 2 are protons. However, from the hodoscope scheme in Fig. 1, it appears likely that a neutron of high energy also originates from the nuclear interaction in the gas, and then produces a secondary hard shower in the upper 5 cm of Pb. The probability of such a process is about 30 percent. Therefore, the event under consideration most probably shows the multiple meson production by a p-p collision according to the following process:

$$p+p\rightarrow p+n+\pi^{+}+\pi^{-}+\pi^{+}.$$

Track A may be the proton and B, C, D may be the π-mesons, but the energy balance and kinematics are not clear. Of course, there is a slight possibility that it might be due to the following ζ^0-meson process:[4]

$$p+p\rightarrow p+n+\pi^{+}+\zeta^{0}\begin{smallmatrix}\nearrow \pi^{+}\\ \searrow \pi^{-}\end{smallmatrix}.$$

However, in this event the Q value of such a process is more than 4 Mev.

In order to increase the detection efficiency of the hard showers and scatterings in hydrogen, the construction of a larger size high pressure cloud chamber (50-cm diameter, 20-cm depth) filled with 150 atmos of hydrogen is now under way. Also, to analyze the hard shower secondaries in more detail, an experiment with a tank filled with 250 atmos of hydrogen above a multiplate cloud chamber is now going on.

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Evidence for the Emission of a Neutrino Following the Nuclear Capture of a Negative μ-Meson*

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A HIGH percentage of the stars in photographic emulsions that are caused by negative μ-mesons, is due to the nuclear capture by the heavy elements (Ag and Br) in the emulsion. However, in a few cases it is possible to identify, from the characteristics of the star, the nuclear capture in carbon, in nitrogen, and in oxygen.[1] In a few of these cases it is necessary to assume that one or more neutrons and a neutrino are ejected from the nucleus in order to explain the relatively low nuclear excitation and the residual momentum of the charged particles from the star.

Since the energy of the neutrino from the nuclear capture of a negative μ-meson is moderately high in many cases (50–80 Mev), it seemed possible to observe the effect of neutrino recoil in those reactions where a neutron is not emitted. Two reactions should be easily identified in a photographic emulsion:

$$\mu^{-}+C^{12}\rightarrow B^{12*}+\nu\rightarrow Li^{8}+He^{4}+\nu \qquad \searrow Be^{8*}+\beta^{-}+\nu \qquad Be^{8*}\rightarrow\alpha+\alpha, \tag{1}$$

and

$$\mu^{-}+O^{16}\rightarrow N^{16*}+\nu\rightarrow B^{12}+He^{4}+\nu \qquad \searrow C^{12}+\beta+\nu. \tag{2}$$

Reaction (1) can be recognized by the Li^{8} "hammer tracks" as well as the small departure from collinearity of the Li^{8} and α-particle tracks. The ratio of the energy of the Li^{8} to the energy of the α-particle should be approximately equal to the ratio of the mass of the α-particle to the mass of Li^{8}, because the momentum of the neutrino is usually small in comparison to the momentum of the charged particles. Reaction (2) can be identified in electron-sensitive plates by the ratio of the energies of the two nuclear particles, the small departure from collinearity, and the electron track from B^{12}. Two additional reactions can be identified, under favorable conditions, by the ratio of the energies of the two nuclear particles and the small departure from collinearity:

$$\mu^{-}+N^{14}\rightarrow C^{14*}+\nu\rightarrow Be^{10}+He^{4}+\nu \tag{3}$$

and

$$\mu^{-}+O^{16}\rightarrow Li^{7}+Be^{9}+\nu. \tag{4}$$

Electron-sensitive G-5 plates and G-5 plates, with two times the normal gelatine content, have been exposed to the University of Chicago cyclotron. The μ-mesons were separated from the π-mesons of the same momentum by utilizing the larger range of the μ-mesons in an absorber.[1] A total of 17 095 μ-meson endings in G-5 plates and 2596 in G-5 2X plates has been studied. No events have been found which correspond to reaction (1). Two events have been found which are ascribed to reaction (2). In addition, two events have been found which correspond to reaction (3). Examples of these two types of events are shown in Figs. 1 and 2. The characteristics of the four events are given in Table I. The energy of the α-particles was obtained from the range and utilizing the range-energy relationship given by Wilkins[2] for normal plates and by Lees *et al.*[3] for the G-5 2X plates. The range-energy relationship given by Miller *et al.*[4] was used to estimate the energy of the Be^{10} and B^{12} fragments.

The multiple scattering has been measured along the minimum ionizing track from the end of the short tracks in events 1 and 2. The energy of the electron was found to be 14±4 and 12±4 Mev, respectively. The maximum energy of the electron spectrum from B^{12} is 13.4 Mev.[5] Since the electron energy is considerably higher than would be expected from any known β-emitter among the light elements other than B^{12}, the identification is quite certain. The assumption that the short nuclear particle track is B^{12} is confirmed by a comparison of the B^{12} range with the range of the α-particle in events 1 and 2. In events 3 and 4 the Be^{10} track and the α-particle track depart from collinearity by about 8 and 11 degrees, respectively. The identification of event 4 is less certain

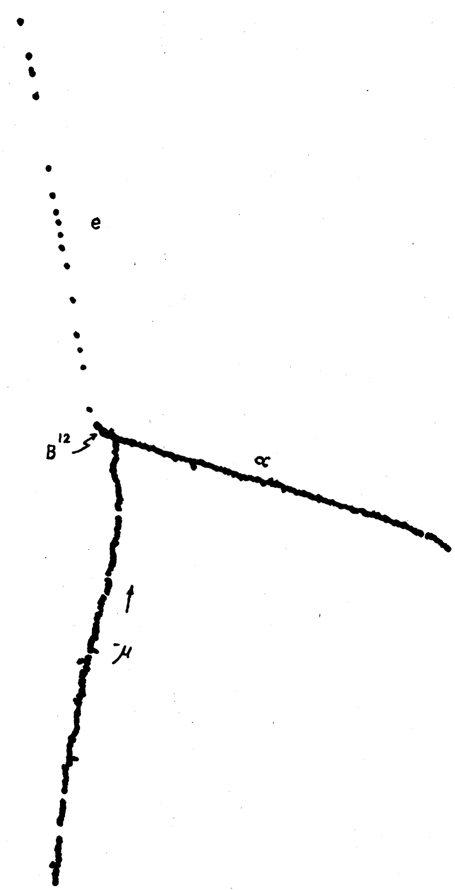

FIG. 1. An unusual two-prong star caused by a negative μ-meson is shown in the above projection-drawing. The event is tabulated as event 1 in Table I. A minimum ionizing track is observed from the end of the short track. The ratio of lengths of the two nuclear particle tracks, the energetic β-particle from the fragment which produced the short track, and the collinearity of the two tracks of the nuclear fragments make it quite certain that the μ-meson was captured by an oxygen nucleus with the emission of a B^{12} fragment, an α-particle, and a neutrino.