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April, 1950

The gamma ray spectrum resulting from the absorption of π^- mesons in high pressure hydrogen has been analyzed by means of a pair spectrometer. The results reported here are preliminary and of low accuracy; some of the implications of the experiment are however of sufficient certainty at present to warrant giving these results here.

The experimental arrangement is shown in Fig. 1. 330 Mev protons circulating in the internal beam of the 184-inch cyclotron strike a 1/2 in. deep .040 in. thin tungsten target. The tungsten target is located 2-1/2 inches from the centerline of a hydrogen pressure vessel of 600 cc. volume. The hydrogen vessel is surrounded by a very thin walled liquid nitrogen jacket. Total thickness to be penetrated by the mesons, including the liquid N_2 and two stainless steel walls is 4.0 g/cm^2. The vessel is operated at a pressure of 2700 p.s.i.; at liquid nitrogen temperature this gives a density of .048[1]. Interference from gamma rays originating outside the hydrogen volume is reduced by two lead collimators. The gamma rays are analyzed using a pair spectrometer similar to the one used by Bjorklund, Crandall, Moyer and York[2]. The detectors placed in the pair spectrometer are proportional counters divided by a central bead on the counting wires into two counting volumes. It is thus possible to make observations simultaneously in 3 energy channels. Various tantalum converters were used to keep multiple scattering losses near 60 percent.

The results from the first series of runs are shown in Fig. 2. The results are principally limited by low counting rate (of the order of 1 c/min) and consequently low resolving power and statistics. The total counting rate is in qualitative agreement with the assumption that all the π^- mesons stopped in the H_2 lead to gamma ray emission. The cross sections as measured by Weissbluth[3] were used in this computation. This fact is in agreement with the conclusion of Wightman[4] that π-μ decay branching is small.

It is certain that the gamma rays observed are not formed by direct p-p collisions due to protons scattered in the cyclotron target. If there were sufficient scattered proton flux hitting the hydrogen vessel, then the background count would be much higher. It is known from the experiments of Crandall, Moyer and York[5] that the cross section for gamma ray production in H_2 is less than .02 of that in carbon; since there is more weight of steel than of H_2 "seen" by the pair spectrometer, and since the background is always less than 1/2 the total count, the H_2 counts cannot be due to direct production.

Several experiments were made using materials other than H_2. Null results were obtained in helium, carbon, polyethylene (CH_2) and lithium hydride. The fact that null results were obtained in hydrogenous materials like CH_2 and LiH is a matter of particular interest. It indicates that the probability of final capture in a K-orbit in H_2 in an hydrogenous compound is small (in fact is less than 1×10^{-3} in CH_2 and less than 3×10^{-3} in LiH). The physical reason is presumably that although a fairly large fraction of π^- mesons is initially captured into high Bohr orbits in hydrogen, the neutral π^--H system will then diffuse through the lattice and make collisions with C or Li atoms respectively. During the collisions the π^- in the high Bohr orbit has a large probability of being captured by a Li or C nucleus, with consequent production of a nuclear star rather than a gamma ray.

The case of absorption of π^- mesons in H_2 as compared to absorption in other materials is a singular one since the reaction $\pi^- + H^+ \rightarrow n$ is possible only in the presence of other nucleons; for absorption by the free proton an additional particle of integral spin must be emitted. Such an additional particle might be a single photon, or, if energetically permitted, a neutral π^0 meson. The details of the absorption process have been discussed by Marshak and Wightman(6) and Wightman(4). In particular it has been shown that the sum of the slowing down time, capture time and arrival time in the K orbit due to collisions leading to Auger electrons, is sufficiently short to compete effectively with the π-μ decay time(7).

The results plotted in Fig. 2 permit us to state definitely that:

1. The emitted gamma rays are not monochromatic near 130 Mev.
2. The group of points near 130 Mev is not just the tail of a distribution near 70 Mev; the points are significantly higher than the amount inferred from the finite resolving power and a peak near 70 Mev. In terms of number of counts the intensity at 130 Mev approximately equals the intensity at 70 Mev; the curve (Fig. 2) results from the conversion factors pertaining to the spectrometer.

Accordingly let us consider three processes:

$$\pi^- + H \rightarrow \underset{9\ \text{Mev}}{n} + \underset{132\ \text{Mev}}{\gamma} \qquad (1)$$

$$\pi^- + H \rightarrow n + 2\gamma \qquad (2)$$

$$\pi^- + H \rightarrow n + \pi^0 + Q, \quad \pi^0 \rightarrow 2\gamma \qquad (3)$$

Process (2) can almost certainly be ruled out. First, the distribution function seems incompatible with any reasonable distribution from a two gamma process. Second, it it very difficult to see how a selection rule favoring a two gamma process over a one gamma process could be constructed.

Accordingly we are led to interpret the results of Fig. 2 in terms of competition between processes (1) and (3). These processes have been discussed by Marshak and

Wightman[6]; in particular they derived the life times of processes (1) and (3) under various assumptions as to the character of the meson. The evidence concerning gamma rays from the cyclotron target[2] in combination with the recent results on gamma-gamma coincidences obtained from material bombarded in the 330 Mev x-ray beam of the synchrotron[8] is highly convincing that a π^0 meson exists and also that it cannot have spin 1.

If the interpretation that both processes (1) and (3) exist is inferred from the data, then some important approximate quantitative conclusions can be drawn. The first conclusion relates to the mass of the π^0 meson. The width of the "π^0 peak" is defined by the Doppler shift of the gamma ray emitted by the decay of the π^0 meson and is thus a measure of the reaction energy Q of process (2). If δ is the fractional half width of the π^0 peak, we can show easily that $\delta = \frac{p}{\mu_{\pi^0} c}$, where p is the momentum of the π^0 and the neutron. Accordingly, the mass difference $u_{\pi^-} - u_{\pi^0}$ between the π^- and π^0 mesons is given by

$$\mu_{\pi^-} - \mu_{\pi^0} = \mu_n - \mu_p + \mu_{\pi^0}\left(\sqrt{\delta^2 + 1} - 1\right) + \frac{\mu_{\pi^0}^2}{2\mu_n}$$

Experimentally we can say that $\delta < .21$. We thus obtain the following inequality for the π^0 mass:

$$1.3 \text{ Mev} < \mu_{\pi^-} - \mu_{\pi^0} < 4.7 \text{ Mev}$$

It is expected that further experiments will narrow these limits considerably. One can furthermore make calculations[6] on coupling constants based on the various forms of meson theories using the relative magnitudes of π^0 and gamma yields.

It should be pointed out that the above calculations are significant only if the qualitative arguments for process (3) can be justified.

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Figure Captions

Fig. 1. Geometrical arrangement of cyclotron target, hydrogen pressure vessel, gamma ray collimators and pair spectrometer.

Fig. 2. Gamma ray intensity as a function of energy. Resolving power "window" is triangular, of 45 percent total base width. One half its area is contained within $\pm$ 7.5 percent of peak.

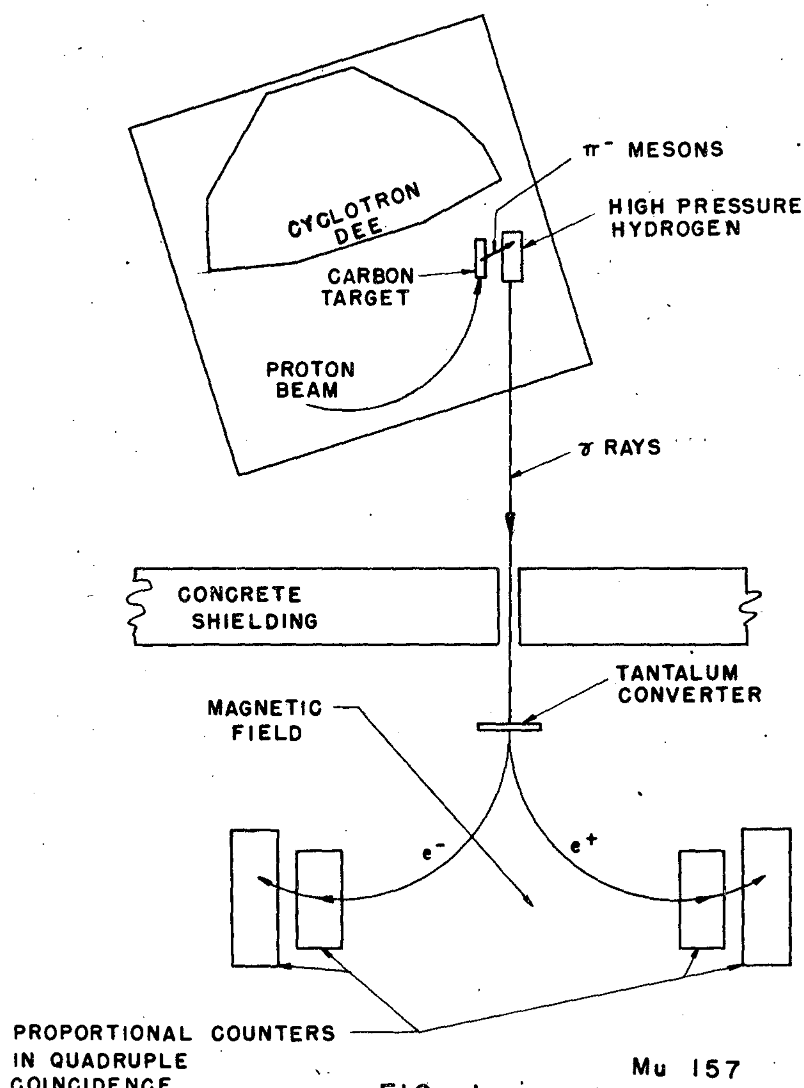
CYCLOTRON DEE
π⁻ MESONS
HIGH PRESSURE HYDROGEN
CARBON TARGET
PROTON BEAM
γ RAYS
CONCRETE SHIELDING
TANTALUM CONVERTER
MAGNETIC FIELD
e⁻
e⁺
PROPORTIONAL COUNTERS IN QUADRUPLE COINCIDENCE

FIG. 1

Mu 157

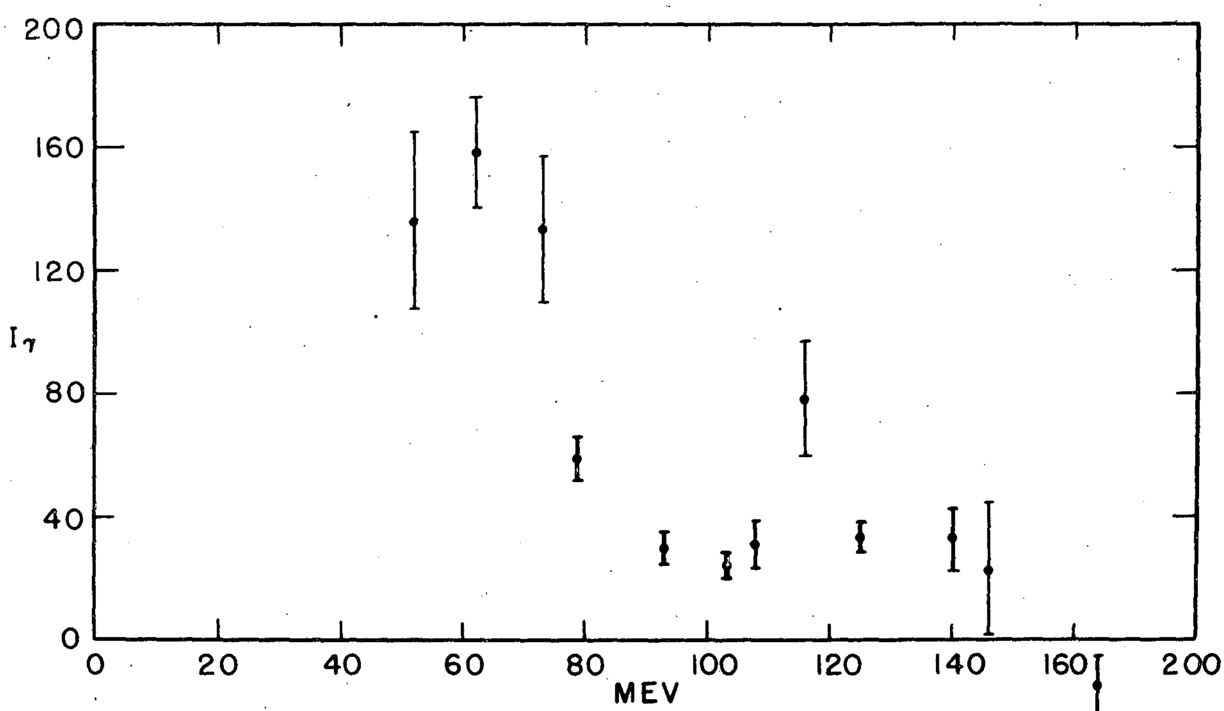

FIG. 2

Mu 156