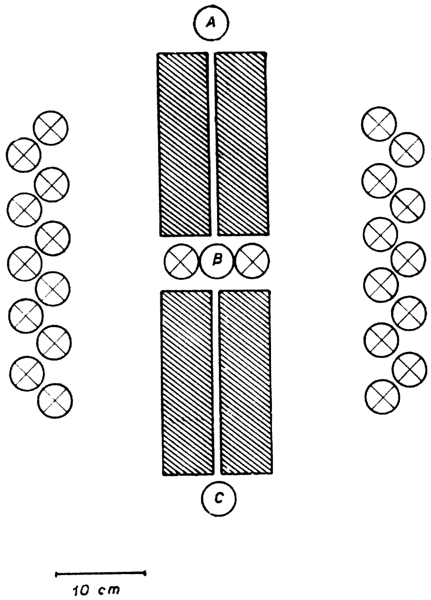

FIG. 1. Schematic diagram of the apparatus.

excess" in the vertical direction shows very little if any increase above 3500 m. *The data given in Table II show that at 3500 m the "charge effect," δ, decreases from positive values in the western direction to negative in the eastern, the observed decrease being monotonic with the change in zenith angle from west to east.*[2] It can be observed that the average values, δ′, of δ for the east and west directions at 3500 m agree very well, as expected, with the corresponding values of δ for the vertical direction at sea level. Further, the intensities of the penetrating component of cosmic radiation, i.e., the sums of N_{cc} and N_{dd}, agree very closely with the relative intensities deduced by Rossi's estimates.[3] Obviously one might first be tempted to explain the observed behavior of the values of δ by assuming that the primary radiation responsible for the hard component contains some negative particles, but more probably the observed east-west asymmetry of δ is due to the deflection of the meson trajectories by the earth's magnetic field.[4]

TABLE II. Charge effect at 3500 m.

Zenith angle	δ_{AB}	δ_{BC}	δ_{ABC}
0°	$+2.5\pm0.7$	$+7.2\pm0.7$	$+12.3\pm0.4$
60°E	-5.3 ± 0.7	-4.9 ± 0.8	-7.4 ± 1.0
60°W	$+11.2\pm0.6$	$+10.9\pm0.7$	$+22.2\pm1.1$
	δ_{AB}'	δ_{BC}'	δ_{ABC}'
$\delta'=\frac{1}{2}(\delta_E+\delta_W)$	$+2.9\pm0.9$	$+3.0\pm1.1$	$+7.4\pm1.5$

For information on this point some measurements on the energy of the particles that cause the "charge effect" are in progress.

We wish to thank Professor G. Bernardini who suggested this experiment, and Mr. Johannes Buschmann[5] who helped construct and operate the apparatus.

[1] Bernardini, Conversi, Pancini, Scrocco, and Wick, Phys. Rev. **68**, 109 (1945).
[2] After completing the above experiments we learned that Professor Brode had performed similar ones; our results seem to agree fairly well with those he reported at the New York meeting (January, 1950).
[3] B. Rossi, Rev. Mod. Phys. **20**, 537 (1948).
[4] This argument was suggested by Dr. T. H. Johnson at the New York meeting, and was also pointed out to us by Dr. G. Bernardini.
[5] Max Planck Institut für Physik at Göttingen; now at Centro di Fisica Nucleare del C.N.R. at Rome.

The Gamma-Ray Spectrum from the Absorption of π^--Mesons in Hydrogen*

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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 of sufficient certainty at present, however, to warrant giving the results here.

The experimental arrangement is shown in Fig. 1. Protons having energy of 330 Mev circulate in the internal beam of the 184-in. cyclotron and strike a ½-in. deep, 0.040 in., thin tungsten target. The tungsten target is located 2½-in. 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/cm². The vessel is operated at a pressure of 2700 p.s.i.; at liquid nitrogen temperature this gives a density[1] of 0.048. Interference from gamma-rays originating outside the hydrogen volume is reduced by two lead collimators. The gamma-rays are analyzed by use of 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 three 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 a 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 $\pi-\mu$-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

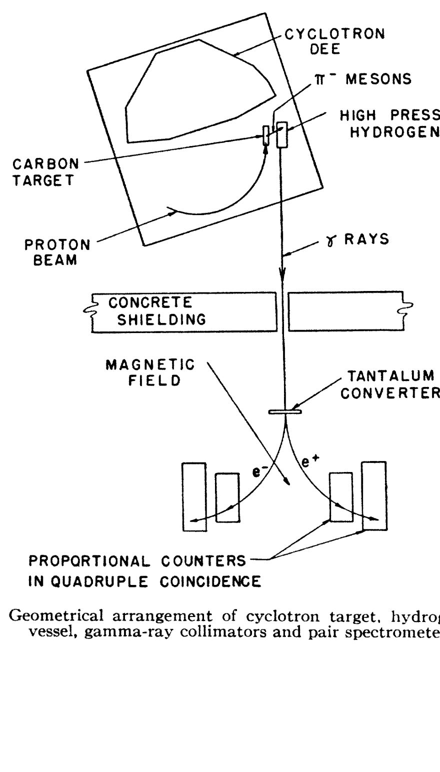

FIG. 1. Geometrical arrangement of cyclotron target, hydrogen pressure vessel, gamma-ray collimators and pair spectrometer.

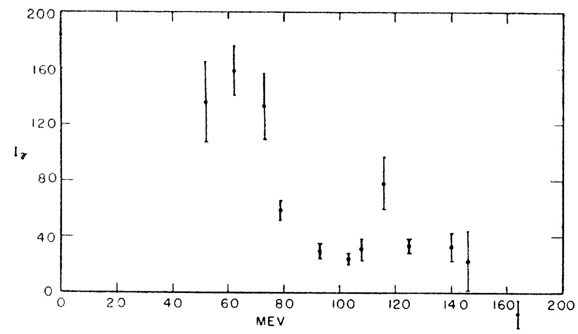

FIG. 2. Gamma-ray intensity as a function of energy. Resolving power "window" is triangular, of 45 percent total base width. One-half its area is contained within ±7.5 percent of peak.

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 0.02 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 one-half 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 hydrogeneous 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 a hydrogeneous 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 $\pi^- - \mathrm{H}$ 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 with absorption in other materials is a singular one, since the reaction $\pi^- + \mathrm{H}^+ \rightarrow n$ 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, caused by collisions leading to Auger electrons, is sufficiently short to compete effectively with the $\pi - \mu$-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:

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

$$\pi^- + \mathrm{H} \rightarrow n + 2\gamma, \qquad (2)$$

$$\pi^- + \mathrm{H} \rightarrow n + \pi^0 + Q. \quad \pi^0 \rightarrow 2\gamma \qquad (3)$$

Process (2) can almost certainy be ruled out. First, the distribution function seems to be incompatible with any reasonable distribution from a two gamma-process. Second, it is 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 lieftimes 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 easily show that $\delta = p/M_{\pi^0}$, where p is the momentum of the π^0 and the neutron. From the data we can conclude that $\delta < 0.21$, and hence we obtain a direct measure of the upper limits on the kinetic energies of the neutron and π^0. Accordingly the mass difference ΔM between the π^-- and π^0-mesons must obey the inequality: 1.3 Mev $< \Delta M <$ 4.7 Mev. It is expected that further experiments will narrow these limits considerably.

Since the π^- is principally captured from an orbit of zero angular momentum, and since the kinetic energy of the π^0 is so small that it can be emitted as an S wave only, one can conclude that the π^-- and π^0-mesons have equal parity. Direct calculations[6] based on the various forms of meson theories using the relative magnitudes of π^0- and gamma-yields have been made and yield estimates of the coupling constants involved.[9]

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

The authors are indebted to Mr. Hugh Smith for mechanical design and to the operating crew of the 184-in. cyclotron for bombardments. The authors have benefited greatly by discussion of this problem with Drs. Wick and Marshak.

* This work was performed under the auspices of the AEC.
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[4] A. S. Wightman, Thesis, Princeton University (June, 1949), and Phys. Rev. **77**, 521 (1950).
[5] Crandall, Moyer and York (private communication).
[6] R. Marshak and A. Wightman, Phys. Rev. **76**, 114 (1949).
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An Oscillographic Method for Observing Magnetic Resonance Spectra

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A NUMBER of paramagnetic salts, especially those containing ions of the iron group, under the influence of a high frequency magnetic field H and of a steady magnetic field H_0, normal to the former, show one or more peaks of energy absorption for different values[1] of H_0 according to the formula:

$$hc/\lambda = g\beta H_0,$$

where g is Landé's constant, β is Bohr's magneton, and the other symbols have their usual meanings.

This resonance absorption has been investigated by several authors, at least qualitatively, by means of a resonant cavity, enclosing a single crystal or powder of the substance placed in the