that α-particles constitute about 10 percent of the primary flux and that accordingly the ratio of α-particles to protons remains relatively constant over a large energy range. This seems to be in agreement with results previously reported,[2] which indicate a similar velocity spectrum for all components of the primary beam, and is not in agreement with the predictions of the simple Fermi[3] theory of acceleration of cosmic-ray primaries.

* This research was assisted by the AEC.

[1] Winckler, Stix, Dwight, and Sabin, Phys. Rev. **79**, 656 (1950).

[2] Kaplon, Peters, and Ritson, Phys. Rev. **85**, 900 (1952).

[3] E. Fermi, Phys. Rev. **75**, 1169 (1949). For an integral energy spectrum varying as $N=K/\epsilon^{\gamma}$, where ϵ is the kinetic energy in Bev/nucleon, Fermi gives $\gamma_p/\gamma_\alpha=\lambda_\alpha/\lambda_p$, where λ is the absorption mean free path. As $\lambda_\alpha\approx\frac{1}{2}\lambda_p$, we find $N_p/N_\alpha=(K_p/K_\alpha)\epsilon^{\gamma}$. For the energy region of this experiment one obtains $N_p/N_\alpha\approx 8\times 10^5$; $(K_p/K_\alpha\gtrsim 5)$. We believe therefore that our results are significant, notwithstanding the poor statistics.

Neutrons and Gamma-Rays from the Proton Bombardment of Beryllium

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THE neutron and gamma-ray yields in the forward direction resulting from the proton bombardment of beryllium have been extended to a maximum proton energy of 5.3 Mev. Voltage calibration of the electrostatic generator has been previously discussed.[1] Targets were thin (approximately 11 kev at threshold) foils obtained through the courtesy of Dr. Hugh Bradner. Neutron yields were measured with a "long" counter placed in the forward direction. Gamma-rays were detected with a large sodium iodide crystal also located along the beam axis. Pulses from the crystal were amplified and fed into two discriminators so that the yields of gamma-rays above approximately 2 and 6 Mev were obtained.

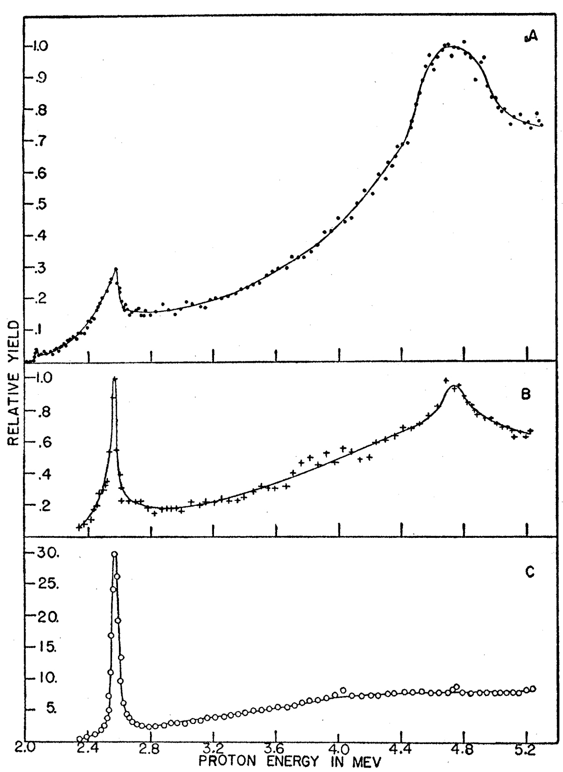

FIG. 1. Yield curves for neutrons and gamma-rays from beryllium bombarded by protons. Top curve, neutron yield; middle curve, gamma-rays of energy greater than approximately 6 Mev; lower curve, gamma-rays of energy greater than approximately 2 Mev. All yields are in arbitrary units.

The upper curve of Fig. 1 shows a typical neutron yield. In addition to the geometrical peak and the well-known rise at 2.56 Mev,[2] a third peak is obtained at a proton energy of 4.7 Mev. The existence of a level at high energy had been predicted from work done at the University of Wisconsin.[3] A run, not shown, using a low energy neutron counter similar to that described by Bonner and Butler[4] showed no obvious levels in the residual B^9 nucleus between 2- and 5.3-Mev proton energy.

The middle and lower curves of Fig. 1 show the yield of gamma-rays with energy greater than approximately 6 Mev and 2 Mev, respectively. The level at 2.57-Mev proton energy is observed in both the high and low energy gamma-ray yields. The level at 4.7 Mev does not appear in the low energy yield due to the relatively high intensity of the nonresonant, low energy gammas.

The gamma-ray yield curves are, in this particular case, essentially free of interferences from neutron reactions occurring in the NaI crystal. This is indicated by the considerably narrower resonance in the gamma-ray yield at 2.56 Mev as compared with the corresponding one in the neutron yield. Boron layers placed between the target and the crystal confirmed this hypothesis.

The new level occurs at a proton bombarding energy of 4.72 ±0.01 Mev and has a full width at half-maximum of approximately 0.5 Mev. We find the lower energy level at 2.57±0.01 Mev. These energies are the averages obtained from several runs.

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[1] Willard, Bair, Kington, Hahn, Snyder, and Green, Phys. Rev. **85**, 849 (1952).

[2] W. J. Hushley, Phys. Rev. **67**, 34 (1945); Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).

[3] Richards, Laubenstein, Johnson, Ajzenberg, and Browne, Phys. Rev. **81**, 316 (1951).

[4] T. W. Bonner and J. W. Butler, Phys. Rev. **83**, 1091 (1951).

Total Cross Sections of Negative Pions in Hydrogen*

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THE interaction of negative pions and protons has been investigated by Steinberger and co-workers[1] for pions of 85-Mev energy by transmission measurements and by Shutt and co-workers[2] for pions of 55 Mev by direct observation of pion tracks in a Wilson chamber. Both measurements indicate a surprisingly low value for the cross section in this range of energies. We have undertaken to extend the total cross section measurements to higher energies.

The negative pions are produced in the large Chicago cyclotron by protons of 450 Mev striking a target which in some of the experiments was copper and in others beryllium. The negative pions are bent in the fringing field of the cyclotron and enter channels in a 6-foot steel shield which separates the cyclotron from the experimental room where the measurements are taken. Further monochromatization and purification of the pion beams are carried out by a deflecting magnet located in the experimental room. In this manner one obtains a sharply collimated beam containing pions with energy defined within ±3 percent. In addition to the pions this beam contains some muons and electrons of the same momentum. Their number has been determined from a range curve. The muons amount to between 5 percent and 10 percent. The electrons are present in negligible numbers for beams above 100 Mev. Below this energy the electron contamination increases rapidly. For this reason low energy measurements have been taken by reducing with a beryllium absorber the energy of the 122-Mev beam.

By using various channels we have taken measurements over the energy range from about 80 to 230 Mev.