explanation of the experimental observations is due to the smallness of the fourth-order contributions. It actually appears that the weak coupling approximation can be applied to scalar theory with considerable justification. However, couplings which are strong enough to predict sufficiently large $P-P$ scattering in fourth-order would at the same time invalidate the neglect of processes of even higher order. Inclusion of such processes would tend to remove the asymmetry in the $N-P$ and $P-P$ scattering which exists for a charged theory only if the lowest few orders in which the process can take place are considered.

There does not appear at present to be any simple way of applying meson theory in even a very qualitative way to the processes of high energy nucleon-nucleon scattering. Both the weak and strong coupling approximations seem to be invalidated by comparison of such calculations with experiment. It is not impossible, however, that in the region of intermediate coupling some of the asymmetry in the $N-P$ and $P-P$ scattering might be retained, while at the same time the correct magnitude of the forces be predicted.

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* This work was sponsored by the AEC.

[1] R. Christian, Phys. Rev. **78**, 82 (1950).

[2] Experimental observations at Berkeley on meson production have not yet indicated conclusively that neutral mesons are coupled directly to protons.

[3] K. Watson and J. Lepore, Phys. Rev. **76**, 1157 (1949).

[4] The range of this potential is too short to agree with measurements of low energy $P-P$ scattering.

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# Production Cross Sections for $\pi^+$ and $\pi^-$ Mesons by 345-Mev Protons on Carbon at 90° to the Beam*, **

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We have developed a method for measuring the absolute production cross sections for $\pi^+$ and $\pi^-$ mesons when various kinds of nuclei are bombarded with high energy charged particles from the Berkeley 184-inch synchro-cyclotron. In this method the external beam from the cyclotron is allowed to pass through the target to be studied. It is then received in a Faraday cup and is integrated by conventional methods. The $\pi^+$ and $\pi^-$ mesons produced by the beam leave the target with various energies, $E$, and at various angles, $\theta$, to the beam. Large absorber blocks are arranged so that mesons leaving the target at any angle are stopped in these blocks at depths determined by their initial energies. Nuclear emulsions are embedded in the absorbers to sample the population of stopped mesons.

The developed emulsions are scanned under high magnification. The ends of the meson tracks are distinguished from the "background tracks" caused by other charged particles by their characteristic scattering and rapid change in grain density. An observed meson is identified as a $\pi^+$ if it gives rise to a $\mu$-meson,[1] and as a $\pi^-$ if it produces a nuclear star.[2] The true number of $\pi^-$ mesons is 1.37 times the star producing mesons.[3]

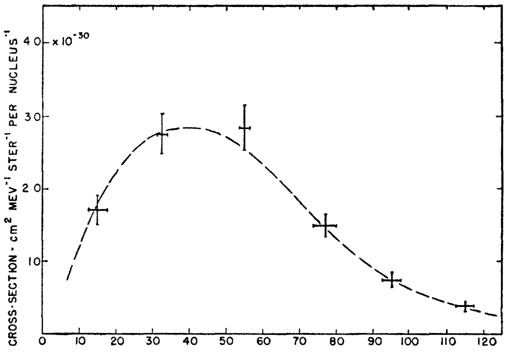

FIG. 1. Differential cross section for the production of $\pi^+$ mesons in carbon by 345-Mev protons. Angle of observation $=90° \pm 12°$ to beam direction.

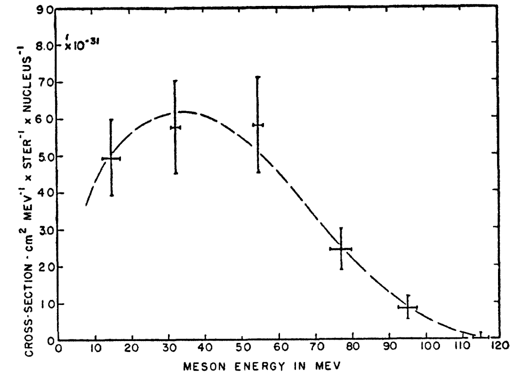

FIG. 2. Differential cross section for the production of $\pi^-$ mesons in carbon by 345-Mev protons. Angle of observation $=90° \pm 12°$ to beam direction.

The absolute differential meson production cross sections are calculated from the geometry, the number of mesons observed per unit volume of emulsion, and the stopping powers of the emulsion and the absorbers. The results are subject to a number of systematic errors. For this reason we assign the usual statistical probable errors to our relative cross sections, whereas to the absolute values we assign an additional ±15 percent.

As a first application of the method we have studied the mesons production by protons on carbon. The beam current was $\sim 10^{-11}$ amperes and the energy was 345 Mev with a spread of about 2 Mev. Thin graphite targets were used. A preliminary study of the energy and angular distribution of mesons and of the other charged particles coming from the carbon target showed that the simple method described above is entirely satisfactory for observations at angles from about 60° to nearly 180° from the direction of the beam. For the forward angles on the other hand, the background on the plates due to the protons scattered by carbon makes scanning very difficult. Our first work has been done at $\theta = 90° \pm 12°$.

Figure 1 shows the differential cross section $\sigma_+(E, 90°)$ for the production of $\pi^+$ mesons in carbon by 345-Mev protons as a function of the energy of the mesons. This curve is based on 205 observed $\pi-\mu$-events. The probable errors shown on the graph are purely statistical in origin and are valid for the relative values of the plotted curves. To these errors must be added the above mentioned ±15 percent to take account of possible systematic errors in the absolute values of the cross sections. Figure 2 is a similar curve for the $\pi^-$ mesons. It is based on 48 observed meson-initiated stars. The integral of the $\sigma_-$ curve over meson energy is $(4.0 \pm 1.6) \cdot 10^{-29}$ cm² ster.$^{-1}$ nucleus$^{-1}$, and the similar integral of the $\sigma_+$ curve is $(2.0 \pm 0.5) \cdot 10^{-28}$ cm² ster.$^{-1}$ nucleus$^{-1}$. The ratio of these integrals is $0.2 \pm 0.1$. The negative to positive ratio, $\sigma_-/\sigma_+$, at each meson energy is limited in accuracy by the scarcity of $\pi^-$ mesons, but there is some evidence to indicate that it drops off at the very high meson energies.

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